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

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1. Introduction

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.

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

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Abstract

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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 freshwater 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 m³ 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 portrays the production of water for reuse from several sources (urban, domestic, industrial, agriculture overflow and runoff) to...
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 binding 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

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**Table 1**

<table>
<thead>
<tr>
<th>Hazard level</th>
<th>Escherichia coli (cfu/100 mL)</th>
<th>Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>SEC</td>
<td>$\geq 10^4$</td>
<td>9</td>
</tr>
<tr>
<td>SEC + disinfection</td>
<td>$10^3 &lt; E. coli &lt; 10^4$</td>
<td>7</td>
</tr>
<tr>
<td>Advanced</td>
<td>$10^2 &lt; E. coli \leq 10^3$</td>
<td>5</td>
</tr>
<tr>
<td>SEC + disinfection + post-chlorination</td>
<td>$10^3 &lt; E. coli \leq 10^2$</td>
<td>3</td>
</tr>
<tr>
<td>Advanced + post-chlorination</td>
<td>$E. coli \leq 10^1$</td>
<td>1</td>
</tr>
</tbody>
</table>

**Table 2**

<table>
<thead>
<tr>
<th>Exposure routes</th>
<th>Importance factors</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ingestion</td>
<td>9</td>
<td>Is always considered as absolute importance</td>
</tr>
<tr>
<td>Inhalation</td>
<td>9</td>
<td>Absolute importance in irrigation systems by aspersions</td>
</tr>
<tr>
<td>Dermal adsorption</td>
<td>3</td>
<td>Weak importance due to the less evidence data of infection</td>
</tr>
</tbody>
</table>

**Table 3**

<table>
<thead>
<tr>
<th>Importance factors</th>
<th>Observations according literature data</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>Exposure routes with very high evidence of occurrence</td>
</tr>
<tr>
<td>7</td>
<td>Exposure routes with medium evidence of occurrence</td>
</tr>
<tr>
<td>5</td>
<td>Exposure routes with low evidence of occurrence</td>
</tr>
<tr>
<td>1</td>
<td>Exposure routes with no evidence of occurrence</td>
</tr>
</tbody>
</table>
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 opportunite 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

![Table 4](https://example.com/table.png)

**Table 4**

<table>
<thead>
<tr>
<th>d</th>
<th>d1</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤0.5</td>
<td>1</td>
</tr>
<tr>
<td>0.5 &lt; d &lt; 1</td>
<td>2</td>
</tr>
<tr>
<td>1 – d &lt; 1.2</td>
<td>3</td>
</tr>
<tr>
<td>1.2 – d &lt; 2</td>
<td>4</td>
</tr>
<tr>
<td>2 – d &lt; 2.4</td>
<td>5</td>
</tr>
<tr>
<td>2.4 – d &lt; 3</td>
<td>6</td>
</tr>
<tr>
<td>3 – d &lt; 3.2</td>
<td>7</td>
</tr>
<tr>
<td>3.2 – d &lt; 4</td>
<td>8</td>
</tr>
<tr>
<td>d ≥ 4</td>
<td>9</td>
</tr>
</tbody>
</table>

![Fig. 2](https://example.com/fig2.png)

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

![Fig. 3](https://example.com/fig3.png)

*Fig. 3.* Expression of partial damage (d1) associated to the barrier failure.
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 (log10) 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]. Therewith, 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 prioritization 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 \((R_{\text{Rec}})\) is achieved by the product between the hazard (Hz), the vulnerability of receptors \((V_{\text{Rec}})\) and associated damage (D), i.e.:

\[
R_{\text{Rec}} = HZ \times V_{\text{Rec}} \times D
\]  

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:

\[
V_{\text{Rec}} = \sum \left( f_{\text{Path}} \times f_{\text{Scen}} \right) / \text{fnormal v}
\]

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

\[
f_{\text{normal v}} = f_{\text{max}} \times \sum \left( f_{\text{Path}} \times R_{\text{Rec}} \right)
\]
where \( f_{\text{max}} \) is the higher value of importance (9) and \( n_{\text{scene}} \) 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]. The probability of occurrence of each specie should be assumed as a qualitative judgment of the characteristics and number of barriers in place. This global damage (D) can be obtained by the following equation:

\[
D = \frac{\sum (d_i \times n_i)}{n_i^{\text{normal}} D}
\]  

(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 \( f_{\text{normal}} D = f_{\text{max}} \times n_i \), where \( f_{\text{max}} \) is the higher value of the importance scale (9) and \( n_i \) is the total number of 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 \( n_i \) 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:

\[
d = \frac{\text{Consequences} \times \text{Likelihood of occurrence}}{5}
\]  

(5)

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

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 \( n_{\text{scene}} \) 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:
### Table 8 Scenarios qualification and explanation (Vineyard workers).

<table>
<thead>
<tr>
<th>Scenario explanation</th>
<th>Importance factor justification</th>
<th>Vineyard workers $f_i$</th>
<th>Scenario</th>
<th>Importance factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intentional water uptake</td>
<td>A worker can intentionally ingest water from the system</td>
<td>7</td>
<td>A worker can intentionally ingest water from the system</td>
<td>Due to the specific training this scenario does not seem very probable to occur but depends on human behaviour and ingestion is an exposure route with demonstrated infection data. For this reason this scenario is considered as having strong importance</td>
</tr>
<tr>
<td>Non-intentional water uptake:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ingestion of droplets during leaks</td>
<td>Since the system is under pressure some leaks may form micro droplets that can be inadvertently ingested</td>
<td>9</td>
<td>The pathogens can accidentally be transferred by hand-mouth-face contact</td>
<td>The probability of occurrence 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]</td>
</tr>
<tr>
<td>Ingestion of droplets from the contact with wet vegetation</td>
<td>The pathogens can accidentally be transferred by hand-mouth-face contact</td>
<td>9</td>
<td>Since the system is under pressure some leaks may form aerosols that can be inadvertently inhaled</td>
<td>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]</td>
</tr>
<tr>
<td>Ingestion of droplets from the contact with irrigation system</td>
<td>The pathogens can accidentally be transferred by hand-mouth-face contact during inspection or maintenance works</td>
<td>9</td>
<td>The pathogens can accidentally be transferred by hand-mouth-face contact</td>
<td>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]</td>
</tr>
<tr>
<td>Ingestion of droplets from the contact with wet PPE</td>
<td>The pathogens can accidentally be transferred by hand-mouth-face contact</td>
<td>9</td>
<td>The pathogens can accidentally be transferred by hand-mouth-face contact</td>
<td>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]</td>
</tr>
<tr>
<td>Ingestion of droplets from wet dogs</td>
<td>The pathogens can accidentally be transferred by hand-mouth-face contact or ingested when dogs shakes off</td>
<td>9</td>
<td>Pathogens can be accidentally be transferred by hand-mouth-face contact</td>
<td>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]</td>
</tr>
<tr>
<td>Ingestion of pathogens from dogs</td>
<td>The pathogens can accidentally be transferred to hands, mouth or face by dog licking</td>
<td>9</td>
<td>Pathogens can be transferred to hands, mouth or face by dog licking</td>
<td>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]</td>
</tr>
<tr>
<td>Intentional ingestion of soil</td>
<td>A worker can intentionally ingest soil</td>
<td>7</td>
<td>Pathogens can be transferred to hands, mouth or face by dog licking</td>
<td>Due to the specific training this scenario does not seem very probable to occur but depends on human behaviour and ingestion is an exposure route with demonstrated infection data. Therefrom this scenario is considered as having strong importance</td>
</tr>
</tbody>
</table>

### Table 8 (continued)

<table>
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<tr>
<th>Scenario explanation</th>
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<th>Vineyard workers $f_i$</th>
<th>Scenario</th>
<th>Importance factor</th>
</tr>
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<tbody>
<tr>
<td>Non-intentional ingestion of soil</td>
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<td>Since the system is under pressure some leaks may form aerosols that can be inadvertently inhaled</td>
<td>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]</td>
</tr>
<tr>
<td>Inhalation of aerosols from dogs (sneezing)</td>
<td>The pathogens can accidentally be inhaled as aerosols from them when they sneeze</td>
<td>4</td>
<td>Pathogens can be transferred to hands, mouth or face by dog licking</td>
<td>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]</td>
</tr>
<tr>
<td>Contact with wet irrigation system</td>
<td>Pathogens can be adsorbed by skin or transferred to eyes (hand-eye) by direct contact with wet surface</td>
<td>3</td>
<td>Pathogens can be transferred to hands, mouth or face by dog licking</td>
<td>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]</td>
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<td>Contact with wet PPE</td>
<td>Pathogens can be transferred to hands, mouth or face by dog licking</td>
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(continued on next page)
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 (RRec $i$), a global risk ($R_{global}$) value is obtained by the expression (6), where $N_{Rec}$ is the number of the considered receptor categories in the process:

$$R_{Global} = \sum_{i} \frac{R_{Rec i}}{N_{Rec}}$$

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>
<thead>
<tr>
<th>Table 9 Scenarios qualification and explanation (Resort workers and resort guests)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenarios qualification</td>
</tr>
<tr>
<td>-------------------------</td>
</tr>
<tr>
<td>Intentional water uptake</td>
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<td>Ingestion of droplets during leaks</td>
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<td>Ingestion of droplets from the contact with wet vegetation</td>
</tr>
<tr>
<td>Ingestion of droplets from the contact with irrigation system</td>
</tr>
<tr>
<td>Ingestion of droplets from the contact with wet clothes</td>
</tr>
<tr>
<td>Intentional ingestion of soil</td>
</tr>
<tr>
<td>Non-intentional ingestion of soil</td>
</tr>
<tr>
<td>Inhalation of aerosols during leaks (irrigation system under pressure)</td>
</tr>
</tbody>
</table>

(continued on next page)

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 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 the low scientific evidence of transmission for water-borne pathogens [44,45]. 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].

<table>
<thead>
<tr>
<th>Table 9 (continued)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resort workers</td>
</tr>
<tr>
<td>Resort guests (adults)</td>
</tr>
<tr>
<td>Contact with wet irrigation system</td>
</tr>
<tr>
<td>Contact with wet clothes</td>
</tr>
<tr>
<td>Contact with wet vegetation (leaf, fruits or roots) or soil</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 10 Scenarios qualification and explanation (Resort guests: children).</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resort guests (children)</td>
</tr>
<tr>
<td>Intentional water uptake</td>
</tr>
<tr>
<td>Non-intentional water uptake:</td>
</tr>
<tr>
<td>Ingestion of droplets during leaks</td>
</tr>
<tr>
<td>Ingestion of droplets from the contact with wet vegetation</td>
</tr>
<tr>
<td>Ingestion of droplets from the contact with irrigation system</td>
</tr>
<tr>
<td>Ingestion of soil</td>
</tr>
<tr>
<td>Non-intentional ingestion of soil</td>
</tr>
<tr>
<td>Inhalation of aerosols during leaks (irrigation system under pressure)</td>
</tr>
</tbody>
</table>

(continued on next page)
characteristics of the project are described in Table 5. Relationships between receptors and possible scenarios are included [32].

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

Table 10 (continued)

<table>
<thead>
<tr>
<th>Resort guests</th>
<th>Importance factor justification</th>
</tr>
</thead>
<tbody>
<tr>
<td>(children)</td>
<td></td>
</tr>
<tr>
<td>$f_{i}$</td>
<td></td>
</tr>
<tr>
<td>Scenario explanation</td>
<td></td>
</tr>
<tr>
<td>Contact with wet irrigation system</td>
<td>2 Pathogens can be adsorbed by skin or transferred to eyes (hand-eye) by direct contact with wet surface</td>
</tr>
<tr>
<td>Contact with wet clothes</td>
<td>2 Pathogens can be adsorbed by skin or transferred to eyes (hand-eye) by direct contact with wet surface</td>
</tr>
<tr>
<td>Contact with wet vegetation (leaves, fruits or roots) or soil</td>
<td>2 Pathogens can be adsorbed by skin or transferred to eyes (hand-eye) by direct contact with wet surface</td>
</tr>
</tbody>
</table>

Table 11

Receptors vulnerability.

<table>
<thead>
<tr>
<th>Receptor category</th>
<th>Vulnerability ($V_{\text{V0}}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vineyard workers</td>
<td>0.84</td>
</tr>
<tr>
<td>Resort workers/Resort guests (adults)</td>
<td>0.66</td>
</tr>
<tr>
<td>Resort guests (children)</td>
<td>0.82</td>
</tr>
</tbody>
</table>

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), it 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 application of equation (5) which will also minimize some uncertainties by the assimilated knowledge [32]. From the previous data and by the application of equation (2), it is possible to obtain the vulnerability to each receptor category. These results can be seen in Table 11.
same only additional calculations on damage and risk are needed. This for the irrigation tank outlet. Since the vulnerability of receptors remains the vulnerability of receptors increases the probability of occurrence. For instance, can be studied the implementation of a post-chlorination system, clogging, decrease of active chlorine by the exposure to sun and systems is possible to occur some malfunctions such as failure on dosage decrease. The damage linked with this barrier can run from 0.67 to 0.70 consequence owing the type of crops (grapes for wine production) and considering the applicable chlorine dose (high or low dose). The damage values when considering different types of barriers. values obtained by equation (4) related with these barriers and with the original project (0.74) can be seen in Table 15.

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

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 this 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

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

<table>
<thead>
<tr>
<th>Category</th>
<th>Risk</th>
<th>Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vineyard workers</td>
<td>5,58</td>
<td>Acceptable</td>
</tr>
<tr>
<td>Resort workers/Resort guests (adults)</td>
<td>4,42</td>
<td>Acceptable</td>
</tr>
<tr>
<td>Resort guests (children)</td>
<td>5,45</td>
<td>Acceptable</td>
</tr>
<tr>
<td>Reduced</td>
<td>5,15</td>
<td>Acceptable</td>
</tr>
</tbody>
</table>

Table 15

Damage values when considering different types of barriers.

<table>
<thead>
<tr>
<th>Barrier Type</th>
<th>Original project</th>
<th>Addition of post-chlorination</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N.º barriers (ni)</td>
<td>Partial damage (di)</td>
</tr>
<tr>
<td>Drip irrigation</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>Pathogen die-off</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Irrigation control</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>Post-chlorination (low level)</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Post-chlorination (high level)</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Workers training</td>
<td>1</td>
<td>9</td>
</tr>
</tbody>
</table>

Damage (D) 0.74 0.70 0.67
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.

This 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.

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