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The challenge of supporting and monitoring safe wastewater use in agriculture in LMIC

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Unsafe water reuse in the informal irrigation sector dominates in the Global South and requires more attention to protect food safety and public health. Promoting formal wastewater use in conjunction with (usually constrained) investment in treatment capacities is not sufficient in LMIC. New approaches and indicators are needed across the formal and informal reuse sectors to increase food safety and monitor progress on safe reuse. Current reuse guidelines need to be updated with greater attention to policy, regulations, investments, and behavior change for a higher implementation potential.

Wastewater management is an important global challenge with 45% of domestic wastewater being, collected or uncollected, released untreated into the environment[1]. Of the treated wastewater share, 22% is intentionally used in various sectors, mostly (52%) in high-income countries, with 37% from upper-middle-income countries, in line with the availability of treatment capacities and supporting regulations[2].

Paradoxically, the direct or indirect reuse of the untreated wastewater share is accelerating, especially in informal (farmer-led) agriculture in and downstream of urban areas. This acceleration is driven by water scarcity, limited regulatory capacities, and declining uncontaminated water sources, covering about 29 million hectares (M ha)[3], roughly the size of Italy, where raw or (partially) treated wastewater is used in irrigated farming, representing about 10% of the irrigated area globally[4]. Most of this wastewater is diluted, i.e., mixed with surface water from rivers and lakes. However, as data from across low- and middle-income countries (LMIC) show[5,6], this dilution reduces insufficiently the risk of infectious disease and about 95% of the area under wastewater use has to be considered unsafe. This informal sector is increasing around growing urban centers with low wastewater treatment capacities, especially where irrigated (peri)urban farming has a strong market advantage for easily perishable vegetables, like in many parts of Sub-Saharan Africa, which are still missing refrigerated lorries to transport these crops in a fresh state over long distance. However, given the informal nature of the (peri)urban irrigation sector, country data on actual water quality and extent of the praxis are missing, undermining monitoring and risk management[3,5].

So far, SDG 6.3 has focused on increasing treatment capacities in support of the safe reuse of wastewater, which covers an estimated 1.5 M ha of farmland (Qadir et al., unpublished) that can be attributed to planned (formal) reuse with 'treated' wastewater whatever the level. However, if the original intent of SDG 6.3 was to safeguard public health, we argue that it is much more crucial to address the existing reuse, which is likely producing unsafe food for about 885 million urban residents[3], than to focus only on new treatment plants and related 'safe reuse' schemes which will even beyond 2030 only benefit a significantly smaller number of consumers. Investing in the transition of those 29 M ha of farmland and their related food chains from unsafe to safe practices could provide a more cost-effective[7] pathway to progress on "safe reuse" till 2030 than waiting for wastewater treatment capacities to materialize. Of course, wastewater treatment is the best solution to safeguard water quality—and, as such, was the pillar of WHO's 1989 water reuse guidelines[8]. However, it is not sufficient to guarantee food safety as long as treatment coverage and quality remain limited and farms still receive untreated wastewater from other tributaries. Moreover, treatment plant failures are likely to become more common even in previously well-functioning systems where stressors like climate change and population growth are not met by re-investments in infrastructure and strong regulatory oversight.

WHO's updated 2006 guidelines were adapted to the reality of limited wastewater treatment capacities in LMIC and widespread poor-quality water[9]. The guidelines, therefore, de-emphasized improvements in water quality as a short-term target. Instead, they recognize that a noteworthy risk reduction can also be achieved through combinations of actions along the toilet to farm-to-fork contamination pathway to achieve health-based targets safeguarding the consumer. This multi-barrier approach[10] is based on the understanding that no single barrier might achieve the desired pathogenic risk reduction, however a suitable combination of barriers (or action) can provide significant protection. Such approaches are well recognized: in the hazard analysis and critical control points (HACCP) concept for food safety; Water Safety Plans as applied to drinking water; and are unified in WHO's overall approach to water-related safety norms[10,11].

While some pathogen barriers or risk reduction practices, like drip irrigation and cessation of irrigation, were already included in the 1989 edition of the WHO guidelines, the 2006 guidelines and the related WHO information kits and Sanitation Safety Planning manual offered a wider spectrum of possibilities to reduce pathogen loads on farm, in markets, and kitchens[8–10,12,13].

Nearly 20 years later, where are we?

Data on wastewater *generation* by country and population are adequate and increasing, however, data on wastewater *use* remain sparse and inadequate[2], especially as mentioned from the vast informal sector; similarly, explicit and coherent risk management strategies are limited to very few countries[14].

On reflection, we can now see that the concept of health-based targets and suggested methodologies like quantitative microbial risk assessment (QMRA)[9] were challenging especially when compared to the simplistic water quality thresholds which they superseded[8]. As much as the multi-barrier approach makes sense, the mechanisms to make it work in the majority of LMIC where its benefits are arguably greatest are challenging[15].

Even in Ghana, where over many years, different pathogen barriers were tested, no promotion, adoption, and consequentially no impact on food safety appears visible[16,17]. This contrasts unfavorably with the widespread adoption of Water Safety Plans for drinking water. The challenges are exacerbated because farmer field schools (FFS) shifted their focus e.g., to antimicrobial resistance, and codex alimentarius expert committees prefer discussing ever-more sophisticated technologies such as washing lettuce leaves in ozonated water, cold plasma treatment, or gamma-ray irradiation[18], with doubtful applicability for (both, informal and formal) vegetable value chains in sub-Saharan Africa. So, are we giving up on increasing food safety in the informal irrigation sector of LMIC, where the use of poorly or untreated wastewater is most common?

The multi-barrier approach works apparently best where (i) the value chain is highly regulated and monitored, (ii) barriers are ideally a combination of technologies, and (iii) stakeholders along the food chain are aware of pathogenic risks (as it is more frequent with drinking-water). However, our knowledge is very limited on how to support behavior change for health risk reduction where (i) risk awareness is low and also not a stakeholder priority, (ii) risk mitigation might increase costs to producers and consumers, and (iii) the health benefits are distant and less certainly associated with their origin, means where an actor, like a farmer, supposed to ascertain food safety might never meet the beneficiary consumers, who might in turn never learn what made them sick to complain[19]? On the other hand, where consumers are aware, they can induce change by objecting to certain traders or their practices[20].

How to progress

Solutions will likely be context-specific and require significant (social science) research to understand and facilitate behavior change where technical barriers are no option[21] like in the informal food sector, which plays a key role in safeguarding public health in LMIC[14]. While behavior triggers and incentives might be location-specific, we can and should identify more generic alternative indicators of progress toward the safety intent of SDG 6.3, recognizing stepwise improvements rather than condemning imperfection. Artificial intelligence (AI) and machine learning (ML) are increasingly applied in wastewater management, but more comprehensive models incorporating social and economic factors are needed[22]. Far preferable to counting water volumes or irrigated areas, which also requires details on what counts as safe for each reuse type, could be, for example, an indicator like the percentage of farmers using safe irrigation practices or, under consideration of post-harvest contamination, the percentage of households disinfecting salad greens eaten raw. Regulatory oversight along the food chain is critical and could be a compliance indicator, but it requires enhancing institutional capacities, [AI/ML] data systems, and improved skills at national, regional, and international level[23]. This approach would shift the emphasis from water treatment to safe reuse and consumption in line with WHO's shift from water quality thresholds to health-based targets for safe wastewater use[9,10]. A stronger focus on the safety of irrigated food could offer SDG 6.3 also an opportunity to make its monitoring independent from the formal vs. informal sector challenge and progress faster on its target of '*substantially increasing recycling and safe reuse globally*'.

Only a few LMICs have their own policies or guidelines for safe water reuse. Those that reference WHO guidelines mostly refer to the water quality thresholds of the WHO 1989 edition, not [the extended multi-barrier approach of] WHO's 2006 edition. Yet, due to the lack of adequate human and financial resources to implement national guidelines[24], most might remain "paper tigers", as Amponsah et al.[16] stated for Ghana. Thus, while the WHO[9] guidelines point countries in the right direction, they urgently need to be updated by taking on board the lessons from their limited adoption in LMIC and related research, with greater attention to policy, regulations, investments, incentive systems, and behavior change, instead of microbiology or sophisticated treatment technologies.

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