



Water safety plans and risk assessment: A novel procedure applied to treated water turbidity and gastrointestinal diseases

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ABSTRACT

Water Safety Plans (WSPs), as recommended by the World Health Organization (WHO), can help drinking water suppliers to identify potential hazards related to drinking water and enable improvements in public health outcomes. In this study we propose a procedure to evaluate the health risk related to turbidity in finished water by determining the cases of drinking water-related gastrointestinal diseases. The results of several epidemiological studies and three-year time series turbidity data, coming from three different drinking water treatment plants (WTPs) located in Tuscany (Italy), have been used to determine the relationship between drinking water turbidity and gastroenteritis incidence and to assess the health risk attributable to the turbidity of tap water. The turbidity variation occurring in the treated water during the monitored period showed an incremental risk compared to the baseline value from 9% to 27% in the three WTPs.

Risk reduction due to each treatment step was also evaluated and it was found that a complete treatment train (clari-flocculation, sand filtration, activated carbon filtration and multi-step disinfection) reduces risk by over 600 times. Our approach is a useful tool for water suppliers to quantify health risks by considering time series data on turbidity at WTPs and to make decisions regarding risk management measures.

1. Introduction

The provision of safe drinking water represents a significant target in order to assure public health. There are many documented cases of outbreaks and endemic diseases caused by drinking water contamination even in developed countries (Hrudey and Hrudey, 2007; Laine et al., 2010; Moreira and Bondelind, 2017). The World Health Organization (WHO) affirms that the most effective means to constantly guarantee the safety of a drinking water system is through the use of a risk assessment and management approach that includes all the phases of the water supply chain, from the abstraction to the treatment and delivery of drinking water (WHO, 2017). In recent years, the interest has turned towards the adoption of a proactive approach, based on the prevention and management of drinking water-related risks whereby end product testing is used to simply verify the effectiveness of the risk management measures (Setty et al., 2018). Since 2004, the WHO has recommended the adoption, by water suppliers, of Water Safety Plans (WSPs). WSP is a model of risk analysis, assessment and management applied to all steps in the water supply, from catchment to consumer (WHO, 2009; Mudau et al., 2017). A WSP builds on different systematic management approaches like the multiple-barrier principle and the

principle of hazard analysis and critical control points (WHO, 2017). WSP implementation can provide improvements in hazard control, microbiological quality, asset management and public health outcomes (Baum et al., 2015; Gunnarsdottir et al., 2012; Setty et al., 2017; Sorlini et al., 2017).

WSPs are currently used in many countries and regulated by national standards (Baum and Bartram, 2018; Bereskie et al., 2017; Gunnarsdottir et al., 2015) and were also introduced to the European Union Drinking Water Directive in 2015 (European Union EU, 2015) which recommended that water suppliers developed and implemented WSPs as early as 2018.

The WHO proposes the use of a definition of risk which identifies the likelihood of the occurrence of an adverse event (P) and evaluates the severity of the consequences (G) (WHO, 2009). Impact on health is the most influencing factor, although considerations regarding the aesthetic aspects of drinking water and related to the continuity and adequacy of the service are considered too. This approach to risk assessment involves the use of a matrix to determine the correlation between the likelihood and severity of the consequences. The implementation of this method consists of assigning a score, from 1 to 5, for the likelihood and severity factors, therefore quantifying the risk in

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a range from 1 to 25. A two-stage risk assessment approach may be considered (WHO, 2009) in order to determine the contribution of the control measures to risk reduction, by assessing the level of risk both in the absence and presence of the identified control measures. The aim of this method is to identify the systematic risk assessment procedures used to determine critical control points (Mudau et al., 2017) and give priority to the most significant control measures. However, although intuitive and simple, this approach relies to a significant extent on expert opinion and does not allow risk quantification based on the likelihood of infections or the incidence of diseases. It therefore becomes necessary to develop methods for the effective quantification of the risk which go beyond the simple qualitative or semi-quantitative approach based on simple scoring matrices.

As far as microbiological contamination is concerned, several studies have investigated the effects produced by drinking water turbidity on human health (Beaudeau et al., 2014a, Beaudeau et al., 2014a,b; 2012; 1999; Hsieh et al., 2015; Schwartz et al., 2000, 1997; Schwartz and Levin, 1999; Tinker et al., 2010). Turbidity is often used as an indicator of drinking water quality since it can reveal the presence of contamination by pathogenic microorganisms and therefore is often associated with the incidence of gastrointestinal diseases related to tap water consumption, especially for WTPs using surface water as a source. The main aetiological agents for the waterborne disease outbreaks related to surface water are the pathogenic protozoa *Cryptosporidium* and *Giardia*, norovirus and rotavirus and the pathogenic bacteria *Campylobacter* (Efstratiou et al., 2017; Moreira and Bondelind, 2017). Most of these pathogens have in common a moderately to long persistence in water supplies and a moderately to high relative infectivity (WHO, 2017).

There are many documented cases of high turbidity values in finished water associated with gastrointestinal diseases (Beaudeau, 2018; Beaudeau et al., 2012, Beaudeau et al., 2014b; De Roos et al., 2017; Hsieh et al., 2015). These studies focus on the estimation of gastrointestinal diseases since, through various symptoms (diarrhoea, vomiting, nausea, cramps), they are typically associated with microbiological contamination of drinking water. Consequently, they are also the most recognized and documented illnesses in outbreaks of drinking water-related disease (Messner et al., 2006).

Setty et al. (2018) propose using the incidence rate of gastrointestinal diseases (cases/person-day) as a definition of risk in the context of WSPs. This approach requires onerous experimental investigations before and after application of the plans in order to determine the correlation between exposure factors (weather, turbidity, etc.) and the incidence of diseases.

In the present work, which is part of the WSP being implemented by Publicacqua SpA for the municipality of Florence, we propose an approach that can be applied to determine the health risk associated with drinking water on the basis of the turbidity data records available for different water treatment plant (WTP) effluents.

2. Materials and methods

Studies that investigate the correlation between water turbidity levels and gastrointestinal diseases have generally been analysed as ‘time-series studies’, that is, they are a type of analytical epidemiological study that evaluates the association between exposure factors and health effects (Bhaskaran et al., 2013). In their investigations the authors generally express the health effect in terms of Excess Relative Risk (ERR), meaning the incremental probability of contracting a gastrointestinal illness linked to drinking water turbidity increment. Table 1 shows the ERR value in literature referring to a turbidity unit increment, in order to uniform the data. The reported values represent the percentage increase in cases of disease corresponding to an increase in turbidity equal to 1 NTU. The final ERR value used in this article is the median of these data. From the literature review five studies were selected (Table 1) which concern WTPs and boundary conditions similar

to our case studies. As shown in Table 1, four ERR values are aligned while one is out of range. We considered it appropriate, for the calculation of the risk and the consequent considerations, to use the median of the these ERR values. However, the results were also reported for the 10th and 90th percentiles.

In this study, ‘increase in turbidity’ is taken to mean the variation between average measured turbidity and the turbidity value x_b , below which there are no incremental cases of gastrointestinal diseases. According to the literature data (Beaudeau et al., 2014b), we have chosen $x_b = 0.1$ NTU. Based on the definition of ERR, the probability of contracting a gastrointestinal disease associated with a specific average daily turbidity $x_i > x_b$ is equal to:

$$P(x_i) = P(x_b) + P(x_b) \cdot \text{ERR} \cdot (x_i - x_b) \quad (1)$$

where $P(x_b)$ is the probability associated with x_b , referred to as the basic probability. If, therefore, the measured turbidity is less than or equal to x_b , there is no increase in cases of disease and therefore $P(x_i) = P(x_b)$. Otherwise if $x_i > x_b$, the increase in cases with respect to the basic situation can be assessed by assuming a linear relationship between ERR and the turbidity variation ($x_i - x_b$). From Eq. (1), on the generic day in which the concentration x_i occurs, it is possible to determine the relationship:

$$\frac{P(x_i)}{P(x_b)} = 1 + \text{ERR} \cdot (x_i - x_b) \quad (2)$$

or the relative incremental term indicated by $\Delta P(x_i)$:

$$\Delta P(x_i) = \frac{P(x_i) - P(x_b)}{P(x_b)} = \text{ERR} \cdot (x_i - x_b) \quad (3)$$

Therefore, the $\Delta P(x)$ function takes the form:

$$\Delta P(x) = \begin{cases} \text{ERR} \cdot (x_i - x_b) & x > x_b \\ 0 & x \leq x_b \end{cases} \quad (4)$$

By indicating the relative frequency associated with each average daily turbidity value x , as $f(x)$, and with P_s , namely the population served by each treatment plant, the risk can be expressed as:

$$R = P(x_b) \cdot P_s + P(x_b) \cdot P_s \cdot \int_0^{\infty} f(x) \cdot \Delta P(x) \, dx \quad (5)$$

which represents the overall risk associated with the WTPs considered in terms of outbreaks per day for the whole population receiving water. The term R includes a component that is closely linked to site-specific conditions ($P(x_b)$) and to the size of the catchment area (P_s); therefore, in order to compare the results associated with different WTPs, the term below is used as the definition of risk:

$$\Delta R_u = \int_0^{\infty} f(x) \cdot \Delta P(x) \, dx \quad (6)$$

which corresponds to the average daily per-capita incremental risk associated with the variable x , of which $f(x)$ is the relative frequency.

The described procedure was applied in three WTPs (plant A, plant B and plant C) located in the Florence area (Tuscany, central Italy), managed by the same water supplier (Publicacqua SpA) and treating water coming from the same surface water body (the River Arno).

Plant A (Fig. 1) has a nominal flow rate of 3.1 m³/s, with an average effective flow rate equal to 2.2 m³/s. The treatment plant includes a clari-flocculation process combined with sand filtration (Empty bed contact time ranging from 12 to 15 min at the nominal flow rate) for the removal of turbidity. There are two main lines, one consisting of ‘Pulsator’ clarifiers (line 1) and the other of ‘Dorr’ clarifiers (line 2). Granular Activated Carbon (GAC) is used to adsorb specific organic molecules that can cause taste and odour problems, as well as natural organic matter (NOM). The treatment plant also provides three disinfection steps (pre-, intermediate and post-disinfection) with different chemicals (ClO₂ and NaClO) in order to enhance the clari-flocculation,

Table 1

Epidemiological studies, ERR: percentage increase of n° outbreaks for each turbidity increase of 1 NTU.

References	ERR	Resource	Type of disinfection
Schwartz et al. (1997)	1.75	Schuylkill River; Delaware River	Pre-chlorination, post-chloramination
Schwartz et al. (2000)	1.8	Schuylkill River; Delaware River	Pre-chlorination, post-chloramination
Beaudeau et al. (2014b)	1.45	Loire River	Ozone disinfection, post-chlorination
Beaudeau (2018)	14	Paris Rivers	Ozone disinfection, post-chlorination
Rambaud et al. (2015)	4.25	Oise River	Ozone disinfection, chlorine disinfection
median	1.8		
10th percentile	1.6		
90th percentile	10.1		

remove pathogenic microorganisms, and reduce the production of by-product compounds.

Treatment plant B (Fig. 2) has a nominal flow rate of $0.75 \text{ m}^3/\text{s}$, with an average effective flow rate equal to $0.35 \text{ m}^3/\text{s}$. The treatment plant comprises a clari-flocculation unit followed by rapid filtration (Empty bed contact time equal to 12 min at the nominal flow rate) and GAC filtration. There are four disinfection steps, three in constant operation (pre-disinfection with ClO_2 or O_3 , intermediate disinfection with a $\text{ClO}_2/\text{NaClO}$ mixture and post-disinfection with ClO_2) and a fourth (post-ozonation, before GAC filtration) that mostly operates in the summer, depending on the quality conditions of the raw water.

Treatment plant C (Fig. 3), with a nominal flow rate of $0.06 \text{ m}^3/\text{s}$, consists of a clari-flocculation unit followed by rapid filtration (Empty bed contact time equal to 12 min at the nominal flow rate); GAC filtration is also present. There are three disinfection steps: initial pre-oxidation with ClO_2 , intermediate disinfection with a $\text{ClO}_2/\text{NaClO}$ mixture and final disinfection with ClO_2 .

Time series turbidity data in finished water were collected in the period 2015–2017, with the exception of plant C whose data refer to the period 2010–2012, since the plant was then closed. A three-year time period was used in order to have enough data to carry out a significant statistical analysis. Daily turbidity values related to plant A were obtained as the mean of several measures carried out during the day to monitor the process. As far as plants B and C are concerned, the daily turbidity value considered is the turbidity value measured for internal water quality controls (one datum per day). For plant B, there are about five data per week, while, for plant C, there is about one datum per week. Turbidity time series data were analysed and plotted over time to visualize trends and a descriptive statistic was calculated for each treatment plant. A statistical analysis was also performed to assess the

probability distribution that best fits the data.

3. Results and discussion

3.1. Turbidity data analysis

Table 2 shows a statistical summary of the finished water turbidity data for each plant. The lowest average turbidity value is associated with plant A, while the highest value is related to plant B. In the analysis, left-censored data were set at half the detection limit (0.1 NTU).

The daily mean turbidity value (three-year data) of the raw water from the River Arno is 30 NTU (max: 1700 NTU, min: 2 NTU and STD: 92 NTU). From the same water resource (River Arno), plant A shows a higher turbidity removal efficiency thanks to its more sophisticated and flexible treatments compared to the other two plants. This also enables lower data variability to be obtained (IQR = 0.06 NTU). Figs. 4, 5 and 6 show the observed trend of each treatment plant finished water turbidity. During the three-year period, the daily turbidity value in plant A remained relatively stable and low ($P50 = 0.13 \text{ NTU}$) with a growing trend in the last months of 2017 probably due to an insufficient dosage of coagulant or to filter backwashing-related problems. The treated water turbidity in plants B and C remained almost constant ($P50 = 0.22 \text{ NTU}$ for plant B and $P50 = 0.19 \text{ NTU}$ for plant C), with some fluctuations probably due to delays in the adaption of the treatment to changes in the raw water quality. The turbidity values in plant outlets B and C are higher than in plant A, and concentration spikes are more present due to the greater difficulty of the plants in coping with sudden variations in water quality compared to plant A. Overall, the plants are able to achieve turbidity values that guarantee protection against pathogens: according to the WHO Guidelines for Drinking Water Quality

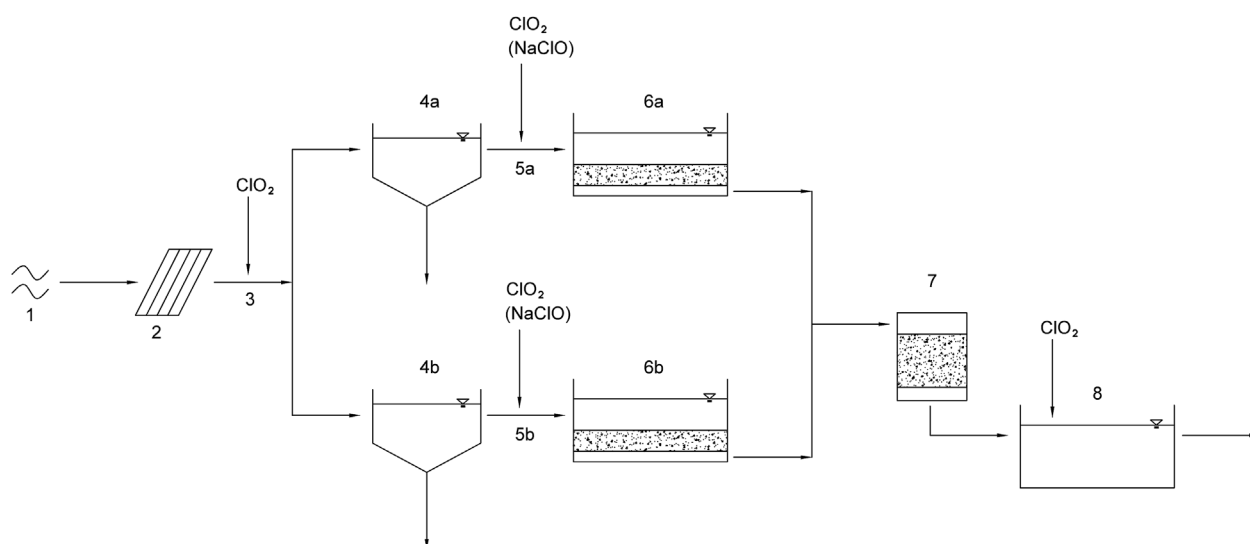


Fig. 1. Plant A – 1: Raw surface water; 2: Screen; 3: Pre-disinfection; 4a: Clari-flocculation line 1; 4b: Clari-flocculation line 2; 5a: Intermediate disinfection line 1; 5b: Intermediate disinfection line 2; 6a: Rapid sand filtration line 1; 6b: Rapid sand filtration line 2; 7: GAC Adsorption; 8: Final disinfection.

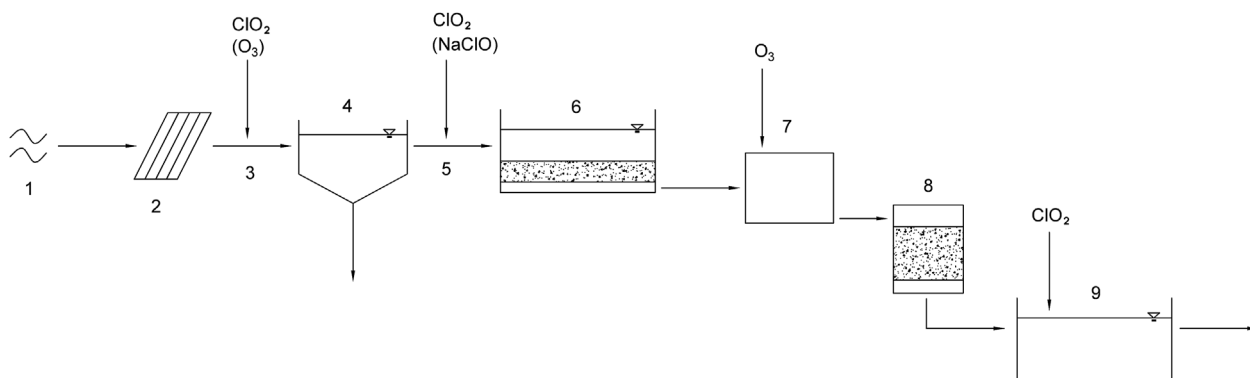


Fig. 2. Plant B – 1: Raw surface water; 2: Screen; 3: Pre-disinfection; 4: Clari-flocculation; 5: Intermediate disinfection; 6: Rapid sand filtration; 7: Post-ozonation (mostly in summer) 8: GAC Adsorption; 9: Final disinfection.

(WHO, 2017), surface water treatment systems should be able to achieve less than 0.3 NTU prior to disinfection to ensure significant barriers against pathogens. This is particularly important if we consider that some pathogens, such as *Cryptosporidium*, are chlorine-resistant. However, especially for plants B and C, turbidity spikes are present which could interfere with the efficiency of disinfection. Particular attention must be paid to the correct operation and maintenance of rapid filters in order to avoid a drop in performance.

3.2. Risk assessment

Table 3 shows the average percentage of daily per-capita incremental risk, ΔR_u , due to the turbidity concentration in the three plant outlets. The value assessed by Eq. (6), considering the median value, is 9% for plant A, 27% for plant B and 23% for plant C. This value represents the average daily increase in gastroenteritis episodes due to the turbidity concentration in the treated water, compared to the base value, $P(x_b)$. The lowest value (9%) reflects the higher turbidity removal efficiency of plant A. The risk was evaluated also considering the 10th and 90th percentile of the ERR; the results are presented in brackets in Table 3.

This conceptual approach has the advantage that it is simple to apply and it only requires drinking water turbidity data from WTPs. It is a methodological approach that is aimed at offering a comparison criterion that can be used in the application of the risk analysis included in the WSPs. Therefore, not the absolute value of the results, but the comparison among the three WTPs is essential. The ΔR_u value can be used to compare the treatment performance of plants with similar disinfection steps and population served. All the three WTPs considered use the same type of disinfection (pre-disinfection with ClO_2 , intermediate disinfection with $\text{ClO}_2/\text{NaClO}$ mixture, post-disinfection with

ClO_2); Plant B provides an additional sporadic disinfection step with ozone used depending on the quality condition of the raw water. The three WTPs treat the water from the same river (the water abstraction point distance is less than 10 km), they guarantee the same degree of protection against pathogens, and they provide drinking water to adjacent populations, therefore with similar susceptibility to waterborne pathogens. This allowed the use of the same ERR value for the three WTPs. To compare the results in different situations, ERR value should be evaluated for the specific case study. The ERR values are not available for the study area and the calculation would require a specific epidemiological investigation that goes beyond the objectives of this work.

The analysis becomes more accurate if more than one daily turbidity datum is available, because it is possible to take into account turbidity spikes which may occur as a result of filter ripening, coagulant faults, pH changes or rapid changes in source water quality. While for plant A we have more than one daily turbidity value that allows us to consider the turbidity spikes that can occur, for plants B and C we have less than one datum per day and, consequently, the risk associated with systems B and C could be underestimated with respect to the real situation.

Through the ΔR_u value, managers can easily compare the performance of their WTPs. However, it represents a percentage increase referring to a base value and does not enable the risk to be quantified in relation to the number of people exposed. Therefore, it is necessary to consider the different population served by each treatment facility, P_s . Table 3 shows, for each plant, the average daily per-capita incremental risk, ΔR_u , the population, P_s , and the comparison among the risk related to the three different plants.

Even though the average daily per-capita incremental risk, ΔR_u , of the plant A is about three times lower than the other two plants, if we also consider the catchment area in the assessment (in addition to the

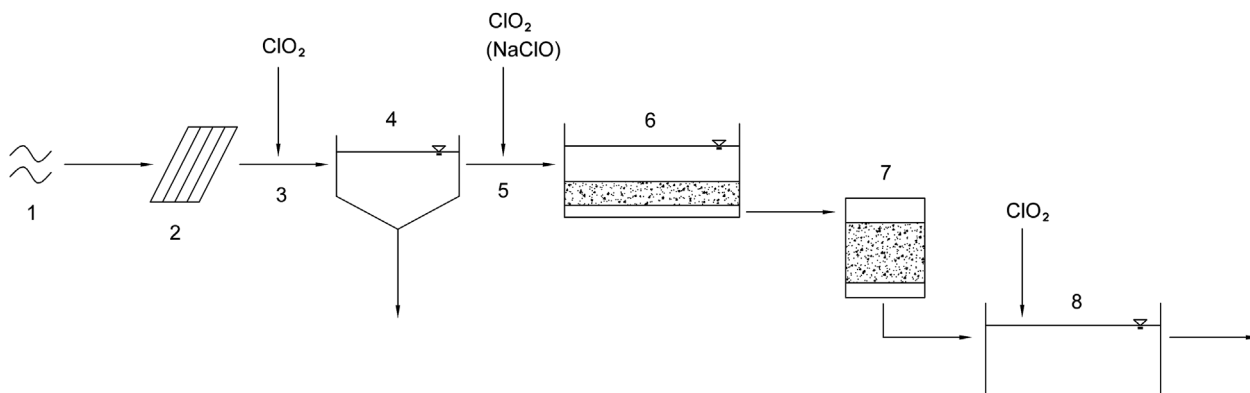


Fig. 3. Plant C – 1: Raw surface water; 2: Screen; 3: Pre-disinfection; 4: Clari-flocculation; 5: Intermediate disinfection; 6: Rapid sand filtration; 7: GAC Adsorption; 8: Final disinfection.

Table 2
Statistical summary of finished water turbidity data for each plant.

			Mean	Minimum	P10 ^a	P25 ^a	P50 ^a	P75 ^a	P90 ^a	P98 ^a	Maximum	IQR ^b
Plant A	Turbidity_FW ^c	NTU	0.14	< 0.1	0.07	0.11	0.13	0.16	0.23	0.33	0.43	0.06
Plant B	Turbidity_FW ^c	NTU	0.24	< 0.1	0.14	0.18	0.22	0.28	0.38	0.58	0.97	0.10
Plant C	Turbidity_FW ^c	NTU	0.22	< 0.1	0.13	0.15	0.19	0.28	0.38	0.47	0.56	0.13

^a P: percentile.
^b IQR: interquartile range.
^c Turbidity_FW: 24-h mean of finished water turbidity.

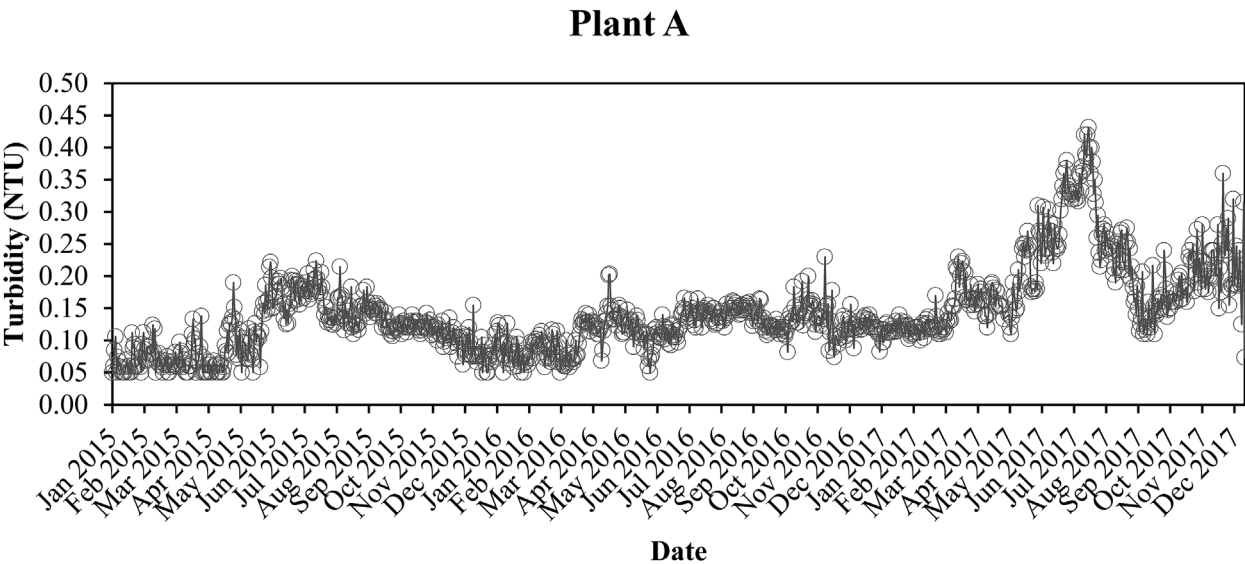


Fig. 4. Plant A treated water turbidity daily mean values.

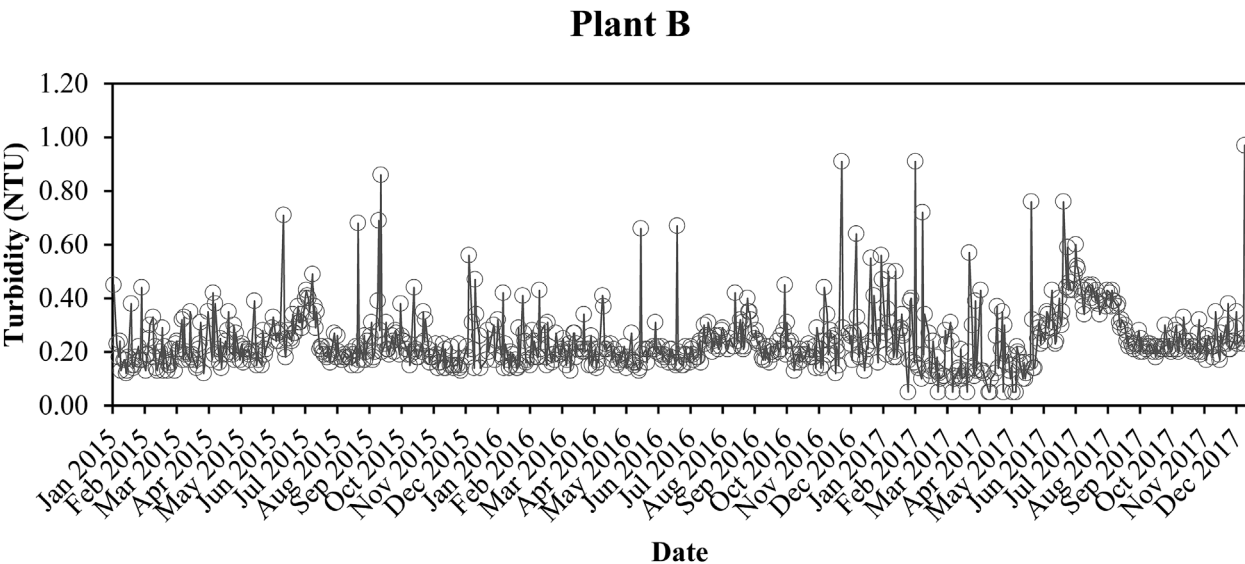


Fig. 5. Plant B treated water turbidity daily mean values.

parameter relating to drinking water quality), the risk associated with plant A becomes over two times greater than plant B and about 20 times higher than plant C. These considerations can be extremely useful for the water supplier in assessing where it is more appropriate to try and improve the service, and therefore public health, for the greatest number of users.

3.3. Risk reduction through WTP

In order to highlight how the incremental risk, ΔR_u , is modified in the presence or absence of more or less refined treatments for the removal of turbidity, turbidity data for plant A were collected not only in the outlet of the plant but also after each single treatment step. This therefore enabled the assessment of the effect of the single treatment step on the reduction of the incremental risk. The two clarification and rapid filtration lines of the plant were considered separately (line 1 and

Plant C

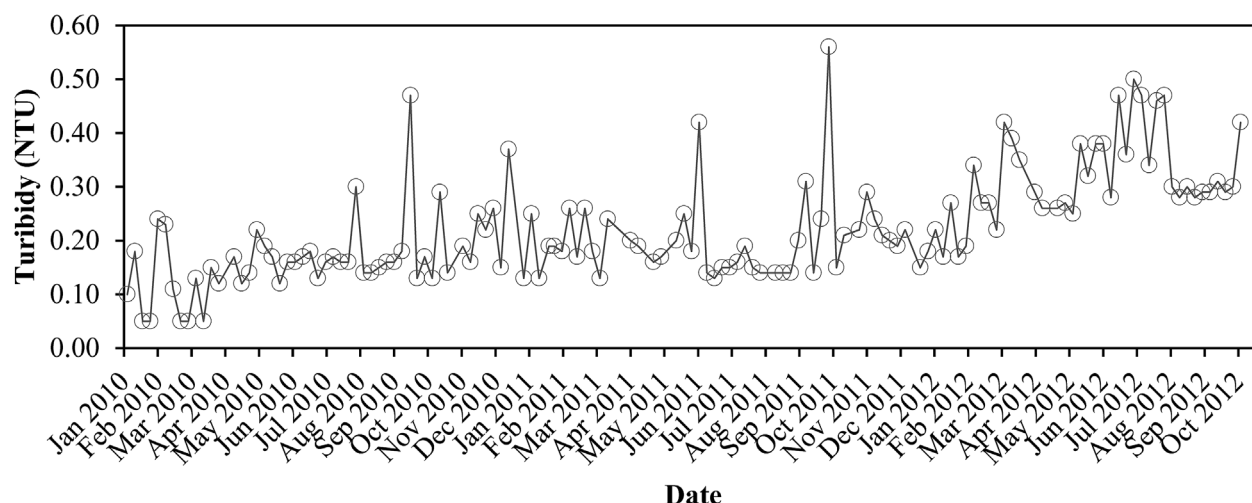


Fig. 6. Plant C treated water turbidity daily mean values.

Table 3

Median, 10th percentile, 90th percentile of the incremental risk and comparison among the risk related to the three WTPs.

	ΔR_u	$\Delta R_{u(\text{plant N})}/\Delta R_{u(\text{plant A})}^a$	$P_s (n^*)$	$R_{(\text{plant N})}/R_{(\text{plant A})}^a$
Plant A	0.09 [0.08; 0.50]	1	333700	1
Plant B	0.27 [0.24; 1.51]	3	47300	0.43
Plant C	0.23 [0.20; 1.29]	2.6	6500	0.05

^a With N = plant A, plant B and plant C.

Table 4

Median, 10th percentile, 90th percentile of the incremental risk and risk reduction due to each step of the treatment plant.

Point	ΔR_u	Risk reduction compared to point 1 ^a
1	53.4 [46.6; 299.6]	–
2a	3.0 [2.6; 16.8]	18
2b	2.1 [1.8; 11.8]	25
3a	0.38 [0.33; 2.15]	139
3b	0.22 [0.19; 1.25]	241
4	0.09 [0.08; 0.5]	601

^a Assessed by: $\Delta R_u(\text{point 1})/\Delta R_u(\text{point n})$, with $n = 2a, 2b, 3a, 3b, 4$.

line 2, see Fig. 1). The ΔR_u was assessed in the following steps used at the plants:

- 1 Absence of specific treatments for turbidity removal;
- 2a Clari-flocculation line 1;
- 2b Clari-flocculation line 2;
- 3a Clari-flocculation followed by rapid filtration line 1;
- 3b Clari-flocculation followed by rapid filtration line 2;
- 4 Complete treatment plant (clari-flocculation, sand and carbon filtration, multi-stage disinfection).

Table 4 shows the risk reduction due to each treatment step assessed by Eq. (6), considering the median value of ERR; the risk values related to the 10th and 90th percentile are presented in brackets.

The results show how the consumption of water without any specific treatments for turbidity removal (point 1) leads to an average daily increase in the risk of illness of more than 50 times the basic value ($P(x_b)$). The ΔR_u value decreases significantly throughout the treatment steps. The clari-flocculation process and the filtration step reduce the risk by 18 times for line 1 and 25 times for line 2, and by 139 times for line 1 and 241 times for line 2, respectively.

The experimental data highlight that, as already shown (see Table 3), while the finished water increases the risk of disease by 9%, it is characterized by a value which is 600 times lower than the value related to point 1, thus pointing to the importance of water turbidity removal.

Moreover, we found that the risk is reduced by more than three times from case 3 (clari-flocculation followed by rapid filtration, average of the two lines) to case 4 (complete treatment plant); this implies that, despite being mainly functional to the removal of organic matter, GAC filtration also helps to reduce turbidity and, consequently, the risk of contracting disease. Another consideration concerns the different manner of operation of the two treatment lines. The results show a clear difference in the risk values in favour of line 2 (points 2b and 3b). As mentioned previously, line 1 of the plant consists of Pulsator clarifiers, while line 2 consists of Dorr clarifiers. Under normal conditions, line 2 treats one third of the total flow, and the remaining two thirds are treated by line 1. This flow distribution is a consequence of the influent turbidity values: for low influent turbidity values the efficiency of the Pulsator clarifiers is greater. Vice versa, for high turbidity values the performance of the Dorr clarifiers is better. During 2015, 2016 only two Dorr clarifiers out of six were in operation (line 2), so line 1 resulted slightly overloaded. In 2017 all the Dorr clarifiers were in operation and the difference between the two lines decreased (see Figs. 7 and 8). Consequently, during this three-year period, line 1 shows a higher risk value than line 2, but this cannot be strictly related to lower turbidity removal efficiency.

4. Conclusions

In the present study, a procedure is proposed to determine the risk associated with drinking water turbidity in terms of the incremental number of episodes of gastroenteritis per day. The approach uses both time series data collected from WTPs and results from several epidemiological studies correlating the incidence of gastrointestinal disease

Line 1

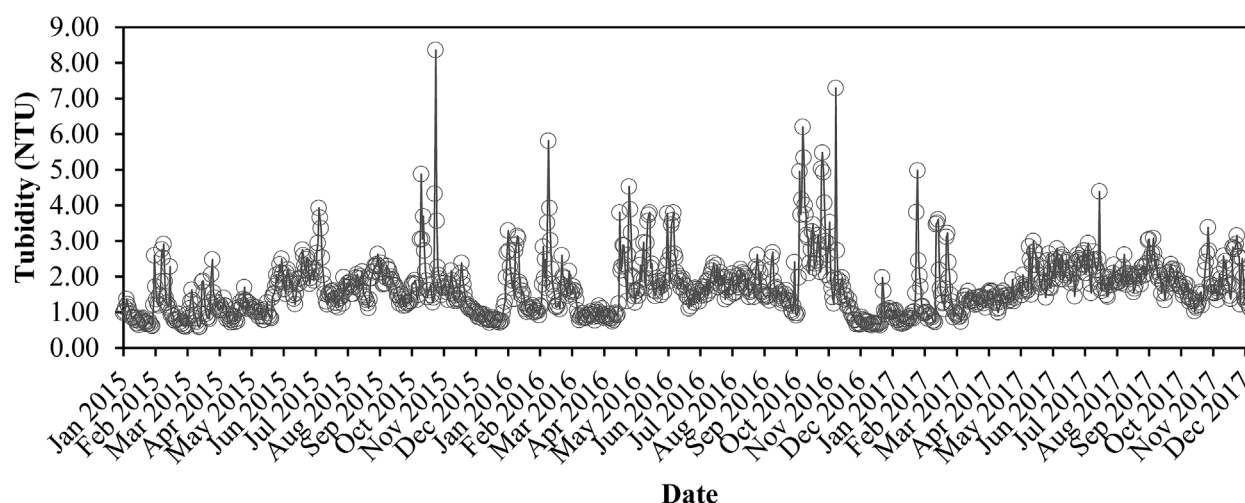


Fig. 7. Plant A (line1) clarified water turbidity daily mean values.

Line 2

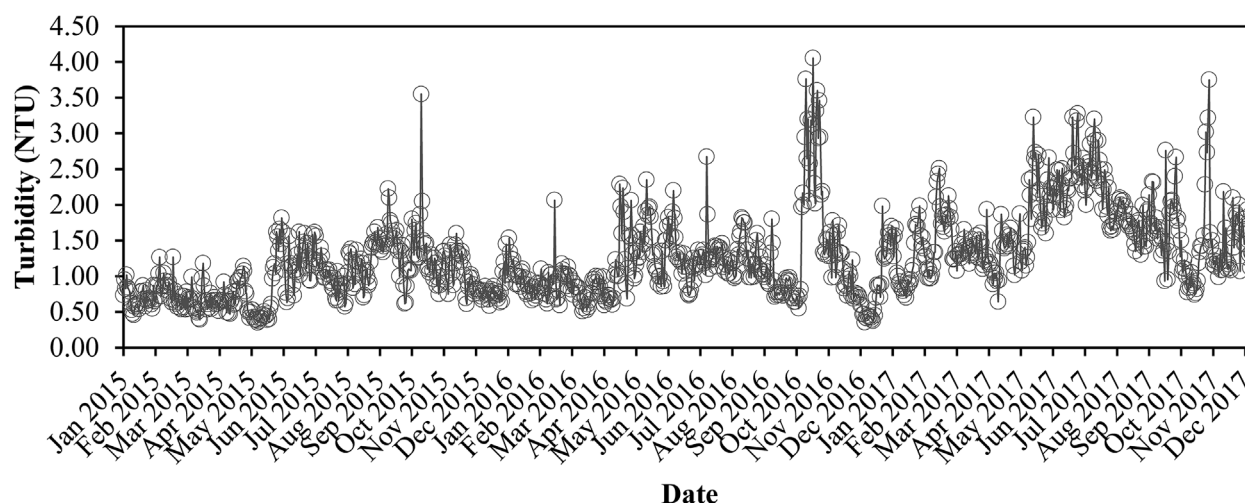


Fig. 8. Plant A (line2) clarified water turbidity daily mean values.

with treated water turbidity. Three WTPs, which treat the same surface water (River Arno), were selected and three years of turbidity data for each plant were analysed to assess the average daily per-capita incremental risk of contracting a gastrointestinal disease due to tap water turbidity. The average daily per-capita incremental risk due to drinking water turbidity ranged from 9% (plant A) to 27% (plant B). The plant with the most sophisticated train obtains the lowest risk value (9%), which then guarantees the lowest turbidity concentrations in the treated water ($P50 = 0.13$ NTU). The risk was evaluated using the median of the literature ERR values. The presence of a single value much higher than the others changes the results if the 90th percentile is considered; in this case risk increases up to 150% could be reached (Plant B).

The benefit in terms of decreases in turbidity-related risk compared to the risk related to water without specific treatments for turbidity removal was also assessed for each single step of the water treatment train. Clari-flocculation and the combined clari-flocculation and filtration process reduce the risk by about 20 and 200 times, respectively. Moreover, the GAC filtration reduce the risk by more than three times compared to the previous treatment step (combined clari-flocculation

and filtration process). The complete treatment train (clari-flocculation, sand and carbon filtration, multi-stage disinfection) allows the risk to be reduced by about 600 times.

According to the WHO estimates, outbreaks of waterborne disease continue to occur in both developed and developing countries, leading to loss of life and significant disease and economic burden for individuals and communities (WHO, 2016). Therefore, given the wide interest in recent years towards the adoption of proactive approaches such as WSP for the prevention and management of drinking water-related risks, the procedure presented to evaluate the impact of drinking water turbidity on the incidence of gastrointestinal diseases could represent a useful tool to support water suppliers' decisions. The presented procedure can be used for:

- Assessing the incremental risk of gastrointestinal diseases related to drinking water turbidity;
- Assessing the risk variation throughout the plant treatment steps in order to highlight how each process contribute to health risk reduction;
- Assessing the risk of a plant over time comparing different time

series data;

- Comparing the performance of different plants with similar disinfection systems;
- Assessing the absolute risk, in terms of number of gastroenteritis cases/year, taking into account the catchment area.

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