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ORIGINAL PAPER

Risk Assessment of Water Accidental Contamination Using Smart Water Quality Monitoring

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Abstract
Accidental contamination and malicious attacks can degrade the water quality in water distribution networks and threat the human health. Therefore, a rapid detection of water contamination is required to prevent waterborne diseases. The use of water quality sensors allows a real-time monitoring of several physical and chemical parameters. The aim of this paper is to combine the smart monitoring with the risk assessment approach to ensure early detection of water contamination. Within the European Project "SmartWater4Europe," S::CAN sensor was implemented, on the water supply system of the Campus of Lille University, France, since 2016. The campus is a representative field study with 15 km of water distribution network. In this paper, Turbidity and Chlorine, recorded online by S::CAN, were analyzed continuously to define the risk assessment parameters (the severity of consequences and the likelihood of an event). The application of the proposed approach indicates that the magnitude of deviation from thresholds limits and the duration of events are the two essential parameters to be considered in risk assessment approach. The paper shows that this new approach provides promising perspective for the early detection of the water contamination. It allows to identify the risk level and the priority required in real time, without resorting laboratory analyses.

Keywords Water quality · Sensors · Smart monitoring: risk assessment · Distribution network · Field study · Water contamination · Early detection

Introduction

Accidental contamination or malicious attacks in the water supply system constitutes a major challenge for both the water industry and public authorities, because it could expose consumers to harmful waterborne diseases, such as Diarrheal syndromes estimated annually to 4.6 billon episodes (WHO 2010). In Strasbourg, France, around 60,000 people were deprived from drinking water for 15 days with several cases of gastroenteritis due to a bacteriological contamination (Deshayes et al. 2001). Therefore, a rapid detection of any potential contamination risk is required to secure the water supply. An Early Warning System (EWS) can then be used to make decisions that are protective of public health and minimize unnecessary concern to public (Hasan et al. 2005). The development of this early detection system constitutes a hard task, because of the multitude of contaminant sources (chemical substances and microorganisms). These substances are generally detected through laboratory-based methods which are too slow to develop operational response (Lambrou et al. 2014).

The recent development of the smart water monitoring resulted in the fabrication of new devices, which allow a real-time monitoring of the water quality. Generally, these devices record physical or chemical parameters, which are related to the water quality, but do not provide exactly the source of contamination. To overcome this difficulty, combining the smart monitoring with the risk assessment approach for the early detection of the water contamination may be helpful.

Risk assessment provides essential information for identifying strategy for reducing and preventing disasters and designing the EWS (RIC Nonprofit Ltd 2014). In the water

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industry, risk assessment can inform individuals and organizations about the nature and risk to, and from, their water and helps in reducing those risks (Adimalla and Wu 2019; Li et al. 2016, 2019; Percival et al. 2000). Water quality assessment should determine whether the final water quality provided to users is able to meet the standards of drinking water (Li and Wu 2019). Although there are a multitude of contaminants that can compromise the drinking water quality, not every potential hazard requires the same degree of attention (NHMRC 2011). The outcome of risk assessment helps in identifying priorities in corrective actions. A high-risk event requires an emergency response, while a low risk needs a lower priority of attention.

Three types of approaches are generally used in risk assessment of the water quality, namely (i) Epidemiological approach, which needs a large sample sizes to uncover very small increases in risk (Fewtrell and Bartram 2001), (ii) Quantitative (Microbial or Chemical) Assessment approach (Thoeye et al. 2003), which is generally time consuming and could result in false alert, and (iii) Qualitative Assessment approach (Dufour et al. 2003), which consists in the classification of risks into categories. However, for a rapid detection of accidental contaminations, the qualitative approach is the most appropriate. It provides a qualitative indication of abnormalities in the water quality. This approach ranks the level of risk using classes without resorting laboratory analyses. It is generally used by the *World Health Organization* (*WHO*) in the execution of Water Safety Plan and has the advantage of being relatively simple (Niedbalski and Cos 2015).

The paper presents the use of a combination of the smart monitoring of the water quality and the qualitative assessment approach for the early detection of the water contamination. After a presentation of this new approach, the paper describes its application in the water supply system of the Campus of Lille University, which was monitored using S::CAN device within the European Project "SmartWater4Europe."

Fig. 1 S::CAN sensor

Methodology

Smart Monitoring

The use of water quality sensors in the water supply system allows a real-time monitoring of the water quality. Figure 1 illustrates the S::CAN device. Its main components—spectro::lyser, sensors, and controller—are assembled with required flow cells, mounting fitting and pipework on a compact panel (Manual micro::station s::can 2011). S::CAN sensor records and transmits to a server in real-time different water quality parameters, such as Free Chlorine, Turbidity, pH, Total Organic Carbon (TOC), Conductivity, and Temperature. During normal functioning, each parameter follows a stable signal (baseline). A significant perturbation in the signal could be related to the presence of an anomaly in the water.

Turbidity and Free Chlorine are two main indicators of the water quality. Turbidity is an indicator of the suspended matters that disturb the water quality. Standards define 1 NTU as a threshold limit for Turbidity. A rapid decrease in the Chlorine level could be related to the presence of microorganisms. According to the WHO (2017), a concentration of Free Chlorine between 0.2 and 0.5 mg/l must be maintained in treated water.

The online tracking of the Turbidity and Free Chlorine provides pertinent information about the water quality. Exceeding the acceptable limit of Turbidity (1 NTU) indicates a potential variation in the water quality. A low amount of Chlorine together with the Turbidity augmentation indicates an abnormal event, which could be related to the water contamination.

Qualitative Risk Assessment

The main purpose of the qualitative assessment is to detect and classify 'events' in function of the frequency of occurrence and the magnitude of consequences. This method includes five steps (Dufour et al. 2003): (i) hazard scenario, (ii) likelihood, (iii) consequence, (iv) risk score, and (v) rank (level of risk).

To estimate the risk level, two main scales should be defined: the likelihood of the event and the severity of its consequences. The likelihood is a ranking of how likely the event could occur. It can be classified in four main categories: Likely, Moderate, Unlikely, and Rare. A weight is assigned to each category, according to its probability of occurrence [once per week, month, year, etc. (Davison et al. 2002)]. The severity of consequences describes the impact of an event on an exposed population during a specific duration. In the same way, four classes define the severity of consequences: Major, Moderate, Minor, and Insignificant. Based on the magnitude of the consequences [harmful or lethal to small or large population (Davison et al. 2002)], a corresponding weight is attributed. Table 1 gives the scales of likelihood and consequences used in the qualitative risk assessment.

A risk score (*R*) is defined as the weight attributed to the likelihood multiplied by the weight associated to the severity of consequences:

$$R = \text{Weight (likelihood)} \times \text{Weight (severity of consequences)}. \quad (1)$$

To determine the magnitude and the priority of risks, a risk matrix is recommended (Bartram 2009). The risk score *R* is classified into four main intervals: $R < 4$, $4 \leq R \leq 7$, $7 \leq R \leq 13$, and $R > 13$. According to the risk score class, a risk-level category is defined, respectively, as Low, Moderate, High, or Very High. The results are illustrated in a risk matrix that combines the likelihood and the severity of consequences of an event (Table 2).

The major issue in qualitative assessment is the definition of scales of likelihood and consequences severity. The following sections present the application of this approach on the water system of the Scientific Campus of Lille University. The use of a Smart Monitoring using S::CAN device provides real-time data of both Turbidity and Chlorine. These two water quality parameters will be used in the Qualitative assessment of the water contamination risk.

Table 1 Qualitative risk assessment scale: (a) likelihood scale; (b) severity of consequences scale

(a) Likelihood scale		(b) Severity of consequences scale	
Category	Weight	Category	Weight
Likely	4	Major	4
Moderate	3	Moderate	3
Unlikely	2	Minor	2
Rare	1	Insignificant	1

Application to the Scientific Campus of Lille University

Site Description

This study is applied in the drinking water system of the Scientific Campus of Lille University. The Campus represents a small town with around 25,000 users. It includes 150 buildings (administration, teaching, university, and restaurants). It covers an area of around 110 ha and includes 100 km of urban networks (drinking water, electrical network, heating, and sewage). The water distribution network length is about 15 km of cast iron pipes (diameter between 20 and 300 mm). The network is equipped with 250 isolations valves, 49 hydrants, purges, and stabilizers (Fig. 2) (Farah and Shahrour 2017).

The water quality in the Campus is monitored using S::CAN device, which measures continuously different water quality parameters such as Turbidity, Chlorine, UV, and Total Organic Carbon (Saab et al. 2018). S::CAN has been installed in the technical room of Polytech'Lille since April 2016. A derivation from the water pipe was used for

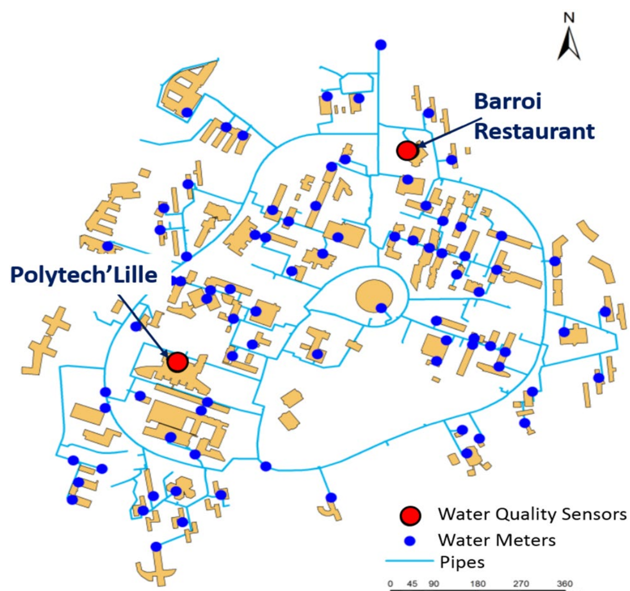

Fig. 2 Location of water quality sensors in the campus of the University of Lille

Table 2 Risk matrix

Likelihood	Severity of Consequences			
	Insignificant	Minor	Moderate	Major
Likely	Moderate	High	High	Very High
Moderate	Low	Moderate	High	High
Unlikely	Low	Moderate	Moderate	High
Rare	Low	Low	Low	Moderate

sensors water supply and the technical room electricity was used for the powers supply. Water samples used by the device pass through an evacuation system.

Values of Turbidity and Free Chlorine recorded during the period between July 1 and July 15, 2017 were used in the risk assessment of the water contamination. The variation of Turbidity and Chlorine, during this period is illustrated in Fig. 3. Some events have been detected for Turbidity, especially on July 6 and July 7, 2017. The concentration of Chlorine varies between 0 and 0.3 mg/l.

Risk Assessment of the Water Contamination

Two approaches are used for the Risk assessment of the contamination of the water of the scientific campus using the water quality parameters: Turbidity and Chlorine. In these approaches, an event is defined as an exceeding of the threshold of Turbidity (Turbidity > 1 NTU).

Approach 1-Level 1

Analysis of real-time data allows defining two major classes: (i) Turbidity < 1 NTU which indicates a safe water quality, and (ii) Turbidity > 1 NTU which indicates a possible contamination event. Data are firstly filtered (Event or not). The list of potential events should be analyzed to estimate the level of risk induced.

If an event occurs, the Turbidity can be divided into four intervals: [1–1.5], [1.5–3], [3–10] and > 10 NTU. Analysis of historical data shows that Turbidity values and their corresponding probability are inversely proportional. An event with Turbidity between 1 and 1.5 NTU occurs very frequently (> 80%). However, the probability that Turbidity exceeds 10 NTU is very low (< 4%).

In this approach, the likelihood is defined as the probability of each class of Turbidity. As Turbidity value increases, the likelihood of its occurrence decreases. It is very rare that Turbidity reaches very high amplitudes. Based on the likelihood scale of Table 1, a weight is attributed for each category of Turbidity (Table 3a).

The severity of consequences is defined according to Chlorine value using four intervals: [0–0.005] or > 0.5, [0.005–0.05], [0.05–0.2], and [0.2–0.5] mg/l. Since the amount of Chlorine should be maintained between 0.2 and 0.5 mg/l, the major consequence occurs when Chlorine concentration is lower than 0.005 mg/l or higher than 0.5 mg/l (Table 3b defining in this case the severity of consequences for Approach 1). The corresponding weight is assigned in function of the severity scale summarized in Table 1.

The risk level is defined as the combination of (i) the probability of Turbidity and (ii) the severity of its consequences based on the Chlorine interval. The risk matrix, defined in Table 2, is used in this approach. It indicates that the risk level is highest for low Chlorine value combined with high probability of contamination event (Turbidity between 1 and 1.5 NTU).

Analysis of risk assessment's results provides the priority score required for risk management. The objective of prioritization is to rank hazardous events to focus on the most significant hazards (Davison et al. 2005). Risk-reduction actions will be based on the level of priority attention. High risk level identifies the need of high priority attention with emergent corrective actions, while low risk level can be ignored or given a low priority attention. Table 4 provides the priority level in accordance with the risk-level ranking.

In this approach, the risk level is assigned by evaluating Turbidity and Chlorine values at each time step. The risk assessment will provide the priority class of events. However, some factors, such as faults in instrument and data transmission problems, can lead to false values of Turbidity and/or Chlorine.

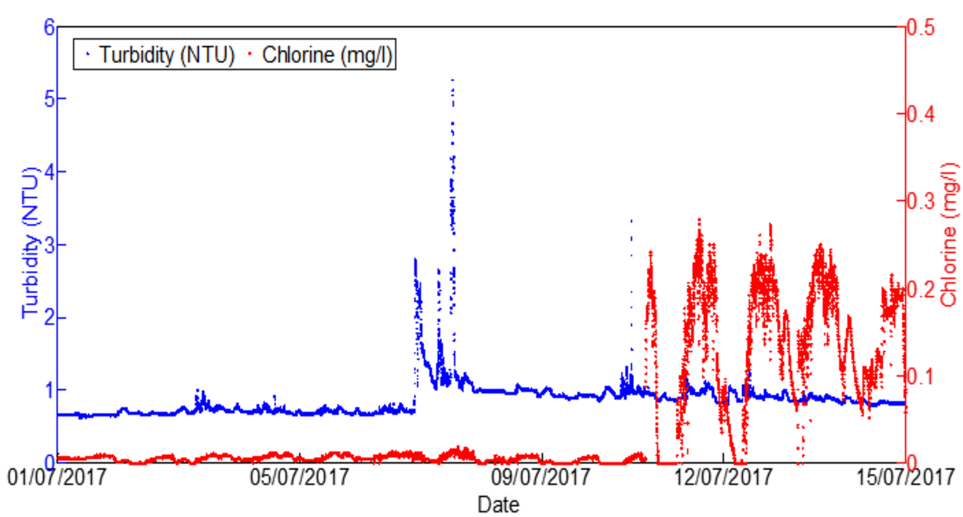

Fig. 3 Variation of Turbidity and Chlorine between July 1 and July 15, 2017

Table 3 Description of Approach 1

(a) Likelihood (for Turbidity > 1 NTU)		
Descriptor	**Description: turbidity (NTU)**	**Weight**
Likely (> 80%)	[1–1.5]	4
Moderate (10–80%)	[1.5–3]	3
Unlikely (4–10%)	[3–10]	2
Rare (< 4%)	>10	1
(b) Chlorine classification		
Descriptor	**Description: chlorine (mg/l)**	**Weight**
Major	[0–0.005] or > 0.5	4
Moderate	[0.005–0.05]	3
Minor	[0.05–0.2]	2
Insignificant	[0.2–0.5]	1

Table 4 Priority level classification

Risk level	Prioritization of risk
No Risk	No attention needed
Low	Low priority attention
Moderate	Intermediate priority attention
High	High priority attention
Very High	Urgent priority attention

Table 5 Priority level scale

Risk level scale		Duration scale	
Category	Weight	Category	Weight
Very High	4	Long (> 120 min)	4
High	3	Medium (60–120 min)	3
Moderate	2	Short (30–60 min)	2
Low	1	Instantaneous (0–30 min)	1

Approach 1-Level 2

The determination of the priority attention level could be enhanced by the consideration of the duration of the event. Level 1 of Approach 1 could be enhanced using the following process:

- Determination of risk level at each time step (according to Approach 1-Level 1).
- Classification of risk level, function of their category (Very High, High, Moderate, and Low).
- Duration of each category of risk level during an event.

This classification will detect the events that occurred, and then identify the different risk category during an event as well as the corresponding duration. The duration of each level is calculated as follows:

$$\text{Duration (min)} = \text{Date (End of risk level)} - \text{Date (Start of risk level)}. \quad (2)$$

To take into account the duration of each category of risk, a new scale for priority level is given in Table 5. It is defined as the combination of the risk level and the duration. A corresponding weight is attributed for each category of risk level. The largest weight is assigned for "Very High" risk. In the same way, the duration is ranked into four classes (from Long to Instantaneous). Weights are given in the increasing order of duration: a long duration will be the most critical. The priority attention score is the product of the weight of risk level and the weight attributed to the duration:

$$\text{Priority attention score } P = \text{Weight(risk Level)} \times \text{Weight (duration)}. \quad (3)$$

The priority score is ranked into four intervals. The priority level is then identified according to the class of priority score (Table 6).

All steps of Approach 1 have been automated in Visual Basic for Applications (VBA) script and are summarized in the flow chart of Fig. 4.

Approach 2-Level 1

In Approach 1, since the likelihood scale is described as the probability of Turbidity values, the highest weight is given to the lowest Turbidity that occurs frequently. However, it is obvious that the impact of an event depends on the magnitude of deviation from the Standard limit (1 NTU). The event becomes more severe when the deviation from the limit is larger. Turbidity close to 1 NTU is not dangerous like high values. Approach 2 will take into account the effect of parameter value (Turbidity) on the severity of consequences

Table 6 Prioritization of risk

Priority score	<4	$4 \leq P \leq 7$	$7 \leq P \leq 13$	>13
Priority level	Low priority attention (L.P)	Intermediate priority attention (I.P)	High priority attention (H.P)	Urgent priority attention (U.P)
Risk level	Duration			
	Instantaneous	Short	Medium	Long
Very High	I.P	H.P	H.P	U.P
High	L.P	I.P	H.P	H.P
Moderate	L.P	I.P	I.P	H.P
Low	L.P	L.P	L.P	I.P

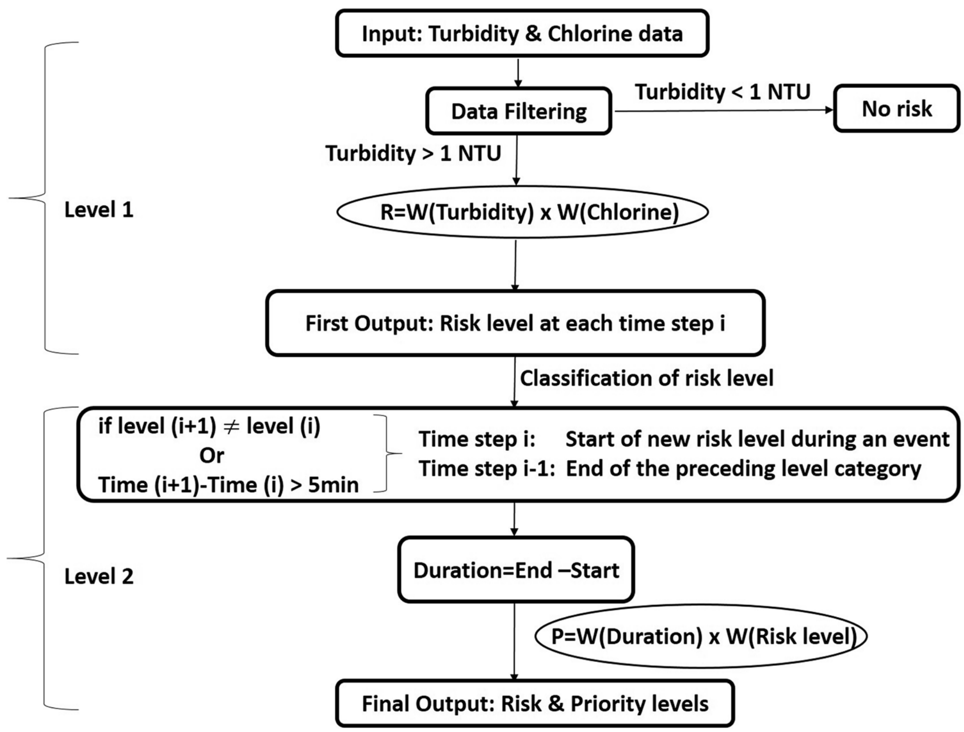

Fig. 4 Flow chart of Approach 1

and will evaluate the frequency of an event in terms of its duration.

The main purpose of Approach 2 is to assess the variation of one single parameter measured by S::CAN. Approach 2 is firstly applied to Turbidity. The main output is the list of events that occurred during a period with the corresponding risk level.

Firstly, data are filtered (Event or not) by analyzing Turbidity value. The start and end time of each event is identified. The corresponding duration is calculated (difference between end and start time of an event). Four categories are defined: Instantaneous, Short, Medium, and Long. Weights proportional to the duration are attributed for each category (Table 7a).

The severity of events consequences is defined according to the average Turbidity during each event (Table 7b defining in this case the severity of consequences for Approach 2). Turbidity is classified into four intervals: [1–1.2], [1.2–1.5], [1.5–3], and > 3 NTU. Weights are assigned in ascending order of Turbidity. An average Turbidity lower than 1.2 NTU has insignificant impact. However, a value greater than 3 NTU can induce a major impact.

The risk score is calculated as the weight of the duration multiplied by the weight of the average Turbidity (indicated as ($\overline{\text{Turbidity}}$)):

$$\text{Risk Score } R = \text{Weight (duration)} \times \text{Weight } (\overline{\text{Turbidity}}). \tag{4}$$

The classification and ranking of risk score, detailed before (in Section "Qualitative Risk Assessment"), is used in this approach. The results of risk ranking (Low, Moderate, High, and Very High) are illustrated in the risk matrix of Table 8.

Table 7 Description of Approach 2

(a) Duration of event

Descriptor	Description: duration (min)	Weight
Long	> 120	4
Medium	60–120	3
Short	30–60	2
Instantaneous	0–30	1

(b) Turbidity classification

Descriptor	Description: $(\overline{\text{Turbidity}})$ (NTU)	Weight
Major	>3	4
Moderate	[1.5–3]	3
Minor	[1.2–1.5]	2
Insignificant	[1–1.2]	1

Table 8 Description of risk matrix of Approach 2

	Severity of Consequences			
Event Duration	Insignificant	Minor	Moderate	Major
Long	Moderate	High	High	Very High
Medium	Low	Moderate	High	High
Short	Low	Low	Moderate	High
Instantaneous	Low	Low	Low	Moderate

Approach 2-Level 2

Approach 2 can be enhanced by considering the variation of two parameters: Turbidity and Chlorine. The risk score is calculated as for Approach 2-Level 1:

$$\text{Risk score} = \text{Weight (Duration)} \times \text{Weight (Severity of consequences)}. \tag{5}$$

The definition of severity of event consequences depends, in this case, on the classification of both Turbidity (Table 7b) and Chlorine (Table 3b). For each event, the average Turbidity and the average Chlorine are calculated. Highest weight is assigned to the biggest value of Turbidity. However, for Chlorine, weights are inversely proportional to the concentration. The consequence of an event is major for high Turbidity combined with small amount of Chlorine. A severity scale with assigned weight (Table 9) is defined as follows:

$$\text{Severity Scale } S = \text{Weight } (\overline{\text{Turbidity}}) \times \text{Weight } (\overline{\text{Chlorine}}). \tag{6}$$

The duration of each event is calculated and given a corresponding weight (Table 7a). The risk level for each event is then identified (Table 8).

A VBA code has been developed for all the steps of Approach 2 as indicated in Fig. 5.

Table 9 Description of the severity scale

Severity score	<4	$4 \le S \le 7$	$7 \le S \le 13$	>13
Severity scale	Insignificant	Minor	Moderate	Major
Weight	1	2	3	4

Results and Discussion

Application of Approach 1

Approach 1-Level 1 can be used to identify the risk level for both historical data and real-time data. The application on historical data is illustrated in Fig. 6a. At each time step, Turbidity and Chlorine are ranked with the specified weights. The risk score is then calculated (Eq. (1)). The corresponding risk category is identified. Figure 6a shows the risk score, as well as the variation of Turbidity and Chlorine between July 1 and July 15, 2017. It indicates events of very high risk, especially on July 7, 2017. This risk level is verified in Fig. 6b. It shows an increase in the Turbidity for many hours coupled with sudden decrease in the Chlorine concentration. This combination, between deviated values with respect to reference thresholds (Cubillo and Pérez 2014), provides an indication of a potential contamination event.

On the other hand, other cases of high risk were observed on July 8 and July 9, 2017. They were induced by very low

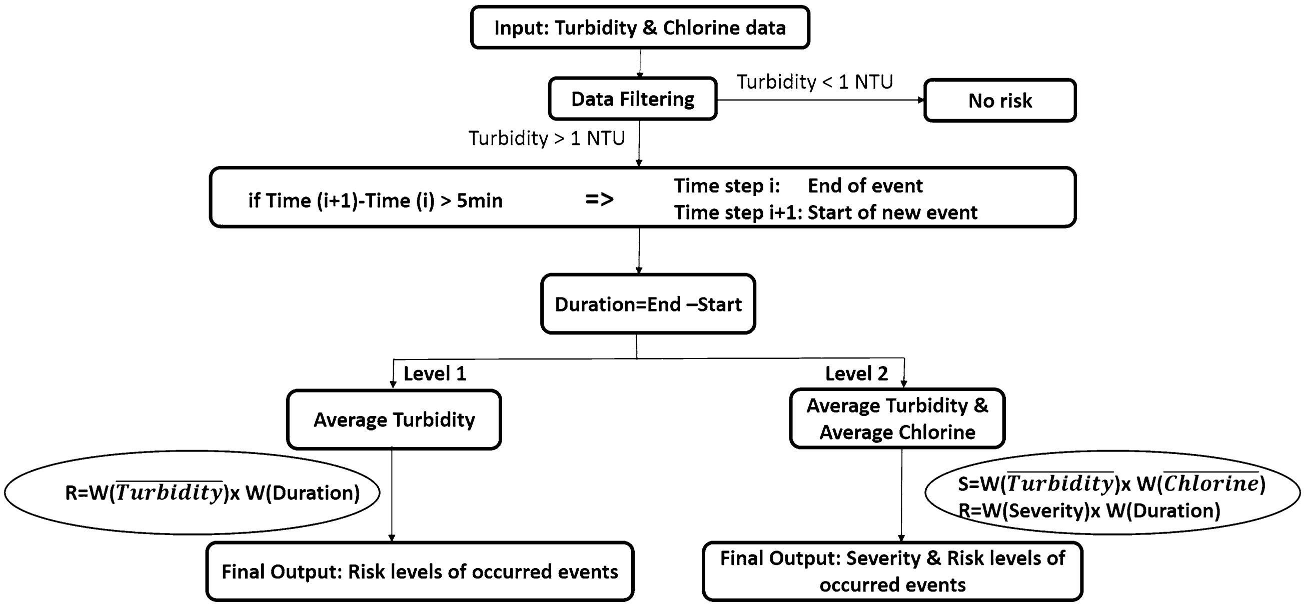

Fig. 5 Flow chart of Approach 2

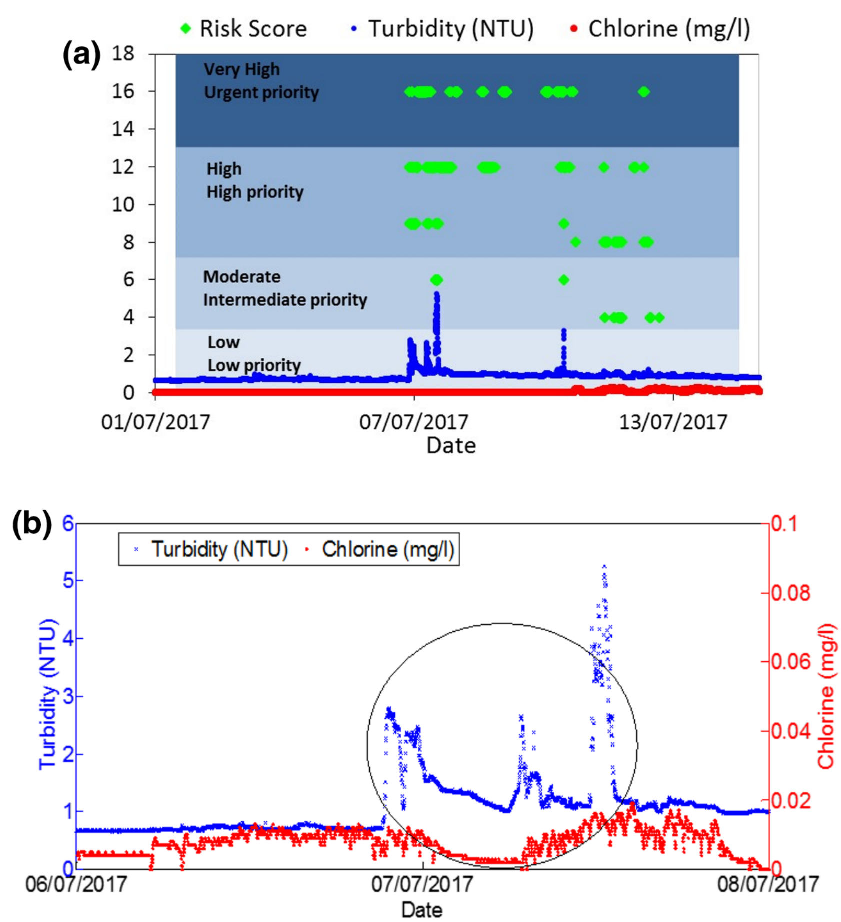

Fig. 6 Application of Approach 1-Level 1. **a** Risk level for S::CAN data; **b** event detected on July 7, 2017

concentrations of Chlorine (near zero) with Turbidity values close to the threshold (1 NTU). Moderate levels were observed, in particular, on July 11 and July 12, 2017. Such levels are obtained from insignificant severity of consequence (Chlorine about 0.2 mg/l) combined with a likely event of Turbidity (between 1 and 1.5 NTU).

Turbidity(NTU):	1,6
Chlorine(mg/l):	0,02
Risk Level:	High
Prioritization of Risk:	High priority attention

Fig. 7 Example of real-time risk assessment according to Approach 1-Level 1

The risk level could be evaluated for real-time data, with the corresponding priority attention. An example of real-time risk assessment is given in Fig. 7 for a Turbidity of 1.6 NTU and Chlorine value of 0.02 mg/l. In this case, the weights attributed to both Turbidity and Chlorine is 3 (Table 3). The calculated risk score is 9 (Eq. (1)). Using Table 2, a high risk level is identified for these data. According to Table 4, high priority attention is then identified.

The application of Approach 1-Level 2 is carried out by (i) classification of risks and (ii) determination of priority level. The histogram in Fig. 8 shows an example of the classification of risk level with the corresponding duration. It indicates the importance of the proportion of time when certain water quality concentration thresholds are exceeded (Pegram et al. 2013). For example, an event of "High" risk level of 135 min (on 07/07/2017 09:25) is more dangerous than an event of "Very High" risk of only 1 min (on 06/07/2017 21:24).

Table 10 illustrates an example of the identification of priority level using Approach 1-Level 2. For each new event, the risk level is classified and the corresponding duration is calculated. The priority attention for each category of risk level is then identified. Analysis of this table proves the influence of the duration factor on the priority level. For example, an event of "High" risk (occurred on 06/07/2017 22:41) requires more attention than an event of "Very High" risk (occurred on 06/07/2017 22:39). Although the risk level is more important on 06/07/2017 22:39, the event on 06/07/2017 22:41 needs more attention for corrective actions, since the latter remains for more than 2 h.

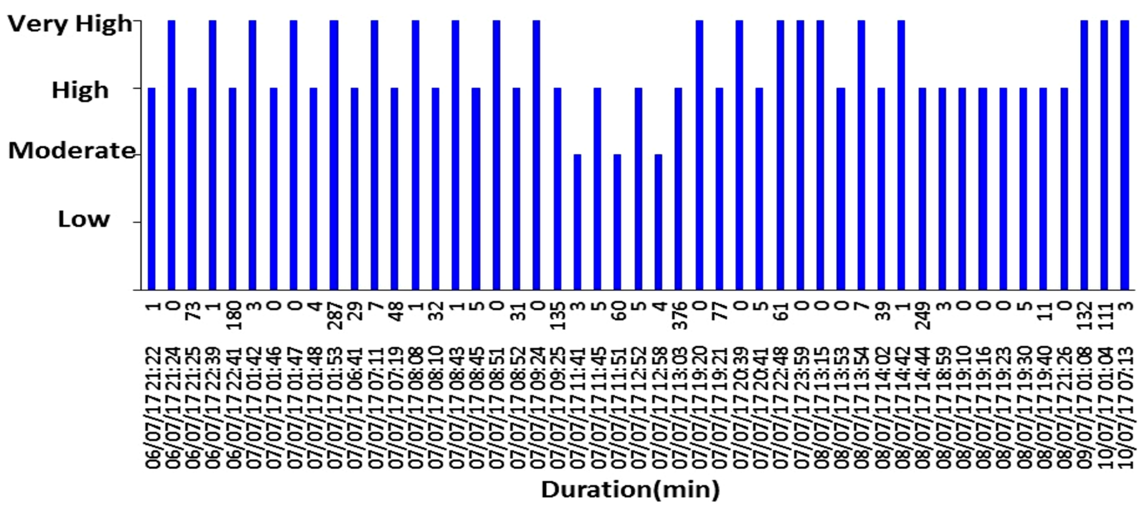

Fig. 8 Risk-level classes with the corresponding duration

Table 10 Risk and priority level for S::CAN data according to Approach 1-Level 2

Start of new level of an event	End of level	Risk Level	Weight of level	Duration (min)	Weight of duration	Priority Score	Priority level
6/7/2017 21:22	6/7/2017 21:23	High	3	1	1	3	L.P
6/7/2017 21:24	6/7/2017 21:24	Very High	4	0	1	4	I.P
6/7/2017 21:25	6/7/2017 22:38	High	3	73	3	9	H.P
6/7/2017 22:39	6/7/2017 22:40	Very High	4	1	1	4	I.P
6/7/2017 22:41	7/7/2017 1:41	High	3	180	4	12	H.P
7/7/2017 1:42	7/7/2017 1:45	Very High	4	3	1	4	I.P
7/7/2017 1:46	7/7/2017 1:46	High	3	0	1	3	L.P
7/7/2017 1:47	7/7/2017 1:47	Very High	4	0	1	4	I.P
7/7/2017 1:48	7/7/2017 1:52	High	3	4	1	3	L.P
7/7/2017 1:53	7/7/2017 6:40	Very High	4	287	4	16	U.P
7/7/2017 6:41	7/7/2017 7:10	High	3	29	1	3	L.P

In Approach 1, Level 2 seems to be more realistic than Level 1, in terms of priority attention. For "Very high" risk (as on 06/07/2017 22:39 in Table 10), Level 1 indicates a need of urgent attention (Table 4). However, Level 2 evaluates the duration of this risk category before defining the priority level as Intermediate. After detecting abnormalities' risk, it is important to take into account the event duration. An instantaneous event should not have the same decision response as an event that remains for several minutes or even hours. The duration will help in determining the nature of contamination events: (i) Instantaneous risk level can be interpreted as problem in sensor data due to connection issues for example and can be ignored (Murray et al. 2010), (ii) significant duration should be analyzed to verify the potential existence of contamination, (iii) Long duration indicates the presence of anomaly in the water system and requires actions.

Application of Approach 2

Table 11 summarizes the application of Approach 2-Level 1. It indicates some events. A "High" risk was identified for the first event (on July 6, 2017). This event lasted for about one day with an average Turbidity of 1.5 NTU. Figure 9 confirms the high risk during this period. Important perturbations are observed in Turbidity signal. Turbidity exceeded significantly the limit of 1 NTU. High priority attention should be assigned in two steps: (i) analysis of the water quality to identify the origin of anomaly and (ii) corrective actions if required.

Most of other events have "Low" risk level where Turbidity values remain close to 1 NTU. The exceeding the limit is restricted to only few minutes. This situation indicates a relatively safe drinking water.

Table 12 summarizes the results of Approach 2-Level 2. It indicates events that occurred (between July 1 and July 15, 2017) with their corresponding severity level. During this period, no Major or Moderate consequences were observed. The level of severity for the majority of events is Insignificant or Minor. This can be verified by the small deviation of Turbidity from the limit, even when Chlorine is close to 0 mg/l. The calculation of the risk level according to Approach 2-Level 2 is illustrated in Table 13. It indicates "Low" risk levels for most events.

Table 11 Risk level for S::CAN data according to Approach 2-Level 1

Start of Event	End of Event	Duration (min)	Weight of Duration	Average Turbidity (NTU)	Weight of Turbidity	Risk Score	Risk Level
06/07/2017 21:22	07/07/2017 20:46	1404	4	1,499	2	8	High
07/07/2017 22:48	07/07/2017 23:49	61	3	1,011	1	3	Low
07/07/2017 23:59	07/07/2017 23:59	0	1	1,001	1	1	Low
08/07/2017 13:15	08/07/2017 13:15	0	1	1,005	1	1	Low
08/07/2017 13:53	08/07/2017 18:53	300	4	1,017	1	4	Moderate
08/07/2017 18:59	08/07/2017 19:02	3	1	1,002	1	1	Low
08/07/2017 19:10	08/07/2017 19:10	0	1	1,004	1	1	Low
08/07/2017 19:16	08/07/2017 19:16	0	1	1,002	1	1	Low
08/07/2017 19:23	08/07/2017 19:23	0	1	1,002	1	1	Low
08/07/2017 19:30	08/07/2017 19:35	5	1	1,004	1	1	Low
08/07/2017 19:40	08/07/2017 19:51	11	1	1,003	1	1	Low

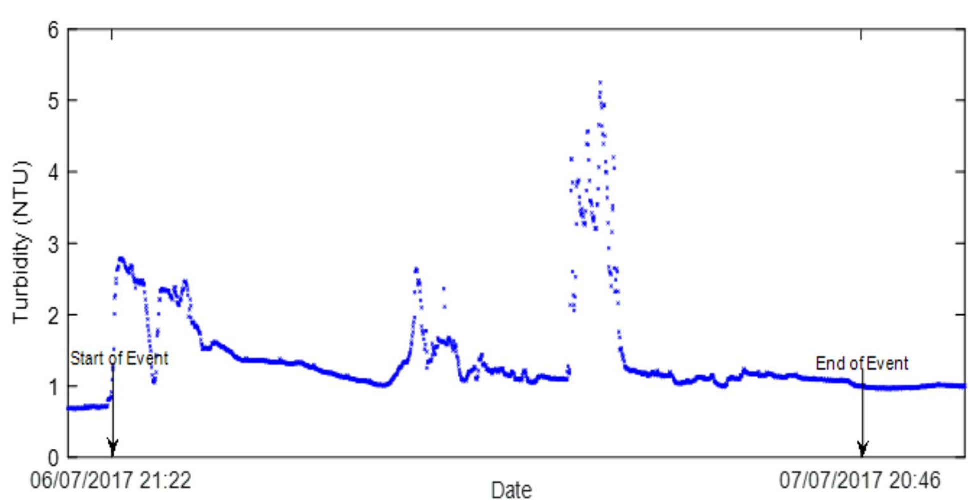

Fig. 9 First event detected by Approach 2-Level 1 between July 6 and July 7, 2017

Table 12 Severity level for S::CAN data according to Approach 2-Level 2

Start of event	End of event	Average turbidity (NTU)	Weight of turbidity	Average chlorine (mg/l)	Weight of chlorine	Severity score	Severity level
6/7/2017 21:22	7/7/2017 20:46	1.499	2	0.008	3	6	Minor
7/7/2017 22:48	7/7/2017 23:49	1.011	1	0.001	4	4	Minor
7/7/2017 23:59	7/7/2017 23:59	1.001	1	0	4	4	Minor
8/7/2017 13:15	8/7/2017 13:15	1.005	1	0.004	4	4	Minor
8/7/2017 13:53	8/7/2017 18:53	1.017	1	0.008	3	3	Insignificant
8/7/2017 18:59	8/7/2017 19:02	1.002	1	0.009	3	3	Insignificant
8/7/2017 19:10	8/7/2017 19:10	1.004	1	0.009	3	3	Insignificant
8/7/2017 19:16	8/7/2017 19:16	1.002	1	0.009	3	3	Insignificant
8/7/2017 19:23	8/7/2017 19:23	1.002	1	0.009	3	3	Insignificant
8/7/2017 19:30	8/7/2017 19:35	1.004	1	0.007	3	3	Insignificant
8/7/2017 19:40	8/7/2017 19:51	1.003	1	0.01	3	3	Insignificant

Table 13 Risk level for S::CAN data according to Approach 2-Level 2

Start of Event	End of Event	Duration (min)	Weight of Duration	Severity Level	Weight of Severity Level	Risk Score	Risk Level
6/7/2017 21:22	7/7/2017 20:46	1404	4	Minor	2	8	High
7/7/2017 22:48	7/7/2017 23:49	61	3	Minor	2	6	Moderate
7/7/2017 23:59	7/7/2017 23:59	0	1	Minor	2	2	Low
8/7/2017 13:15	8/7/2017 13:15	0	1	Minor	2	2	Low
8/7/2017 13:53	8/7/2017 18:53	300	4	Insignificant	1	4	Moderate
8/7/2017 18:59	8/7/2017 19:02	3	1	Insignificant	1	1	Low
8/7/2017 19:10	8/7/2017 19:10	0	1	Insignificant	1	1	Low
8/7/2017 19:16	8/7/2017 19:16	0	1	Insignificant	1	1	Low
8/7/2017 19:23	8/7/2017 19:23	0	1	Insignificant	1	1	Low
8/7/2017 19:30	8/7/2017 19:35	5	1	Insignificant	1	1	Low
8/7/2017 19:40	8/7/2017 19:51	11	1	Insignificant	1	1	Low

Table 14 Risk-level comparison between Approach 1 and Approach 2

Event N°	Start of Event	End of Event	*Turbidity* (NTU)	*Chlorine* (mg/l)	Risk Level	
					Approach 1	Approach 2
1	07/07/2017 22:48	07/07/2017 23:49	1,011	0,001	Very High	Moderate
2	07/07/2017 23:59	07/07/2017 23:59	1,001	0	Very High	Low
3	08/07/2017 13:15	08/07/2017 13:15	1,005	0,004	Very High	Low

Some different results are observed between Level 1 and Level 2. For example, the event of 07/07/2017 22:48: Level 1 identifies a "Low" risk, while Level 2 indicates "Moderate" risk (Tables 11, Table 13). During this event, Chlorine concentration (0.001 mg/l in Table 12) was very low which indicates major impact. The neglect of this Chlorine concentration could lead to an underestimation of the risk level. Risk assessment is more accurate by combining the variation of different parameters (Turbidity and Chlorine).

Comparison of Approach 1 and Approach 2

The main difference between Approach 1 and Approach 2 (Levels 2) concerns the consideration of the Turbidity. In Approach 1, the Turbidity defines the likelihood scale, while in Approach 2, the Turbidity affects the severity of the events consequences; weights are attributed to Turbidity values in the increasing order of Turbidity.

Table 14 illustrates the classification of three events using these approaches. Approach 1 indicates "Very High" risk for the three events, while these events are classified by Approach 2 as Moderate and Low risks. Figure 10 shows the variation in the Turbidity and Chlorine during the first event. The Turbidity remains around 1.01 NTU and the Chlorine level around 0.001 mg/l. Although the Chlorine concentration is very low, the Turbidity value is very close to the limit (1 NTU). The identification of risk as "Moderate" is more precise.

For Event No. 2 and 3, a "Low" risk level seems to be more correct than a "Very High" risk. Despite the low concentration of the Chlorine, the Turbidity value is acceptable (near the limit). Such combinations should not generate an urgent attention, especially for an instantaneous event.

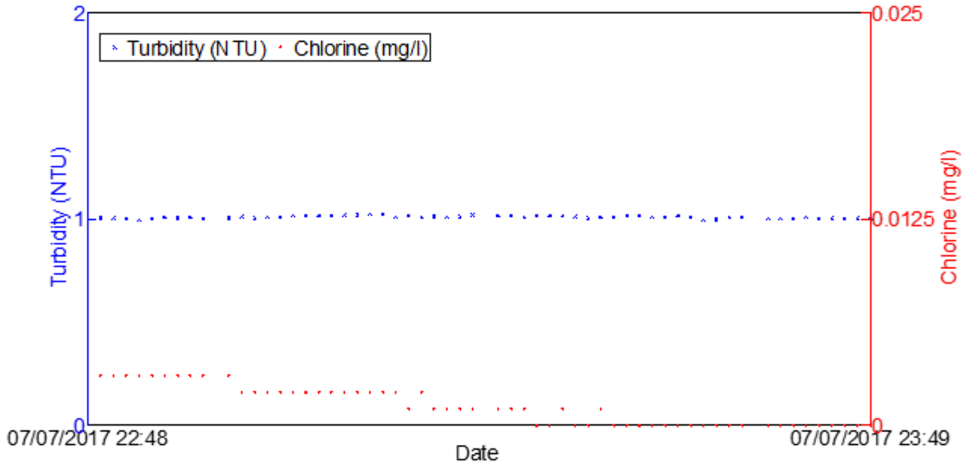

Fig. 10 Variation of Turbidity and Chlorine between 07/07/2017 22:48 and 23:49

This comparison shows that Approach 1 overestimates the risk level, while Approach 2 is more accurate. It shows that both the magnitude of deviation from the limit and the duration of event should be considered in the risk assessment of the water contamination.

Conclusion

In this paper, a combination between the smart monitoring and the qualitative risk assessment was proposed. The smart monitoring was ensured by S::CAN device, which is installed on the water supply of Lille University, France. The qualitative risk assessment used Turbidity and Chlorine, measured by S::CAN, to define the severity of consequences and the duration of an event. The study, conducted within two levels of approaches, led to the following results:

1. S::CAN device has shown a high efficiency in the rapid detection of abnormal events in water. Some perturbations were observed in the signals of Turbidity and Chlorine and could be related to microbial contamination, due to the aging water pipes in the campus of Lille University.
2. The two approaches proposed have verified that the magnitude of deviation from the thresholds limits and the duration of the event are the two primary factors to be used for the risk assessment of the water contamination.
3. The developed method of risk assessment allowed the real-time detection and identification of the risk level as well as the priority required. It showed that a severe abnormality was identified in case of large Turbidity combined with very low concentrations of Chlorine. As the duration of event is important, a higher priority of attention will be needed.

The proposed method showed a higher efficiency over the conventional risk assessment approaches which are based on sample collection and laboratory analyses. The study conducted proved that a rapid identification of water risk level could be done using smart monitoring. This helps in conducting a rapid and reliable strategy of response according to the priority required. Therefore, the early detection of water contamination will assist in the protection of the public health.

Compliance with Ethical Standards

Conflict of interest The authors declared that they have no conflict of interest.

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