Water Cycle 1 (2020) 41–53

Contents lists available at ScienceDirect

Water Cycle

journal homepage: www.keaipublishing.com/en/journals/water-cycle/

Water reuse in Portugal: New legislation trends to support the definition of water quality standards based on risk characterization

A. Rebelo [*], M. Quadrado, A. Franco, N. Lacasta, P. Machado

Portuguese Environment Agency, 2610-124, Amadora, Portugal

ARTICLE INFO

Keywords:
Water reuse
Risk characterization
Exposure route
Exposure scenario
Multi-barrier

ABSTRACT

The increasing demand for water for multiple purposes and the intensification of severe weather conditions due to climate change have put significant strain on freshwater supplies. Portugal can be very vulnerable to climate change impacts and the use of reclaimed waters has been identified as a suitable alternative water source to overcome water shortages. To face the absence of legislation, Portugal has recently approved a policy for the production of reclaimed water from several sources to use in multiple non-potable purposes. The legislation is supported on the recent developments at European Level and its main basis are the international guidelines developed by the International Organization for Standardization, namely for irrigation, urban uses and health risk assessment. Since water reuse can pose risks to health primarily due to pathogenic microorganisms, the new policy defines that all reuse projects shall follow a risk assessment. Besides quantitative assessment should be desirable, these models are complex and presents a high uncertainty insofar requires extensive local data that are not often available for non-potable uses. In this work is presented the brief history of the water reuse in Portugal and a conceptual methodology developed to deal with the limitations on risk assessment. The method involves a strategic appraisal sustained on a semi-quantitative approach for risk characterization to validate the quality standards that meets the needs of the project. The methodology comprises the use of an empirical qualitative judgment to assess the relative importance for hazards, exposure routes and scenarios of contact and multi-barriers in place.

1. Introduction

The increasing demands for water resources for multiple purposes such as public water supply, agriculture, industry, recreational uses and others are leading to water scarcity and quality deterioration [1]. The intensification of severe weather conditions due to climate change, such as droughts, and urban development has put a significant strain on freeshwater supplies [2,3]. Portugal can be very vulnerable to climate change impacts considering the rising sea levels, the heat waves, flooding and droughts and some regions are already suffering pressure on water resources, which is expected to increase under the future climate conditions [4]. To face water shortages special attention has been paid to water reuse in recent years and treated wastewater has been considered as a possible alternative for water supply [3,5].

The absence of adequate legislation and the availability of infrastructure for treatment and distribution of the water as well as costs and energy requirements have been limiting the water reuse projects in Portugal, where only a few cases are in place. Over the years, some water reuse projects were developed, namely in Southern Portugal (Algarve) for the irrigation of golf courses, some agriculture like citrus and ecosystem support with treated urban wastewaters. One of the best examples is the irrigation of a golf course and the maintenance of an ecosystem from a single treatment plant, where a daily average of 14500 m^3 of tertiary effluent are used to irrigate the course and the remain flow is used to keep a pond classified as protected landscape under the habitats directive, which is an important nesting area for protected bird species. Other projects in place are small scale reuse symbiosis by horticulture and agriculture, where water drainage from red fruit production is used for irrigation of other crops, such as citrus or pomegranates. This process allows to suppress around 15% of the total irrigation needs during dry season [6,7].

Until recently there was only in force a national non-binding standard, the NP 4434:2005 and the permitting process was not clear [7]. In August 2019 a new policy was approved (Law decree n.º 119/2019, 08/21) that portraits the production of water for reuse from several sources (urban, domestic, industrial, agriculture overflow and runoff) to

* Corresponding author. Agência Portuguesa do Ambiente, I.P., Rua da Murgueira, 9/9A, Zambujal – Alfragide, 2610-124, Amadora, Portugal.
E-mail address: anabela.rebelo@apambiente.pt (A. Rebelo).

https://doi.org/10.1016/j.watcyc.2020.05.006
Received 20 April 2020; Received in revised form 18 May 2020; Accepted 19 May 2020
Available online 18 June 2020

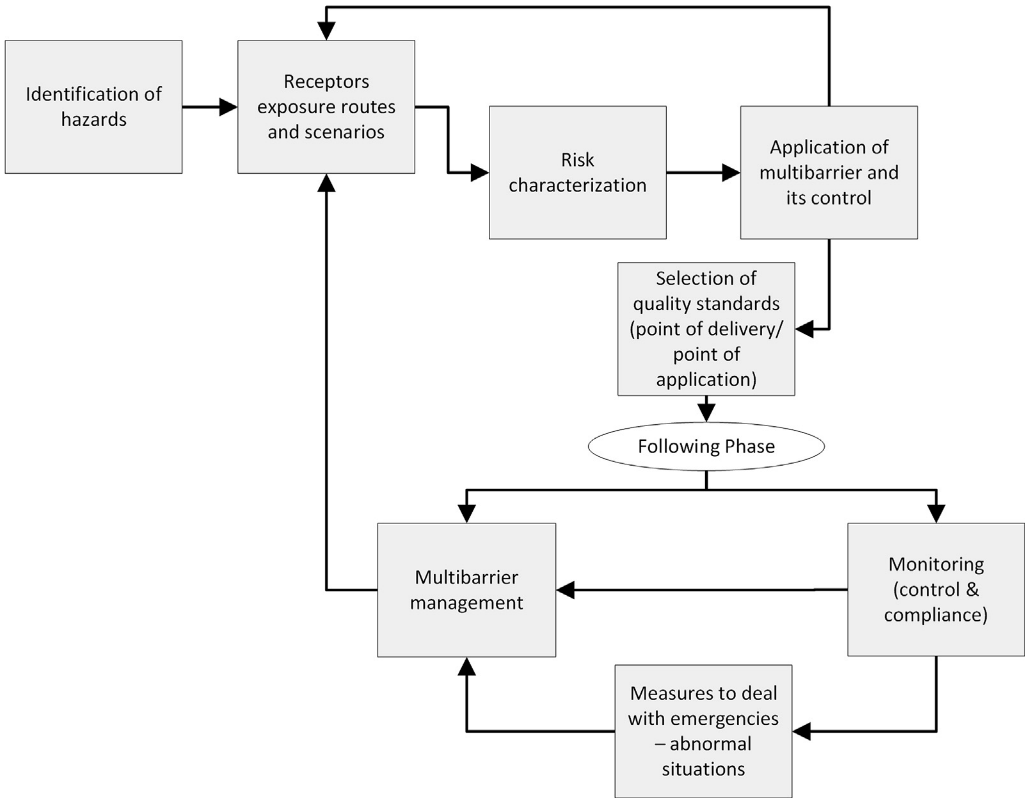

Fig. 1. Risk assessment model under the new Portuguese policy for water reuse.

Table 1
Hazard level.

Examples of treatment	***Escherichia coli*** **(*cfu*/100 mL)**	Hz
SEC	$\geq 10^4$	9
SEC + disinfection	$10^3 < E.\ coli < 10^4$	7
Advanced	$10^2 < E.\ coli \leq 10^3$	5
SEC + disinfection + post- chlorination	$10^1 < E.\ coli \leq 10^2$	3
Advanced + post-chlorination	$E.\ coli \leq 10^1$	1

Table 2
Importance factors applicable to exposure routes.

Exposure routes	f_{iPath}	Observations
Ingestion	9	Is always considered as absolute importance
Inhalation	9	Absolute importance in irrigation systems by aspersion
	5	Essential or strong importance in other irrigation systems (since some leaks could promote some fine droplets)
Dermal adsorption	3	Weak importance due to the less evidence data of infection

Table 3
Importance factors applicable to exposure scenarios.

f_{iScen}	Observations according literature data
9	Exposure routes with very high evidence of occurrence
7	Exposure routes with high evidence of occurrence
5	Exposure routes with medium evidence of occurrence
3	Exposure routes with low evidence of occurrence
1	Exposure routes with no evidence of occurrence

use in multiple non-potable purposes such as agriculture irrigation, urban uses (landscape, flushing, fire-fighting, street cleaning, recreational uses) or even for ecosystem support [8]. The main strategy adopted by Portugal, to promote the water reuse, is:

- Integration of last developments of water reuse, namely at European level and the best international practices (such as the ones developed by the International Organization for Standardization (ISO);
- Envelopment of multiple non-potable uses (agriculture, forestry, urban cycle, landscape);
- Assessment of reclaimed water producers *versus* end-users to overlap distance and infrastructures disruption;
- Definition of a flexible management approach without compromising the health and environmental safety [9].

In a sustainable urban water management, centralized models may play a leading role while decentralized facilities can increase flexibility and suitability in specific projects [10]. Water reuse may provide an opportunity to shift towards a more efficient and sustainable water supply system [11]. As a result, this legislation also previews the production of water for reuse in centralized and decentralized systems, following the principles of the ISO Standard 20760. Here the centralized system refers to projects where the water source is the treated urban wastewater, in accordance with Directive 91/271/EC [12–14].

However, water reuse can pose risks to health and environment due to pathogenic microorganisms, disinfection by-products and compounds of emerging concern [2,15–17]. Several countries such as Spain, France, Italy, Greece and other have national biding standards for water reuse where common quality standards are applicable to every project [6,7,18] while other countries, like the United States of America, water reuse regulations are developed at the state and local level [19]. To ensure the application of best practices, the new Portuguese policy focuses on the adoption of projects supported on a risk management framework and in quality standards defined according to a fit-for-purpose approach based

			Likelihood of occurrence				
			Rare	Unlikely	Possible	Likely	Almost certain
			1	2	3	4	5
Consequences	Insignificant	1	Very low 0,2	Very low 0,4	Low 0,6	Low 0,8	Moderate 1,0
	Minor	2	Very low 0,4	Low 0,8	Low 1,2	Moderate 1,6	High 2,0
	Moderate	3	Low 0,6	Low 1,2	Moderate 1,8	High 2,4	High 3,0
	Major	4	Low 0,8	Moderate 1,6	High 2,4	High 3,2	Very high 4,0
	Catastrophic	5	Moderate 1,0	High 2,0	High 3,0	Very high 4,0	Very high 5,0

Fig. 2. “Matrix for damage adopted from ISO 20426:2018.

Table 4
Qualification of partial damage.

d	d_i
d ≤ 0,5	1
0,5 < d < 1	2
1 = d < 1,2	3
1,2 = d < 2	4
2 = d < 2,4	5
2,4 = d < 3	6
3 = d < 3,2	7
3,2 = d < 4	8
d ≥ 4	9

on ISO standards 16075. This concept entails the production of reclaimed water quality that meet the needs of the intended end-users [20,21]. At European level has been developed a proposal for a regulation for minimum quality requirements for water reuse in agricultural irrigation that follows the same principles [2]. Accordingly, the new Portuguese policy previews that all projects shall follow a risk assessment under the permitting process. For this purpose, the Portuguese Environment Agency developed a guideline which provides advice on the several aspects of the permitting procedures and technical support for risk assessment for health and environment. Through this assessment will be defined the quality standards applicable to each reuse project and it will also allow to select the risk management conditions that should be followed to ensure an associated minimum risk value [9]. This new Portuguese policy adopted the baseline for the health risk assessment from the ISO standard 20426 and its model scheme can be seen in Fig. 1.

The point of delivery corresponds to the point where the operator in a centralized system delivers the reclaimed water to the end-user and point of application is the place where the end-user applies the water.

To deal with health risk assessment dose-response models are suggested in some international guidelines [22] which entails the establishment of the relationship between the dose of the hazard and the incidence or likelihood of illness [23]. However, quantitative risk assessment is only available to a limited set of contaminants and with high uncertainty since it requires extensive data in terms of the definition of exposure routes, exposure volumes and frequency of exposure of the hazards considering local conditions [2,18,24,25]. Moreover, these models are not usually designed to provide opportune information, and their terminology and numerical outputs are also often confusing [26]. Owing to this lack of scientific knowledge, specifically when considering non-potable uses, the quantitative models should only be applicable in uses that require water with high quality [16]. Although during the past years, extensive research has been conducted on water reuse risk assessment [24, 27, 28] there is still a lack of evidence on the application of knowledge-based models [29,30]. The knowledge-based approaches need to deal with large data sets [30,31] and semi-quantitative methods can be useful to overlap some of the uncertainties and variabilities of quantitative models. Taking into account these considerations the aim of the current study is to propose the development of a semi-quantitative methodology to perform water reuse risk characterization. Is also intended identifying its suitability to validate the quality standards for microbial surrogate parameters to be noted in the water reuse permits.

2. Methodology

According ISO 16075 standards, the Portuguese legal framework also proposes the *Escherichia coli* as the main surrogate parameter for pathogens, which is identified as the “hazard” in the current methodology for risk characterization, as can be seen in Fig. 1. *Escherichia coli* is considered as the most suitable indicator of faecal contamination and the sensitivity analysis of studies in several treated wastewaters revealed that this pathogen ratio, i.e., its concentration per time, and morbidity were the most sensitive input parameters [18].

On a first phase, besides the hazard, are identified the receptors that could contact directly or indirectly with reclaimed waters, namely humans. Other receptors like animals, crops and other types of vegetation and also surfaces and other immobile components should be identified considering the possible occurrence of hazard transfer in particular to

			Likelihood of occurrence				
			Rare	Unlikely	Possible	Likely	Almost certain
			1	2	3	4	5
Consequences	Insignificant	1	Very low 1	Very low 1	Low 2	Low 2	Moderate 3
	Minor	2	Very low 1	Low 2	Moderate 4	Moderate 4	High 5
	Moderate	3	Low 2	Moderate 4	Moderate 4	High 6	Very high 7
	Major	4	Low 2	Moderate 4	High 6	Very high 8	Very high 9
	Severe	5	Moderate 3	High 5	Very high 7	Very high 9	Very high 9

Fig. 3. Expression of partial damage (d_i) associated to the barrier failure.

Table 5
Project description.

Characteristics	Observations
Reclaimed water source	Urban wastewater (secondary treatment by activated sludge)
Irrigation system	Surface drip irrigation under pressure. Valves are disposed inside valve boxes with anti-vandal bolt
Irrigation period	From flowering to *veraison* (i.e. around 35–55 days before ripeness/harvest. After *veraison* irrigation cannot occur since can affect in the grape maturation process and subsequently the wine production
Irrigation schedule	Early morning and late afternoon
Near vineyard	Resort supported on wine tourism. Some houses are 100 m away from the limit of the agriculture field and guests have access to the vineyards without restrictions, except to the water storage and pumping system
Property limits (Resort + vineyard)	Existence of fences in all surrounding area and no nearest constructions around 2 km away from fence
Water storage and pumping	Covered tank where 20% of the water is reclaimed water. From this tank the water is pumped and distributed by pressure to the irrigation system.
Workers (Vineyard and resort)	Vineyard workers have specific training to deal with reclaimed waters, namely on safety procedures, personal protection equipment (PPE) needs and respective use best practices. The resort workers have indication to avoid contact with water and wet surfaces due to the use of reclaimed waters and also inform guest accordingly
Animals	The resort does not allows pets but in the property there is a couple of dogs that only interact with vineyard workers

Table 6
Receptors.

Receptor	Observations
Consumers	Not applicable since the grapes are exclusively for wine production and not for direct consumption
Workers	
Vineyard	They may contact with reclaimed water on the storage tank, on the irrigation system, through contact with animals, wet vegetation, wet PPE and soils
Resort	They may contact with reclaimed water on the irrigation system and through contact with animals, wet vegetation, wet clothes (by early contact with the other wet surfaces) and soils
Resort Guests: Adults and children	They may contact with reclaimed water on the irrigation system and through contact with animals, wet vegetation, wet clothes (by early contact with the other wet surfaces) and soils
Dogs	They may contact with reclaimed water on the irrigation system, soils and through the vegetation and further transfer the hazard to humans[a]
Vegetation and irrigation system	By contact can contribute for some exposure to humans and dogs

[a] The exposure scenarios for animals are defined to found how they can transfer the hazard to humans.

humans. The human receptors are divided in several categories according ages and occupation when applicable, e.g., public, consumers or workers.

In a second phase are identified the exposure routes, i.e., ingestion, inhalation and dermal contact, and related exposure scenarios, since for the same exposure route, several pathways can be present. For example, considering ingestion it may occur in multiple ways, such as intentional purpose, by accident, by the lack of information about the water potability, inadvertently thru ingestion of micro-droplets during sprinkler irrigation, etc. Many studies only assess a specific exposure scenario that is initially considered with higher risk based on former information or expert opinions. While other studies appraise more than one exposure scenario but presume independence between them. Nonetheless, the health risks associated with exposure route and the multiple associated scenarios have multiple relations that should be studied [32]. Therefore, the selection of possible scenarios, i.e., the pathways, is one of the most critical steps of the process and should take into account the complexity of the reclamation project. This procedure allows the identification of the most critical points. Nevertheless, may involve a high level of uncertainty, namely in wide areas with no restriction access where people movements could be more erratic and difficult to preview or in complex projects where a high number of scenarios could be present for the same exposure route.

Subsequently, should be identified the adopted preventive measures to reduce hazards and exposure to hazards, i.e., the adopted barriers to minimize contact between hazard and recognized receptors. A barrier can be defined as the means that reduces or prevents the health and environmental risks, by preventing contact with the reclaimed waters and/or by improving its quality, i.e., a means that reduces contact between pathogens present in the treated waters and humans [20,25]. Thus, the water quality is not the only parameter that can ensure health protection in water reuse projects. Other options such as irrigation type and schedule, harvest options, crop characteristics or some best practices, could limit the contact between people and pathogens present in reclaimed waters. By considering such options, reclaimed water with lower quality can be used for reuse purposes, namely when multiple barriers are in place [20,33]. The strength of the multi-barrier principle is that a failure of one barrier may be compensated by effective operation of the remaining barriers forasmuch making the project more reliable [34]. Several guidelines establish a logarithmic reduction ($\log_{10}$) for a few preventive measures which are known as equivalent barriers. This literature also establishes the number of barriers that must be combined with a specific water quality grade to ensure an adequate level of protection against pathogens [1,20,22]. Therefrom, the water quality level at the delivery point, described in Fig. 1, could be lower than the required at the end-use if appropriate barriers are in place [8].

The risk characterization consists of the quantification and prioritisation of the risk to human health resulting directly from the factors associated with the hazard, exposure routes, applicable scenarios and multi-barriers in place [35]. For this purpose, this study entitles a semi-quantitative approach supported on the use of an empirical qualitative judgment to assess the relative importance of the specific factors used in the process. To each factor is applied a hierarchical analytical process based on an importance scale 1 to 9, as the one described by Saaty [36], where 1 is low importance, 3 is weak importance, 5 is essential or strong importance, 7 is demonstrated importance, 9 is absolute importance and for intermediate levels between two judgements may be assigned values of 2, 4, 6 or 8 [35,37].

The risk for each respective receptor category (R_{Rec}) is achieved by the product between the hazard (Hz), the vulnerability of receptors (V_{Rec}) and associated damage (D), i.e.:

$$R_{Rec} = Hz \times V_{Rec} \times D \tag{1}$$

As previously mentioned, hazard is considered as the surrogate parameter *Escherichia coli* and Hz quantification is obtained by a direct scale applied to a set of expected concentrations according treatment level in place, wherefrom higher treatment leads to lower pathogen concentration and consequently lower risk perception [2,20] as shown in Table 1:

The vulnerability of each receptor category is determined by the following equation:

$$V_{Rec} = \frac{\sum (f_{iPath} \times f_{iScen})}{f_{normal\ V}} \tag{2}$$

The parameters f_{iPath} and f_{iScen} are the importance factors linked with the exposure route and exposure scenario, respectively. A normalization factor ($f_{normal\ V}$) is also included to adjust scale to a common range [38], which can be obtained by the following equation:

$$f_{normal\ V} = f_{imax} \times \sum (f_{iPath} \times n_{Scen}) \tag{3}$$

Table 7
Exposure routes and scenarios.

	Exposure scenarios			
Exposure routes	Vineyard workers	Resort workers Resort guests (adults)	Resort guests (children)	Dogs
Ingestion	Intentional water uptake Non-intentional water uptake: Ingestion of droplets during leaks Ingestion of droplets from the contact with wet vegetation Ingestion of droplets from the contact with irrigation system (normal function conditions) Ingestion of droplets from the contact with wet PPE Ingestion of droplets from wet dogs Ingestion of pathogens from dogs Intentional ingestion of soil Non-intentional ingestion of soil	Intentional water uptake Non-intentional water uptake: Ingestion of droplets during leaks Ingestion of droplets from the contact with wet vegetation Ingestion of droplets from the contact with irrigation system (normal function conditions) Ingestion of droplets from the contact with wet clothes [a] [a] Intentional ingestion of soil Non-intentional ingestion of soil	Intentional water uptake Non-intentional water uptake: Ingestion of droplets during leaks Ingestion of droplets from the contact with wet vegetation Ingestion of droplets from the contact with irrigation system (normal function conditions) Ingestion of droplets from the contact with wet clothes [a] [a] Intentional ingestion of soil Non-intentional ingestion of soil	Intentional water uptake Non-intentional water uptake: Ingestion of droplets during leaks Ingestion of droplets from the contact with wet vegetation Ingestion of droplets from the contact with irrigation system (normal function conditions) Ingestion of droplets from the wet hair – – Intentional ingestion of soil Non-intentional ingestion of soil
$n_{Scen\ ingestion}$	*9*	*7*	*7*	…
Inhalation	Inhalation of aerosols during leaks (irrigation system under pressure) Inhalation of micro droplets from wet dogs Inhalation of aerosols from dogs (sneezing)	Inhalation of aerosols during leaks (irrigation system under pressure) [a] [a]	Inhalation of aerosols during leaks (irrigation system under pressure) [a] [a]	Inhalation of aerosols during leaks (irrigation system under pressure) [a] [a]
$n_{Scen\ inhalation}$	***3***	***1***	***1***	—
Dermal adsorption	Contact with wet irrigation system Contact with wet PPE Contact with wet vegetation (leafs, fruits or roots) or soil Contact with wet dogs	Contact with wet irrigation system Contact with wet clothes Contact with wet vegetation (leafs, fruits or roots) or soil [a]	Contact with wet irrigation system Contact with wet clothes Contact with wet vegetation (leafs, fruits or roots) or soil [a]	Contact with wet irrigation system Contact with wet clothes Contact with wet vegetation (leafs, fruits or roots) or soil [a]
$n_{Scen\ dermal\ adsor}$	*4*	*3*	*3*	—

[a] Dogs only interact with vineyard workers.

where f_{imax} is the higher value of importance (9) and n_{Scen} is the number of scenarios considered by exposure route. According the World Health Organization (WHO) the exposure routes of higher risk for water reuse are the ingestion and inhalation, namely when aerosols are able to be produced. Less evidence of infection is known for dermal adsorption [22]. Subsequently, a direct score for these exposures routes is applicable as can be seen in Table 2.

To each proposed scenario is also applicable the direct score from 1 to 9. The importance of each one should be founded according available literature data. This step involves a high level of uncertainty owing to the absence of infection data linked with non-potable uses [16]. To minimize part of the uncertainty the empirical judgments should always follow a worst-case approach and scenarios related with exposure routes with high evidence of infection, such as ingestion, should be at first place scored with higher importance values. Later adjustments should be made according the probability of occurrence of each specific scenario, which can be assumed as a qualitative judgment of the "volume of exposure" [18,24]. Table 3 shows how scenarios can be initially scored according to the available data on the related exposure routes. Each qualified scenario must contain a justification of its score to transfer knowledge to the process, which will promote an additional minimization of uncertainty and consequently strengthen the risk assessment process.

Following Table 3, scenarios related with ingestion route should be initially scored from 7 to 9 while the inhalation and dermal adsorption scenarios should be qualified from 5 to 9 and from 1 to 5, respectively. These values should be further adjusted according project characteristics, additional minimization measures and the probability of scenario occurrence. As can be seen the definition of appropriate scenarios is the critical step of the process and the number (n_{Scen}) increases with the complexity of the water reuse projects.

The final parameter needed for the risk characterization is the damage that can be achieved by the severity *versus* the likelihood of occurrence, i.e. the probability of a hazardous event by the occurrence of failure in the barriers. The damage represents the global harm that can occur by the failure of the set of barriers in place forasmuch depending on the characteristics and number of barriers in place. This global damage (D) can be obtained by the following equation:

$$D = \frac{\sum (d_i \times n_i)}{f_{normal\ D}} \quad (4)$$

The factor d_i is the partial damage associated to each barrier failure and n_i the number of barriers [20]. This expression is also normalized to adjust scale [38] and $f_{normal\ D} = f_{i\ max} \times n_t$, where $f_{i\ max}$ is the higher value of the importance scale (9) and n_t is the total number of barriers in place. As mentioned above some international guidelines establish the principle of equivalent barrier which was also adopted in the new Portuguese legislation. According this principle some barriers can represent more than one single barrier depending on the associated logarithmic pathogen reduction. Then n_i is equal to the number of equivalent barriers in place according literature or can be equal to one (1) when the mean *in situ* is not listed as an equivalent barrier and n_t is given by the sum of all barriers ($\sum n_i$) in place [1,8,20,22].

The partial damages (d_i) are obtained by an additional algebraic process using the matrix given on the ISO 20426:2018, according Fig. 2 [16], and the following expression normalized to the higher value (5) displayed on this matrix:

$$d = \frac{Consequences \ \times Likelihood\ of\ occurence}{5} \quad (5)$$

These partial damage (d) are then qualified according the importance scale to obtain d_i in Table 4 as follows:

Through this process a modified matrix is achieved to determine the damage as can be seen in Fig. 3:

Table 8
Scenarios qualification and explanation (Vineyard workers).

Vineyard workers	f_i Scen	Scenario explanation	Importance factor justification
Intentional water uptake	7	A worker can intentionally ingest water from the system	Due to the specific training this scenario does not seem very probable to occur but depends on human behaviour and ingestion is an exposure routes with demonstrated infection data. For this reason this scenario is considered as having strong importance
Non-intentional water uptake:			The literature suggests that minimal contact with water may cause less ingestion and thus less evidence of illness [44]
Ingestion of droplets during leaks	9	Since the system is under pressure some leaks may form micro droplets that can be inadvertently ingested	The probability to occur is high due to the characteristics of the system (under pressure and exposed to elements) and since ingestion is considered an important route of transmission for water borne diseases is proposed the adoption of an absolute importance value, besides the low scientific evidence of transmission [44]
Ingestion of droplets from the contact with wet vegetation	9	The pathogens can accidentally be transferred by hand-mouth-face contact	This is a demonstrated pathway and therefore is proposed the adoption of an absolute importance value, besides the low scientific evidence of transmission for water-borne pathogens [44,45]
Ingestion of droplets from the contact with irrigation system	9	The pathogens can accidentally be transferred to by hand-mouth-face contact during inspection or maintenance works	This is a demonstrated pathway and therefore is proposed the adoption of an absolute importance value, besides the low scientific evidence of transmission for water-borne pathogens [42,44]
Ingestion of droplets from the contact with wet PPE	9	The pathogens can accidentally be transferred by hand-mouth-face contact	This is a demonstrated pathway and therefore is proposed the adoption of an absolute importance value, besides the low scientific evidence of transmission for water-borne pathogens [44,45]
Ingestion of droplets from wet dogs	9	The pathogens can accidentally be transferred by hand-mouth-face contact or ingested when dogs shakes off	This is a demonstrated pathway and therefore is proposed the adoption of an absolute importance value, besides the low scientific evidence of transmission for water-borne pathogens [44,45]
Ingestion of pathogens from dogs	9	The pathogens can accidentally be transferred to hands, mouth or face by dog licking	This is a common scenario with pets and therefore is proposed the adoption of an absolute importance value, besides the low scientific evidence of transmission for water-borne pathogens [44,45]
Intentional ingestion of soil	7	A worker can intentionally ingest soil	Due to the specific training this scenario does not seem very probable to occur but depends on human behaviour and ingestion is an exposure routes with demonstrated infection data. Therefrom this scenario is considered as having strong importance
Non-intentional ingestion of soil	9	The pathogens can accidentally be transferred by hand-mouth-face contact	This is a demonstrated pathway and therefore is proposed the adoption of an absolute importance value, besides the low scientific evidence of transmission for water-borne pathogens [44,45]
Inhalation of aerosols during leaks (irrigation system under pressure)	9	Since the system is under pressure some leaks may form aerosols that can be inadvertently inhaled	The probability to occur is high due to the characteristics of the system (under pressure and exposed to elements) and therefore of absolute importance since there is strong evidence of disease transmission (*legionella*) through inhalation of water aerosols [46]
Inhalation of micro droplets from wet dogs	4	The pathogens can accidentally be inhaled when dogs shakes off	This is a common scenario with pets but there is no scientific evidence of occurrence of aerosols. Therefore, a judgment between weak (3) and essential (5) importance is proposed to be adopted
Inhalation of aerosols from dogs (sneezing)	4	The pathogens inhaled by dogs can accidentally be inhaled as aerosols from them when they sneezes	This is a common scenario with pets, the transference pathway (aerosols from sneeze) is demonstrated [45], however the common water borne pathogens linked with zoonotic (man-pets) diseases are *Cryptosporidium* and *Giardia* [47]. Wherefrom a judgment between weak (3) and essential (5) importance is proposed to be adopted.
Contact with wet irrigation system	3	Pathogens can be adsorbed by skin or transferred to eyes (hand-eye) by direct contact with wet surface	There is a low evidence for this pathway when there is low contact with the water and transmission through ocular exposure also remains unknown. So, a judgment of weak (3) importance is proposed to be adopted [44,48]
Contact with wet PPE	3	Pathogens can be adsorbed by skin or transferred to eyes (hand-eye) by direct contact with wet surface	There is a low evidence for this pathway when there is low contact with the water and transmission through ocular exposure also remains unknown. So, a judgment of weak (3) importance is proposed to be adopted [44,48]
Contact with wet vegetation (leafs, fruits or roots) or soil	3	Pathogens can be adsorbed by skin or transferred to eyes (hand-eye) by direct contact with wet surface	There is a low evidence for this pathway when there is low contact with the water and transmission through

(*continued on next page*)

Table 8 (*continued*)

Vineyard workers	f_i Scen	Scenario explanation	Importance factor justification
			ocular exposure also remains unknown. So, a judgment of weak (3) importance is proposed to be adopted [44,48]
Contact with wet dogs	3	Pathogens can be adsorbed by skin or transferred to eyes (hand-eye) by direct contact with wet surface	There is a low evidence for this pathway when there is low contact with the water and transmission through ocular exposure also remains unknown. So, a judgment of weak (3) importance is proposed to be adopted [44,48]

From the observation of Figs. 2 and 3 it is possible to notice that this qualification process increases the risk significance. This perception can be seen as an additional safety factor that may allow integrating some random uncertainties connected to the natural systems, which are not possible to be measured. The uncertainties and the variability of process parameters in a risk assessment should be considered to promote a better support of the respective decision-making process [39,40].

The level of likelihood of occurrence is prioritised according ISO 20426:2018, where;

- "Rare" has not happened in the past and is highly improbable that will happen in the reasonable period;
- "Unlikely" has not happened in the past but may occur in exceptional circumstances in the reasonable period;
- "Possible" may have happened in the past and/or may occur under regular circumstances in the reasonable period;
- "Likely" has been observed in the past and/or is likely to occur in the reasonable period;
- "Almost certain" has often been observed in the past and/or will almost certainly occur in the most circumstances in the reasonable period [16].

The reasonable period is defined according to the validity period of reuse permits as mentioned in the Portuguese legislation, i.e., 10 years [8].

The consequences qualification was also adopted from the ISO 20426:2018, where "insignificant" means event with no or negligible health effects compared to background levels; "Minor" is an event that potentially results in minor health effects; "Moderate" is an event that potentially results in a self-limiting health effects or minor illness; "Major" is an event that potentially results in illness and "Severe" is an event that potentially results in serious illness or injury [16].

Once determined the risk for each receptor category ($R_{Rec\ i}$), a global risk (R_G) value is obtained by the expression (6), where N_{Rec} is the number of the considered receptor categories in the process:

$$R_{Global} = \frac{\sum R_{Rec\ i}}{N_{Rec}} \quad (6)$$

The R_{Global} value varies from a minimum value above zero (0) to nine (9) depending on the number of scenarios, barriers and the normalization. The prioritisation is attained by conversion of the R_{Global} results into a three-level qualitative scale as follows: Despicable Risk ($R_{Global}<3$), Acceptable Risk ($3 \leq R_{Global}<7$) and Unacceptable Risk ($R_{Global} \geq 7$). This level description is similar to those used by other authors [35,41].

Whenever the risk is unacceptable the whole process should be repeated considering additional minimization measures, which could be an increase of treatment level and as a result a lower level of hazard (Hz), which means a proposal for a quality standard more restrict. Another

Table 9
Scenarios qualification and explanation (Resort workers and resort guests: adults).

Resort workers Resort guests (adults)	f_i Scen	Scenario explanation	Importance factor justification
Intentional water uptake	5	A worker or guest can intentionally ingest water from the system	Depends on human behaviour and ingestion is an exposure routes with demonstrated infection data. For this reason, this scenario is considered as having an essential importance
Non-intentional water uptake:			The literature suggests that minimal contact with water may cause less ingestion and hence less evidence of illness [44]
Ingestion of droplets during leaks	7	Since the system is under pressure some leaks may form micro droplets that can be inadvertently ingested	Ingestion is considered an important route of transmission for water borne diseases thus is proposed the adoption of strong importance value, besides the low scientific evidence of transmission [44]
Ingestion of droplets from the contact with wet vegetation	7	The pathogens can accidentally be transferred by hand-mouth-face contact	This is a demonstrated pathway and therefore is proposed the adoption of a strong importance value, besides the low scientific evidence of transmission for water-borne pathogens [44,45]
Ingestion of droplets from the contact with irrigation system	7	The pathogens can accidentally be transferred to by hand-mouth-face contact during inspection or maintenance works	This is a demonstrated pathway and therefore is proposed the adoption of a strong importance value, besides the low scientific evidence of transmission for water-borne pathogens [44,45]
Ingestion of droplets from the contact with wet clothes	7	The pathogens can accidentally be transferred by hand-mouth-face contact	This is a demonstrated pathway and therefore is proposed the adoption of a strong importance value, besides the low scientific evidence of transmission for water-borne pathogens [44,45]
Intentional ingestion of soil	5	A worker or guest can intentionally ingest soil	Depends on human behaviour and ingestion is an exposure routes with demonstrated infection data. Therefrom this scenario is considered as having an essential importance
Non-intentional ingestion of soil	7	The pathogens can accidentally be transferred by hand-mouth-face contact	This is a demonstrated pathway and therefore is proposed the adoption of a strong importance value, besides the low scientific evidence of transmission for water-borne pathogens [44,45]
Inhalation of aerosols during leaks (irrigation system under pressure)	9	Since the system is under pressure some leaks may form aerosols that can be inadvertently inhaled	This scenario can occur any time of day due to the characteristics of the system (under pressure and exposed to elements) and thence of absolute importance since there is strong evidence of

(continued on next page)

Table 9 (*continued*)

Resort workers Resort guests (adults)	f_i Scen	Scenario explanation	Importance factor justification
			disease transmission (*legionella*) through inhalation of water aerosols [46]
Contact with wet irrigation system	1	Pathogens can be adsorbed by skin or transferred to eyes (hand-eye) by direct contact with wet surface	There is a low evidence for this pathway when there is low contact with the water and transmission through ocular exposure also remains unknown. So, a judgment of low (1) importance is proposed to be adopted [44,48]
Contact with wet clothes	1	Pathogens can be adsorbed by skin or transferred to eyes (hand-eye) by direct contact with wet surface	There is a low evidence for this pathway when there is low contact with the water and transmission through ocular exposure also remains unknown. So, a judgment of low (1) importance is proposed to be adopted [44,48]
Contact with wet vegetation (leafs, fruits or roots) or soil	1	Pathogens can be adsorbed by skin or transferred to eyes (hand-eye) by direct contact with wet surface	There is a low evidence for this pathway when there is low contact with the water and transmission through ocular exposure also remains unknown. So, a judgment of low (1) importance is proposed to be adopted [44,48]

option can be the addition of supplementary barriers. However, a project may not be feasible if it is not possible to below the R_G at least to an acceptable level.

This process follows a strategic appraisal where a reassessment will allow defining the best management options [39,42]. To ensure a high level of protection, the risk level should be despicable although some projects may be approved with an acceptable risk when demonstrating that further reduction would be grossly disproportionate to the benefit gained. To choose the adequate level of risk two different approaches can be followed: The "Precautionary Principle (PP)" or "As the Low as Reasonably Practicable Principle (ALARP)". The first is often adopted when there is low scientific certainty. The application of the ALARP approach through the adoption of cautious and preventive measures may help to understand and minimize the probability of occurrence and consequences [43]. Hence, the treatment level and multi-barriers should be chosen to ensure a high level of health protection according both principles which in some cases may be referred to projects with an acceptable risk, i.e., with a risk as low as reasonably possible.

Once attained the adequate level of risk to a specific project, the *Escherichia coli* concentration correspondent to the Hz value used in the risk characterization can be validated and consequently can be adopted as "the quality standard". Furthermore, specific management options should be also defined as a part of the risk management plan according barriers and other minimization measures adopted to minimize the risk to the lowest reasonable level [2].

3. Results and discussion

In order to illustrate the application of the developed methodology was chosen an example of an agriculture production site. Therefore, the case-study used was a vineyard where grapes are used to produce exclusively wine and part of the water used for irrigation is reclaimed

Table 10
Scenarios qualification and explanation (Resort guests: children).

Resort guests (children)	f_i Scen	Scenario explanation	Importance factor justification
Intentional water uptake	7	A child can intentionally ingest water from the system	Ingestion is an exposure routes with demonstrated infection data. For this reason, this scenario is considered as having a value of strong importance
Non-intentional water uptake:			The literature suggests that minimal contact with water may cause less ingestion and hence less evidence of illness [44]
Ingestion of droplets during leaks	8	Since the system is under pressure some leaks may form micro droplets that can be inadvertently ingested	Ingestion is considered an important route of transmission for water borne diseases thus is proposed the adoption of a value between strong (7) and absolute (9) importance, besides the low scientific evidence of transmission [44]
Ingestion of droplets from the contact with wet vegetation	8	The pathogens can accidentally be transferred by hand-mouth-face contact	This is a demonstrated pathway and therefore is proposed the adoption of a value between strong (7) and absolute (9) importance, besides the low scientific evidence of transmission for water-borne pathogens [44,45]
Ingestion of droplets from the contact with irrigation system	8	The pathogens can accidentally be transferred to by hand-mouth-face contact during inspection or maintenance works	This is a demonstrated pathway and therefore is proposed the adoption of a value between strong (7) and absolute (9) importance, besides the low scientific evidence of transmission for water-borne pathogens [44,45]
Ingestion of droplets from the contact with wet clothes	8	The pathogens can accidentally be transferred by hand-mouth-face contact	This is a demonstrated pathway and therefore is proposed the adoption of a value between strong (7) and absolute (9) importance, besides the low scientific evidence of transmission for water-borne pathogens [44,45]
Intentional ingestion of soil	9	A children can intentionally ingest soil	Ingestion is an exposure routes with demonstrated infection data. This scenario is very common on children and thus considered as having a value of absolute importance
Non-intentional ingestion of soil	8	The pathogens can accidentally be transferred by hand-mouth-face contact	This is a demonstrated pathway and therefore is proposed the adoption of a value between strong (7) and absolute (9) importance, besides the low scientific evidence of transmission for water-borne pathogens [44,45]
Inhalation of aerosols during leaks (irrigation system under pressure)	9	Since the system is under pressure some leaks may form aerosols that can be inadvertently inhaled	This scenario can occur any time of day due to the characteristics of the system (under pressure and exposed to elements) and therefrom of

(*continued on next page*)

Table 10 (*continued*)

Resort guests (children)	$f_{i\ Scen}$	Scenario explanation	Importance factor justification
			absolute importance since there is strong evidence of disease transmission (*legionella*) through inhalation of water aerosols [46]
Contact with wet irrigation system	2	Pathogens can be adsorbed by skin or transferred to eyes (hand-eye) by direct contact with wet surface	There is a low evidence for this pathway when there is low contact with the water and transmission through ocular exposure also remains unknown. So, a judgment between low (1) and week (3) importance is proposed to be adopted [44,45]
Contact with wet clothes	2	Pathogens can be adsorbed by skin or transferred to eyes (hand-eye) by direct contact with wet surface	There is a low evidence for this pathway when there is low contact with the water and transmission through ocular exposure also remains unknown. So, a judgment between low (1) and week (3) importance is proposed to be adopted [44,45]
Contact with wet vegetation (leafs, fruits or roots) or soil	2	Pathogens can be adsorbed by skin or transferred to eyes (hand-eye) by direct contact with wet surface	There is a low evidence for this pathway when there is low contact with the water and transmission through ocular exposure also remains unknown. So, a judgment between low (1) and week (3) importance is proposed to be adopted [44,45]

Table 11
Receptors vulnerability.

Receptor category	Vulnerability (V_{Rec})
Vineyard workers	0,84
Resort workers/Resort guests (adults)	0,66
Resort guests (children)	0,82

water. Nevertheless, the procedure has also been successfully applied to other water reuse situations in Portugal such as green urban parks. The main steps of the diagram depicted in Fig. 1 were followed and the characteristics of the project are described in Table 5.

As only secondary wastewater treatment is implemented, the Hz presents an absolute importance being qualified with a value of nine (9) according Table 1. In Table 6 is presented the identification of receptors and some observations how they can contact with the hazard enclosed in the reclaimed water. To integrate more knowledge in the process some relationships between receptors and possible scenarios are included [32] In Table 7 are displayed the exposure routes and scenarios.

The importance qualification of each exposure scenario is presented in Table 8, **9** and **10**.

Regarding the resort workers and the guest exposure to the reclaimed waters all the below scenarios are possible to occur since they have access to the vineyards without restriction. However, the workers have more information about the use of the reclaimed water, and responsibility to advice guests to avoid touch with irrigation equipment and wet surfaces. Also, the irrigation schedule is early morning and late afternoon when visits to the fields are not common. Although these scenarios may occur

Table 12
Barriers and equivalent barriers implemented in the project.

Type of barrier	Application	Pathogen reduction (log_{10})	Number of equivalent barriers (n)
Drip irrigation	Drip irrigation of high-growing crops such as 50 cm or more above from the ground	4	2
Pathogen die-off	Die-off support through irrigation cessation or interruption before harvest	2 per day[a]	2
Irrigation control[b]	Irrigation at distances greater than 70 m from residential areas or places of public access	1	1
Workers training	Vineyard workers have specific training to deal with reclaimed waters, namely on safety procedures and PPE needs and resort workers have information on the reclaimed water use (they are informed to avoid touch in wet surfaces and advice guests)	—[c]	1
Reclaimed water dilution	Mixing of 20% of reclaimed water with other water sources in a tank	–	Is not an equivalent barrier and also not considered as any type of barrier according the Portuguese legal framework

[a] This pathogen log_{10} reduction can varies from 0,5 a 2 per day depending to crops and weather conditions. The climate in the property area during the crop production varies from mild during spring to hot and dry in summer, where in some days the temperatures can reach 40 °C, which justifies the adoption of the higher number taking into account that irrigation is stopped around 35–55 day before harvesting [49].
[b] Adopted from equivalent barrier concept (spray irrigation).
[c] Is not listed as equivalent barrier [8].

its probability is lower, than similar exposure situations for vineyard workers. Wherefrom the respective importance values should also be lower.

The scenarios proposed for the adult resort guest are similar to the ones defined for infants. However, some critical situations could be more probable to occur by the typical children behaviour, namely in case of failure of adult surveillance. Moreover, children appear to have a higher susceptibility for water borne contamination than adults, viz. for gastrointestinal diseases [44]. Thus, importance values for the exposure scenarios are than enlarged when compared with the adult category.

The scenario assessment includes several relationships between them which will also minimize some uncertainties by the assimilated knowledge [32]. From the previous data and by the application of equation (2) is possible to obtain the vulnerability to each receptor category. These results can be seen in Table 11.

The new Portuguese policy adopted the concept of equivalent barrier from other international guidelines such as WHO and ISO and giving the logarithmic reduction (log_{10}) of each mean this can represent a certain number of barriers, i.e., a number of equivalent barriers [8,20,22]. In the current case-study the barriers and number of equivalent barriers in place is displayed in Table 12.

The damage (D) is obtained by equation (4) and Fig. 3. To each of the identified barrier is appraised the likelihood of failure and the consequences as described in Table 13.

Thru the application of equation (4) is obtained a damage of 0,74. in Table 14 is disposed the risk by receptor category obtained through

Table 13
Damage associated to the barrier failure.

Barrier Type	Likelihood of failure	Justification	Consequences	Justification	d_i
Drip irrigation	Likely	Leaks and clogging issues are probable to occur even with high maintenance level [50]	Major	Non-intentional ingestion or inhalation may occur due leaks or maintenance works (see Tables 8–10). But minimal contact with water may cause less ingestion and subsequently less evidence of illness [44]	8
Pathogen die-off	Rare	Irrigation stops around 35–55 days before harvesting. Irrigation after this period is not probable to occur since it can affect the production (see Table 5)	Severe	If occur during harvesting the consequences may be high	3
Irrigation control	Almost certain	Guests have full access to the irrigated area without restrictions	Major	Non-intentional ingestion or inhalation may occur due leaks or maintenance works (see Tables 8–10). But minimal contact with water may cause less ingestion and hence less evidence of illness [44]	9
Workers training and use of PPE	Likely	Is often seen failures on the use of PPE in multiple situations due to personal behaviour [51]	Severe	Non-intentional ingestion or inhalation may occur and higher level of contact works (see Tables 8–10)	9

Table 14
Risk for reuse project.

Category	Risk	Classification
Vineyard workers	5,58	Acceptable
Resort workers/Resort guests (adults)	4,42	Acceptable
Resort guests (children)	5,45	Acceptable
R_{Global}	5,15	Acceptable

equation (1), the project global risk given by equation (6) and the respective classification when a Hz equal to 9 is considered.

The results assessment reveals that the project presents to all receptors an acceptable risk level. As expected, the vineyard workers followed by children are the groups with higher exposure and hence subject to a higher risk. Additional measures can be defined to reduce the risk. For instance, can be studied the implementation of a post-chlorination on the irrigation tank outlet. Since the vulnerability of receptors remains the same only additional calculations on damage and risk are needed. This type of barrier is classified as equivalent under the Portuguese legislation and corresponds to:

- $\log_{10}$ pathogens reduction of 2 and 1 barrier when chlorine is applied in low doses;
- $\log_{10}$ pathogens reduction of 4 and 2 barriers when the disinfectant is applied in high doses [8].

The failure of this disinfection system may lead to a moderate consequence owing the type of crops (grapes for wine production) and the dilution with other water sources in place. However, in these types of systems is possible to occur some malfunctions such as failure on dosage system, clogging, decrease of active chlorine by the exposure to sun and other. Therefore, the probability of occurrence presents a "possible" level. The damage linked with this barrier can run from 0,67 to 0,70 considering the applicable chlorine dose (high or low dose). The damage values obtained by equation (4) related with these barriers and with the original project (0,74) can be seen in Table 15.

The reassessment reveals that the addition of post-chlorination does not contribute to variations on the risk levels. Although some decrease on its values occur as can be seen in Fig. 4.

However, is possible to observe a variation on the risk level when disinfection option is considered at the hazard option. A reassessment of the project with original conditions and considering only changes of the hazard level shows that for a content of *Escherichia coli* lower than 10^3 cfu/100 mL (Hz below 5) the partial receptor risks and global risk tend to despicable levels as can be seen in Fig. 5.

This means that several management options can be applied, namely:

- Before the delivery point (see Fig. 1) at the wastewater treatment plant by the operator of the urban system;
- After the delivery point by the end-user (manager of the vineyard) thru the implementation of a polishing treatment prior or after the storage tank.

In this review was only considered changes on the hazard level since the exposure scenarios and barriers remain the same. To ensure a despicable risk value, the quality standard for *Escherichia coli* should be lower than 10^3 cfu/100mL. Nonetheless, without additional minimization measures (i.e., with just a secondary treatment with an *Escherichia coli* equal or higher than 10^4 cfu/100mL) the case-study presents an acceptable risk level to all receptors. Following the equivalent barrier principle, the drip irrigation of high growing crops from the ground (50 cm or higher) corresponds to a four (4) $\log_{10}$ pathogens reduction, therefore the evaluation of further minimization measures should include a cost-benefit analyse to increase confidence on decision-making and to ensure that the adopted standard follows a risk as low as reasonably practicable but, without jeopardizing the Precautionary Principle considering the level of uncertainty involved [27,43]. Other minimization measures can also be evaluated to increase confidence on

Table 15
Damage values when considering different types of barriers.

Barrier Type	Original project		Addition of post-chlorination			
			Low level		High level	
	N.º barriers (n_i)	Partial damage (di)	N.º barriers (n_i)	Partial damage (di)	N.º barriers (n_i)	Partial damage (di)
Drip irrigation	2	8	2	8	2	8
Pathogen die-off	2	3	2	3	2	3
Irrigation control	1	9	1	9	1	9
Post-chlorination (low level)	–	–	1	4	–	–
Post-chlorination (high level)	–	–	–	–	2	4
Workers training	1	9	1	9	1	9
Damage (D)	**0,74**		**0,70**		**0,67**	

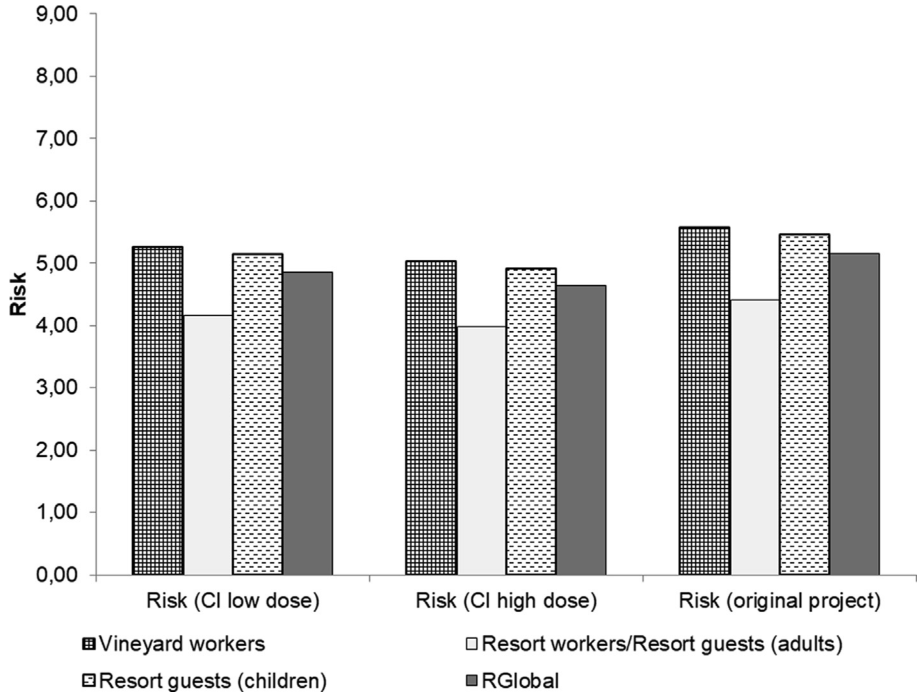

Fig. 4. Case Study: Risk characterization (before and after additional post-chlorination barrier).

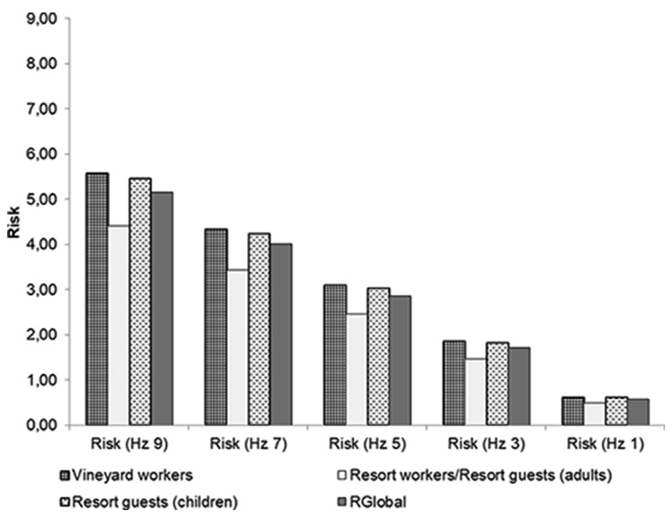

Fig. 5. Case Study: Risk characterization (considering changes o Hz level).

the adoption of a less restrict quality standard. Some of those measures could be the adoption of adequate signage for irrigated areas, access restriction to vineyards during irrigation schedules or period and increasing best practices on the use of PPE. This type of practices decreases the probability of occurrence of certain scenarios and subsequently reduces the vulnerability of receptors and associated risk.

According this Precautionary Principle [43] and as defined on the Portuguese water reuse legislation a monitoring program must be adopted to ensure that the water quality does not decrease during the project lifetime and a robust risk management plan should also be promoted according barriers and minimization measures in place to ensure a proper barrier control with a periodic risk reassessment as defined in Fig. 1.

The Portuguese water reuse legislation also defines as mandatory to perform a risk assessment for water resources, in order to prevent potential damage to surface and groundwater, which may jeopardize the achievement or maintenance of good water status, or affect possible water uses. For the water resources, chemical hazards must be considered, namely nutrients, compounds of emerging concern, microbiological hazards for the protection of the water uses and parameters classified under the Water Framework Directive (Directive 2000/60/EC) such as priority substances, priority hazardous substances, specific pollutants and other critical parameters for the status of water bodies [8,52]. Some of these substances can be released from households into sewer system, such as, pharmaceuticals, estrogens, biocides [15], while others can result for secondary reaction. For instance, the reclaimed waters are often post-chlorinated to maintain a residual given the need of protection against microbiological regrowth. However, this post-disinfection can lead to secondary reactions with the natural organic matter and subsequent formation of halogenated compounds, such as trihalomethanes [17]. Therefrom, additional research is needed to develop a similar a strategic semi-quantitative approach for the risk characterization applicable to water resources. Since, a sustainable water management will only be achieved by the establishment of reliable and safe systems that maximizes water reuse and minimize the discharge loads to water bodies [10] without endangering human health and environment, in particular the water resources.

4. Conclusions

To increase water reuse practices in Portugal was developed a new policy supported on international guidelines, such as ISO standards, and one of most challenging aspects is the promotion of a flexible management approach without compromising the health and environmental safety. For this reason, the Portuguese Environment Agency developed a guideline which provides technical support for risk assessment for health where the proposed methodology plays a significant role. The proposed methodology, supported on a strategic assessment, allows validating appropriate quality standards to be noted on water reuse permits and helps authorities on the decision-making process. In addition, this methodology also offers the possibility for proposers to evaluate different management options for their systems, eventually supported in a cost-benefit analyse. These methods also allow obtaining suitable results with simple outputs which is one of its main strength. This scheme also encourages the public confidence since promotes the adoption of a transparent and accountable process that deals with the several aspects of risk including vulnerability of receptors, possible damage, uncertainties and variabilities.

This methodology combined with the several aspects for risk assessment and management termed on the Portuguese Law Decree for water reuse assist authorities and water reuse agents on the application of the fit-for-purpose principle described on the ISO standards for water reuse and on the new European Regulation on minimum quality requirements for water reuse for agriculture irrigation (EU Regulation 2020/741, published on 5th june 2020). The strategic assessment scheme ensures the possibility of several options to achieve risk minimization namely in terms of multi-barrier conjunction with treatment options.

The appraisal of exposure scenarios allows identifying the most critical situation and the efforts needed for barrier control and monitoring. Subsequently, the methodology contributes for the development of dynamic risk management plan in terms of for monitoring, barriers management and risk updating that would help to enhance the safety of water reuse projects and regaining the public confidence on the practice.

The application of the methodology was demonstrated in a case-study, namely a vineyard irrigated with reclaimed water from an urban wastewater treatment plant.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors gratefully acknowledge the Portuguese Environment Agency for their financial support and to the anonymous reviewers for their for their valuable comments.

References

[1] USEPA, USAID, Guidelines for Water Reuse, U.S. Environmental Protection Agency, Washington, DC, 2012.
[2] L. Alcalde-Sanz, B.M. Gawlik, Minimum Quality Requirements for Water Reuse in Agricultural Irrigation and Aquifer Recharge - towards a Water Reuse Regulatory Instrument at EU Level, Publications Office of the European Union, Luxembourg, 2017.
[3] V. Lazarova, T. Asano, A. Bahri, J. Anderson, Milestones in Water Reuse: the Best Success Stories, IWA Publishing, London; New York, 2013.
[4] P. Quinteiro, S. Rafael, B. Vicente, M. Marta-Almeida, A. Rocha, L. Arroja, A.C. Dias, Mapping green water scarcity under climate change: a case study of Portugal, Sci. Total Environ. 696 (2019) 134024.
[5] T. Asano, Water Reuse: Issues, Technologies, and Applications, first ed., McGraw-Hill, New York, NY, 2007.
[6] European Commission, Guidelines on Integrating Water Reuse into Water Planning and Management in the Context of the WFD, European Commission, Brussels, 2016.
[7] A. Rebelo, G. Farabegoli, F. Andreotti, J. Balmer, M. Vella, R.V. Tunen, S. Gunput, S. Perikenti, P. Ece, Report on Urban Water Reuse - Integrated Water Approach and Urban Water Reuse Project, European Union Network for the Implementation and Enforcement of Environmental Law (IMPEL), Brussels, 2018.
[8] Portugal, Decreto-Lei N, de 21 de Agosto, 2019, pp. 21–44, º 119/2019.
[9] A. Rebelo, A. Franco, Guia para a reutilização de água para usos não potáveis, 2019. https://apambiente.pt/_zdata/Politicas/Agua/Licenciamento/ApR/APA_Guia_Reutilizacao_v1.pdf. accessed 10/04/2020,14:25.
[10] Z. Chen, Q. Wu, G. Wu, H.-Y. Hu, Centralized water reuse system with multiple applications in urban areas: lessons from China's experience, Resour. Conserv. Recycl. 117 (2017) 125–136. Part B.
[11] J. Wilcox, F. Nasiri, S. Bell, M.S. Rahaman, Urban water reuse: a triple bottom line assessment framework and review, Sustain. Citi. Soc. 27 (2016) 448–456.
[12] Economic European Communities, Council Directive 91/271/EEC of 21 May 1991 concerning urban waste water treatment, off, J. Eur. Commun, L 135 (1991) 40–52.
[13] International Organization for Standardization, ISO 20760-2:2017 - Water Reuse in Urban Areas — Guidelines for Centralized Water Reuse System — Part 2: Management of a Centralized Water Reuse Syste, International Organization for Standardization, Geneva, 2017.
[14] International Organization for Standardization, ISO 20760-1:2018 - Water Reuse in Urban Areas — Guidelines for Centralized Water Reuse System — Part 1: Design Principle of a Centralized Water Reuse System, International Organization for Standardization, Geneva, 2018.
[15] R. Delli Compagni, M. Gabrielli, F. Polesel, A. Turolla, S. Trapp, L. Vezzaro, M. Antonelli, Risk assessment of contaminants of emerging concern in the context of wastewater reuse for irrigation: an integrated modelling approach, Chemosphere 242 (2020) 125185.
[16] International Organization for Standardization, ISO 20426:2018 - Guidelines for Health Risk Assessment and Management for Non-potable Water Reuse, International Organization for Standardization, Geneva, 2018.
[17] A. Rebelo, I. Ferra, A. Marques, M.M. Silva, Wastewater reuse: modeling chloroform formation, Environ. Sci. Pollut. Control Ser. (2016) 1–7.
[18] G. Chhipi-Shrestha, K. Hewage, R. Sadiq, Microbial quality of reclaimed water for urban reuses: probabilistic risk-based investigation and recommendations, Sci. Total Environ. 576 (2017) 738–751.
[19] C.M. Rock, N. Brassill, J.L. Dery, D. Carr, J.E. McLain, K.R. Bright, C.P. Gerba, Review of water quality criteria for water reuse and risk-based implications for irrigated produce under the FDA Food Safety Modernization Act, produce safety rule, Environ. Res. 172 (2019) 616–629.
[20] International Organization for Standardization, ISO 16075-2:2015 - Guidelines for Treated Wastewater Use for Irrigation Projects - Part 2: Development of the Project, International Organization for Standardization, Geneva, 2015.
[21] International Organization for Standardization, ISO 16075-1:2015 - Guidelines for Treated Wastewater Use for Irrigation Projects — Part 1: the Basis of a Reuse Project for Irrigation, International Organization for Standardization, Geneva, 2015.
[22] WHO, Guidelines for the Safe Use of Wastewater, Excreta and Greywater, World Health Organization, Geneva, 2006.
[23] J.A. Soller, S.E. Eftim, S.P. Nappier, Comparison of predicted microbiological human health risks associated with de Facto, indirect, and direct potable water reuse, Environ. Sci. Technol. 53 (22) (2019) 13382–13389.
[24] G. Huang, P. Zhang, S. Sun, D. Zhang, Research on the method of human health risk assessment for reclaimed water, Ekoloji 26 (99) (2017) 23–31.
[25] D. Page, J.P.S. Sidhu, S. Toze, Microbial risk reduction of withholding periods during public open space irrigation with recycled water, Urban Water J. 12 (2015) 581–587.
[26] E. Tristán, A. Demetriades, M.H. Ramsey, M.S. Rosenbaum, P. Stavrakis, I. Thornton, E. Vassiliades, K. Vergou, Spatially resolved hazard and exposure assessments: an example of lead in soil at Lavrion, Greece, Environ. Res. 82 (1) (2000) 33–45.
[27] H. Shakeri, S. Nazif, Development of an algorithm for risk-based management of wastewater reuse alternatives, J. Water Reuse. Desal. 8 (1) (2018) 38–57.
[28] E. Shakir, Z. Zahraw, A.H.M.J. Al-Obaidy, Environmental and health risks associated with reuse of wastewater for irrigation, Egyptian J. Petrol. 26 (1) (2017) 95–102.
[29] Y. Li, J. Li, S. Chen, W. Diao, Establishing indices for groundwater contamination risk assessment in the vicinity of hazardous waste landfills in China, Environ. Pollut. 165 (2012) 77–90.
[30] B. Sizirici, B. Tansel, V. Kumar, Knowledge based ranking algorithm for comparative assessment of post-closure care needs of closed landfills, Waste Manag. 31 (6) (2011) 1232–1238.
[31] Z. Chen, H. Li, H. Ren, Q. Xu, J. Hong, A total environmental risk assessment model for international hub airports, Int. J. Proj. Manag. 29 (7) (2011) 856–866.
[32] Y. Wang, C.L. Moe, P.F.M. Teunis, Children are exposed to fecal contamination via multiple interconnected pathways: a network model for exposure assessment, Risk Anal. 38 (11) (2018) 2478–2496.
[33] International Organization for Standardization, ISO 20670:2018 - Water Reuse — Vocabulary, International Organization for Standardization, Geneva, 2018.
[34] WHO, Guidelines for Drinking-Water Quality, fourth ed., World Health Organization, Geneva, 2011.
[35] A. Rebelo, I. Ferra, I. Gonçalves, A.M. Marques, A risk assessment model for water resources: releases of dangerous and hazardous substances, J. Environ. Manag. 140 (2014) 51–59.
[36] T.L. Saaty, The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation, first ed., McGraw-Hill, New York, NY, 1980.
[37] S. Ahlroth, M. Nilsson, G. Finnveden, O. Hjelm, E. Hochschorner, Weighting and valuation in selected environmental systems analysis tools – suggestions for further developments, J. Clean. Prod. 19 (2–3) (2011) 145–156.
[38] A. Ishizaka, M. Lusti, How to derive priorities in AHP: a comparative study, Cent. Eur. J. Oper. Res. 14 (4) (2006) 387–400.
[39] Á. Gormley, S. Pollard, S. Rocks, E. Black, Guidelines for Environmental Risk Assessment and Management - Green Leaves III, Department for Environment, Food & Rural Affairs, London, 2011.
[40] S. Heise, U. Förstner, Risk assessment of contaminated sediments in river basins - theoretical considerations and pragmatic approach, J. Environ. Monit. 9 (9) (2007) 943–952.
[41] Great Britain, the Control of Major Accident Hazards (Amendment) Regulations 2005, The Stationery Office, 2005, pp. 1–15.
[42] R. Marshall, T.B. Fischer, Best practice use of SEA – industry, energy and sustainable development, in: M. Schmidt, E. João, E. Albrecht (Eds.), Implementing Strategic Environmental Assessment, Springer Berlin, Heidelberg, 2005, pp. 673–690.
[43] H. Pike, F. Khan, P. Amyotte, Precautionary principle (PP) versus as low as reasonably practicable (ALARP): which one to use and when, Process Saf. Environ. Protect. 137 (2020) 158–168.
[44] G.S. Russo, S.E. Eftim, A.E. Goldstone, A.P. Dufour, S.P. Nappier, T.J. Wade, Evaluating health risks associated with exposure to ambient surface waters during recreational activities: a systematic review and meta-analysis, Water Res. 176 (2020) 115729.

[45] Y.-R. Guo, Q.-D. Cao, Z.-S. Hong, Y.-Y. Tan, S.-D. Chen, H.-J. Jin, K.-S. Tan, D.-Y. Wang, Y. Yan, The origin, transmission and clinical therapies on coronavirus disease 2019 (COVID-19) outbreak – an update on the status, Military Med. Res. 7 (1) (2020).

[46] S. Dyke, I. Barrass, K. Pollock, I.M. Hall, Dispersion of Legionella bacteria in atmosphere: a practical source location estimation method, PloS One 14 (11) (2019), e0224144.

[47] L. Xiao, Y. Feng, Molecular epidemiologic tools for waterborne pathogens Cryptosporidium spp. and Giardia duodenalis, Food. Waterborne Parasitol. 8–9 (2017) 14–32.

[48] Y. Peng, Y.H. Zhou, Is novel coronavirus disease (COVID-19) transmitted through conjunctiva? J. Med. Virol. (2020) 1–2, https://doi.org/10.1002/jmv.25753.

[49] IPMA, Área educativa - clima de Portugal continental. https://www.ipma.pt/pt/educativa/tempo.clima/index.jsp?page=clima.pt.xml, 2020 accessed 10/04/2020, 12:15.

[50] International Organization for Standardization, ISO 20419:2018 - Treated Wastewater Reuse for Irrigation — Guidelines for the Adaptation of Irrigation Systems and Practices to Treated Wastewater, International Organization for Standardization, Geneva, 2018.

[51] C.A. Damalas, G. Abdollahzadeh, Farmers' use of personal protective equipment during handling of plant protection products: determinants of implementation, Sci. Total Environ. 571 (2016) 730–736.

[52] European Commission, Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy, off, J. Eur. Commun, L 327 (2000) 1–72.