MULTIWARE, a participatory simulation tool for integrated and collective pathogens risk management in agricultural water reuse projects

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ABSTRACT

Wastewater reuse (WR) and, more broadly, the recovery of unconventional water is becoming widespread on a global scale. Although the practice is not new (Angelakis *et al.*, 2018), it is now part of many national and international strategies for sustainable and integrated resource management. However, it may pose risks to human health, especially in terms of pathogenic microorganisms (Adegoke *et al.*, 2018). To regulate the practice, most regulatory frameworks require a high reduction in the concentration of microorganisms in treated wastewater (TW). As an example, for agricultural irrigation, the threshold for Class A in the European regulation 2020/741 is 100 times lower than the "Good quality" standard for inland waters required by the International Swimming Federation for the organisation of international events (World Aquatics, 2024). To achieve these levels of quality, advanced treatment processes need to be added. However, this requires technical skills and generates investment and operating costs that can be significant. Bringing projects up to standard can therefore raise concerns, particularly for small communities with limited resources, which generally account for the majority of cases of agricultural WR. The environmental impact of treatment processes is also increasingly questioned (de Boer *et al.*, 2022).

However, for nearly 20 years now, the World Health Organisation (WHO) has been calling for a different approach especially in its guidelines for agricultural WR (WHO, 2006). Rather than focusing risk management on quality classes and advanced treatment, it proposes health-based targets. This translates into a tolerable dose per person per year that must not be exceeded. Risks are then managed in relation to this dose, with the implementation

of “barrier” measures throughout the system: localised irrigation, natural inactivation of pathogens, post-harvest preparations… This approach has a number of advantages: it takes into account the proven and non-negligible contribution of practices put in place after the treatment plant, it overcomes the limitations associated with additional treatments, and it provides a more adaptive approach that can take account of the specific features of projects. It is the subject of growing interest in the academic world and is now formalised in certain regulations as another risk management option. However, its application remains very limited (Drechsel *et al.*, 2022). This approach raises a number of questions that could explain its limited development.

First, how to choose the combination of barriers that will ensure sufficient protection? The chosen combination must achieve sufficient risk management. Depending on the regulatory framework, this may be defined by a number of barriers to be implemented, a log reduction to be achieved or a disease burden threshold that should not be exceeded. The level of precision may therefore vary. The WHO recommends the use of QMRA whenever possible. Although QMRA is more precise and objective than other risk assessment methods (WHO, 2016), it can be complex to apply in the field. Secondly, how to ensure the effective implementation of barriers? What impact will the chosen barriers have on the system? How can responsibilities be shared? The "multi-barrier" approach implies moving beyond risk management focused solely on treatment to a more systemic approach throughout the reuse system. If additional measures need to be added, they must be chosen in consultation with all stakeholders, especially farmers (Drechsel *et al.*, 2009 ; Maffettone and Gawlik, 2022). Collective management implies a more integrated organisation among stakeholders who are not always used to work together. Consultation between stakeholders is even more important since risk perception is subjective and varies from one stakeholder to another (Baggett *et al.*, 2006). It influences management decisions (Goodwin *et al.*, 2019), affects the understanding of the practice (Noury, 2021) or the barriers implementation (Drechsel *et al.*, 2009 ; Amoah *et al.*, 2011). Participatory mechanisms are therefore increasingly encouraged in WR projects (Maffettone and Gawlik 2022). They promote the sharing of representations and the involvement of stakeholders through the provision of information, experimentation and the creation of relationships between actors (Goodwin *et al.*, 2019; Noury, 2021). Among the participatory tools that can be used, serious games provide a simplified representation of a real system and help stakeholders to collectively consider solutions. They allow players to set aside their reality, tensions and beliefs and allow themselves to imagine and explore new possibilities (Ferrand *et al.*, 2024). However, these tools are still very rarely used for WR and, as far as we know, there is no such tool for pathogen risk management.

A participatory simulation tool, in the form of role-playing game, has been developed to help stakeholders to collectively create, test and simulate pathogen risk management scenarios for water reuse for agricultural irrigation. This tool has been named “MULTIWARE" for MULTI-actors, MULTI-barriers, MULTI-WAter REuse. It enables the comparison of these scenarios in terms of risk management, organisational and economic impacts, facilitating decision-making and the identification of an optimal scenario. The originality of the tool is that it integrates a database of barrier measures, a risk assessment model based on Quantitative Microbial Risk Assessment (QMRA) while also allowing for the input of expert knowledge. MULTIWARE was built in two parallel phases: i) a "state of the art" phase on possible barriers for risk management and on QMRA and ii) a "co-construction" phase using the Companion modelling approach (Etienne *et al.*, 2011) with key players of an emblematic case of WR for agricultural irrigation in Clermont-Ferrand, France. After the co-construction phase, the tool was then used in a workshop with the Clermont-Ferrand project monitoring committee. It was also used with another existing case of WR for agricultural irrigation (Porquerolles) and a project under construction (Drôme). These workshops brought together operational and institutional stakeholders, as well as some members of civil society and scientists.

There are two possible approaches to risk management: i) achieving the required quality for each culture by adding an advanced treatment unit (the "conventional" approach) or ii) to implement sufficient barriers to achieve health-related objectives (the "multi-barrier" approach). For each workshop, the participants had to collectively produce at least 1 scenario for each approach based on a fictitious WR case (Figure 1).

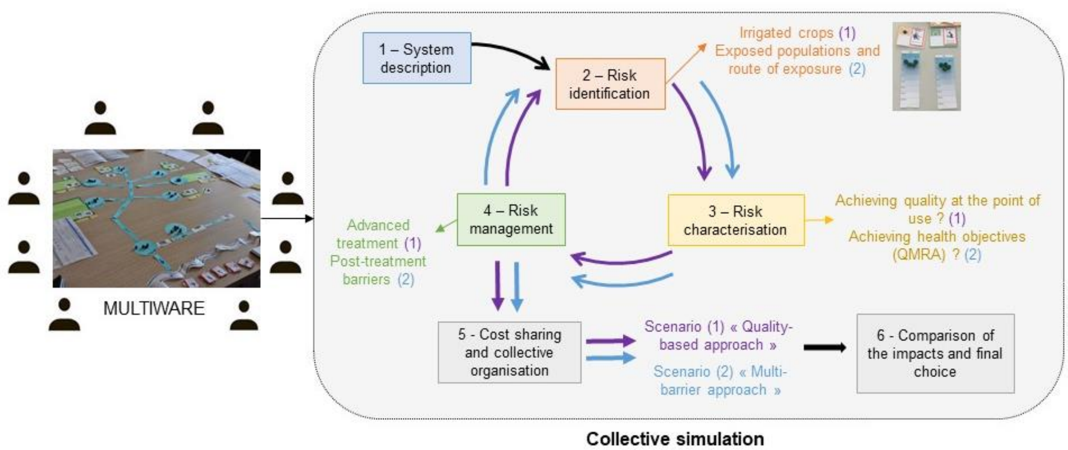

Figure 1 – Construction process of the two risk management scenarios

The objective was to compare the health, economic, and organisational impacts of each approach. The construction of each scenario prompted numerous discussions among the participants and raised several questions. The "simplest" solution in terms of health monitoring seems to be the implementation of an additional unit at a collective scale. However, during the workshop, there was no real consensus among the participants on the distribution of costs distribution and the sharing of responsibilities. In fact, a collective-scale treatment will represent high additional costs especially for players like seed corn growers who want to maintain field crops and will not need A quality. They represent the majority of the irrigated area and therefore, have strong decision-making power compared to other players such as market gardeners. Given the high costs associated with achieving A-quality, this could lead to crop restrictions that would be unfavourable to food crops. Costs are lower in scenario 2 (multi-barrier), but the responsibility no longer rests solely with the municipality and farmers' association but also with the farmers or their staff. The exercise identified many barriers that are already naturally integrated into farming practices and managed by farmers, such as irrigation systems and post-harvest preparations. This result is interesting because behaviour change related to the implementation of barriers is often cited as a hindrance to the application of this approach (Drechsel *et al.*, 2022). Although water quality is an important element, some participants indicated that they had realised that treatment was not the only measure to reduce risks and that risks could be safely managed without achieving A quality. The tool and the input from the other participants helped them to take ownership of the barriers. However, the construction of scenario 2 was felt to be the most complex, particularly when it came to identifying risks and using concepts such as DALYs. Some participants expressed a sense of confusion when the results of the QMRA were projected, especially when the 10^{-6} DALYs were not achieved ("how serious is it ?"). The barriers chosen for scenario 2 did not always seem realistic and applicable in real life, such as signage or changing irrigation systems. Nevertheless, participants highlighted the value of the tool and its game format in their learning about risk assessment and management.

After the simulation, the session ended with a collective debriefing. The feedback from the participants (also collected through individual interviews) showed that the simulation session allowed them to have a first collective approach to key concepts of risk assessment and management. It creates a common knowledge base of both the tool and the participants. Participants were able to discuss management choices and the problems faced by all. It helped to create links between different stakeholders. The live simulation of the costs and effects on health allows the discussion to be based on concrete elements. This tool could therefore contribute to the operational application of regulatory frameworks. However, several questions remain. The QMRA parameters are based on literature data, raising concerns about the validity of the results. Furthermore, the participants could not reach an agreement on a final scenario. While the results were used to build the Clermont-Ferrand's risk management plan, questions remain about the practical implementation of the barriers, particularly at the farmer level.

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