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Review

Reducing Groundwater Contamination from On-Site Sanitation in Peri-Urban Sub-Saharan Africa: Reviewing Transition Management Attributes towards Implementation of Water Safety Plans

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Abstract: High urbanization in Sub-Saharan Africa (SSA) has resulted in increased peri-urban groundwater contamination by on-site sanitation. The World Health Organization introduced Water Safety Plans (WSP) towards the elimination of contamination risks to water supply systems; however, their application to peri-urban groundwater sources has been limited. Focusing on Uganda, Ghana, and Tanzania, this paper reviews limitations of the existing water regime in addressing peri-urban groundwater contamination through WSPs and normative attributes of Transition Management (TM) towards a sustainable solution. Microbial and nutrient contamination remain prevalent hazards in peri-urban SSA, arising from on-site sanitation within a water regime following Integrated Water Resources Management (IWRM) principles. Limitations to implementation of WSPs for peri-urban groundwater protection include policy diversity, with low focus on groundwater; institutional incoherence; highly techno-centric management tools; and limited regard for socio-cultural and urban-poor aspects. In contrast, TM postulates a prescriptive approach promoted by community-led frontrunners, with flexible and multi-domain actors, experimenting through socio-technical tools towards a shared vision. Thus, a unified risk-based management framework, harnessing attributes of TM and IWRM, is proposed towards improved WSP implementation. The framework could assist peri-urban communities and policymakers in formulating sustainable strategies to reduce groundwater contamination, thereby contributing to improved access to safe water.

Keywords: contamination; integrated water resources management; groundwater; pollution; Sub-Saharan Africa; transition management; water safety plan

1. Introduction

Groundwater contamination by human activities is a growing global concern in light of increasing population, urbanization, industrialization, and agriculture [1,2]. Over one-third of the global water use is derived from groundwater, which is under increasing stress from anthropogenic contamination and diminishing resource quantities due to over-extraction and climate change effects [2]. On-site sanitation practices for disposal of human excreta and greywater are major contributors to groundwater contamination, especially in peri-urban areas where settlement patterns are dense [3,4].

On-site sanitation facilities, mainly pit latrines and septic tanks, remain the primary form of improved sanitation in rural and peri-urban areas in most of the developing world, including Sub-Saharan Africa (SSA); South, East, and Central Asia; Southern and Middle America, and Oceania [4–6]. While such facilities have promoted access to improved sanitation to the peri-urban communities, their increased number, and usually poor construction and maintenance, results in increased groundwater contamination [4,7–13]. Groundwater contamination by on-site sanitation systems in SSA is, thus, a significant hindrance to providing access to safe water to vulnerable populations [7–9]. Indeed, SSA lags behind other regions of the world in the struggle to meeting sustainable development goal (SDG) number 6 on universal access to safe water and sanitation [5,14].

Sub-Saharan Africa continues to register unprecedented urbanization, mainly occurring in peri-urban areas, which have low access to safe water and sanitation [10–12]. Groundwater, drawn mainly from boreholes, shallow wells, and springs, is the predominant source of water for domestic consumption, small scale industry, and irrigation to the majority of peri-urban residents in SSA due to its relatively low cost of abstraction and high availability [3,7,9]. Despite this high reliance on groundwater, on-site sanitary practices have increased contamination, leading to severe human health and ecological consequences [12,15–17]. For instance, Murphy et al. [18] reported that over 60% of groundwater sources tested in Kampala (Uganda) were positive for *Escherichia coli* (*E. coli*), which is commonly attributed to fecal contamination, during a typhoid outbreak in 2015, which affected more than 10,000 people. The scale and nature of the contamination and associated risks increase in complexity with a growing population.

The failure to address groundwater resource challenges, such as the increasing stress of groundwater resources due to contamination by on-site sanitation in peri-urban areas, can be attributed to limitations in the groundwater management (governance) framework [12,19,20]. Vardy et al. [20] described groundwater governance to include elements of institutional setting; availability and access to information and science; robustness of civil society; and economic and regulatory frameworks. Generally, groundwater governance has evolved within the overall realm of water governance, dating back to the Helsinki Rules on the use of waters of international rivers in 1966 [19]. Globally, there have been several groundwater governance approaches, depending upon the geographical scale (local, regional, or transboundary). These have included approaches based on 1) international water law and political ecology perspectives, especially in transboundary aquifer governance [19,21–23]; institutionalism, including management of "common pool resources" through polycentric approaches advanced by Elinor Ostrom and associates [24–26]; economic and market regulation perspectives [20,27]; and socio-ecological approaches [19,28]. Generally, the current water governance framework in SSA is mainly influenced by Integrated Water Resources Management (IWRM) principles, adopted after the International Conference on Water and Environment (Dublin) and the United Nations Conference on Environment and Development (Rio de Janeiro), both in 1992 [29]. However, despite the high importance of groundwater resources, it has always received less profiling within the overall water governance frameworks [19,22,30–32].

Many countries in SSA embraced IWRM as a multi-stakeholder framework towards addressing water resources challenges, including contamination [33–35]. IWRM is defined as 'a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems' [29]. IWRM introduced improved integrated policies, and improved participatory and gender-responsive approach, which have provided an enabling environment for implementing water resources improvement initiatives. However, implementation of IWRM in SSA has faced several challenges, including; (1) a high level of diversity (ambiguity), leading to complexity and limited action to address specific societal challenges [30,33–36]; (2) contested institutional framework based on catchment-based structures [32,37–40]; (3) ineffective stakeholder participation and cooperation frameworks [30,37]; (4) undefined monitoring framework for assessing results [33,39]; (5) ineffective cost recovery mechanisms [35]; and (6) limited resources to implement the ambitious targets of IWRM approaches [40]. These IWRM experiences have influenced the adoption and implementation of water resources management initiatives within the water sector in SSA [40].

In 2004, the World Health Organization (WHO) introduced Water Safety Plans (WSPs) as an instrument for identification, prevention, and management of contamination risks to water supply systems, which has been adopted in SSA as well [41–43]. The WSP approach is based on the principles and steps of the "Multiple-Barrier" concept for prevention of contamination to water sources and the "Hazard Analysis and Critical Control Points (HACCP)" concept, adopted from food safety management systems [44]. The WSPs are intended to ensure continuous provision of safe water, free from any contamination, for all levels and types of community water supply systems [41,44]. WSPs have been implemented, mainly by water utilities, in all regions of the world, voluntarily or by regulation [42,45]. Uganda was among the first countries in SSA to implement WSPs for prevention of pollution to public water supplies [45]. Ghana and Tanzania have also recently adopted implementation of WSPs for protection of public water supplies [42]. Although WSPs have mainly been implemented for conventional urban water supply systems, with complex infrastructure, there have also been efforts to apply them for improvement of the safety of basic water supply infrastructure in rural and peri-urban areas [46]. However, like other management instruments, adoption and implementation of WSPs is greatly influenced by the existing water governance regime [47–51]. The influence of the existing water regime (IWRM) towards the implementation of WSPs for addressing peri-urban groundwater contamination, in particular, has not been comprehensively documented. An analysis of the challenges to the existing framework in implementing WSPs to address the growing challenge of peri-urban groundwater contamination would identify the gaps, which can be addressed by emerging management concepts.

Transition Management (TM) is an emerging management framework, within the context of sustainability science, which has been explored in various developing and developed countries to address complex socio-technical sustainability challenges [52–54]. TM is described as a 'prescriptive and descriptive, complex-based governance framework towards long-term social change through small steps basing on searching, learning and experimenting' [52]. TM has evolved in the past two decades in the realm of sustainability science, attempting to provide solutions to societal complex and persistent problems [52,53]. Groundwater contamination by on-site sanitation in peri-urban SSA is certainly one such challenge, which could benefit from developments of the emerging field of TM. TM acknowledges that societal problems are getting more complex with increased pressures like population growth, climate change, and technological advancement, and traditional management approaches are ill-equipped for this complexity [55]. Since 2015, a project has been implemented by the research team, T-group, focusing on adapting TM approach towards improved peri-urban groundwater management in Uganda, Ghana, and Tanzania [56,57].

Through a critical review, this paper aims to highlight the existing water regime challenges towards implementing WSPs for protecting peri-urban groundwater against contamination by on-site sanitation and explore normative attributes of TM towards a sustainable solution. The paper first illustrates the complex socio-technical system influencing peri-urban groundwater contamination arising from on-site sanitation in peri-urban SSA and then reviews the challenges of IWRM framework and the normative attributes of TM framework towards improved risk management. Using the Entity-Relationship Diagramming (ERD) technique, complementary attributes of IWRM and TM are demonstrated in a proposed risk-based management framework for reducing peri-urban groundwater contamination by on-site sanitation through WSPs for small communities. This framework could be a sound tool for comprehensive assessment and formulation of strategies to improve adoption and implementation WSPs targeted at reducing peri-urban groundwater contamination in SSA.

2. Methodology

The literature survey was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [58]. Relevant documentation (both published and unpublished) were searched, with no date restrictions, from Google Scholar, Google, Scopus, Water Safety Portal, and Web of Science. Titles of all retrieved documents were reviewed to remove any duplications followed by an analysis of abstracts for eligibility. Eligible documents included those that contained information on groundwater contamination/pollution, on-site sanitation, water contamination risk management, water safety plans, integrated water resources management, groundwater management/governance, aquifer management, and transition management. The full-text analysis was only undertaken for the documents with implication to SSA context, with particular focus on Ghana, Uganda, and Tanzania. Relevant subject articles and documents from WHO and other sources pertinent to WSP and groundwater contamination by on-site sanitation were also included in the review. The documents reviewed also provided additional sources, which were assessed for eligibility. The review was conducted between January 2019 to May 2020. Figure 1 shows the flow diagram for the literature review.

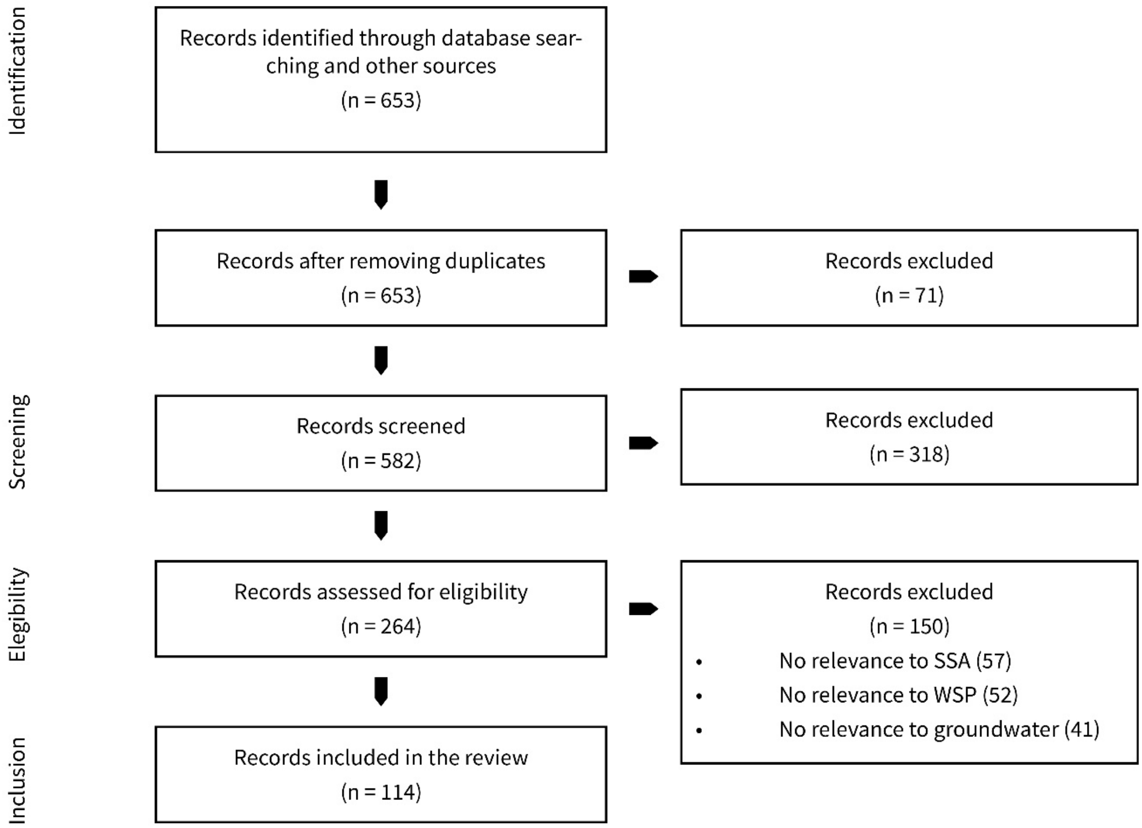

Figure 1. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flow diagram for the literature survey.

From the comprehensive review, the governance factors influencing implementation of WSPs for reducing peri-urban groundwater contamination in SSA were analyzed and represented using Entity-Relationship Diagramming technique (ERD). ERD can be used to visually display qualitative data on system entities, their relationships, and attributes [59]. Content validation of the proposed framework was achieved through expert opinion and stakeholder consultation at a stakeholder workshop held in Entebbe (Uganda), in February 2020. The workshop was attended by 37 participants drawn from government institutions, private sector, and research institutions. Iterative improvements were made to the final version presented.

3. Understanding the Complex Socio-Technical System Influencing Groundwater Contamination by On-Site Sanitation in Peri-Urban SSA

On-site sanitation, through pit latrines and septic tanks, is the predominant sanitation system used in peri-urban areas for disposal of human waste in most of SSA, and the developing world, particularly in Asia, Middle America, and Oceania [3–8]. In the developed world, including Europe and North America, on-site facilities, mainly in the form of decentralized treatment options, are mostly used in the rural setting [60,61]. While on-site systems have contributed to the increased access to improved sanitation in peri-urban areas, they have been reported to be a source of contamination hazards to groundwater, which is used by many peri-urban dwellers [1–10,12,15–18,60,61]. Table 1 summarizes recently documented cases of peri-urban groundwater chemical and microbial contamination from on-site sanitation in the three focus countries of Uganda, Tanzania, and Ghana.

Table 1. Recently documented cases of urban groundwater contamination by on-site sanitation in Uganda, Tanzania, and Ghana.

Country	Reported Contaminants from On-Site Sanitation in Peri-Urban Areas [1]	Reference
Uganda	Nutrient contamination (nitrate of up to 94.6 mg/L; orthophosphate up to 2.4 mg/L) in shallow groundwater in Kampala and Lukaya	[3,9,62]
	Microbiological contamination (*E. coli*, fecal coliforms, viruses, salmonella) detected from springs in Kampala	[18,63]
Tanzania	Nutrient contamination (nitrate of up to 445 mg/L in Dar es Salaam; 449 mg/L in Dodoma; 100 mg/L in Tanga and 180 mg/L in Manyara)	[64]
	Microbial contamination (Fecal coliforms, *E. coli* and fecal streptococci) in Arusha, Dar es Saalam, and Babati	[12,16,65]
Ghana	Nutrient contamination (nitrate of up to 170 mg/L in Volta Region)	[66]
	Microbial contamination (Fecal coliforms, *E. coli*, and salmonella) in Kumasi, Ashanti Region, and Accra	[10,67–69]

[1] Data covering the period of 2010–2020.

From Table 1, it can be noted that *E. coli*, fecal coliforms, and salmonella are widely studied in peri-urban groundwater matrices in SSA. Due to increased access to modern analytical methods in SSA, previously un-detected microbial groundwater contaminants like viruses are also increasingly being analyzed and reported [70]. Chemical contamination has also been well documented, arising from on-site sanitation facilities, especially with respect to nitrate contamination (Table 1). High nutrient (nitrate and phosphorous) and microbial groundwater contamination by on-site sanitation are also widely reported in countries of other regions of the world, including India [4], France [60], and Sweden [61]. Shivendra and Ramaraju [4] reported microbial contamination in the majority of wells sampled from Kanakapura town (India), with nitrate concentration of up to 45.9 mg/L, which is comparable to the Table 1 data. In the developed world setting, there is growing concern over emerging organic and inorganic contaminants, including pharmaceutical and personal care products, which could be attributed to on-site sanitation systems [17,71]. However, there is still limited information on occurrence, distribution, and ecological effects of emerging contaminants in peri-urban groundwater in the SSA context, which could also potentially be attributed to on-site sanitation practices [17,71–73].

The WHO introduced WSPs as a management tool towards identification, reduction, and prevention of such hazards (Table 1) in a water supply system, from catchment to consumer [41]. Rickert et al. [44] provided a simplified WSP process for small communities encompassing six steps from assembling a WSP team, describing the community water supply system, hazard assessment, deriving improvement plans, monitoring, and finally reviewing the WSP process (Figure 2). The process acknowledges consideration of societal and technical factors across the entire catchment, which may affect the quality of a water supply system. The process, thus, attempts to integrate comprehensive technical and socio-institutional aspects influencing risks to water supply stems. A socio-technical approach to resolving groundwater resources challenges has gained prominence due to the complexity of interactions [74,75].

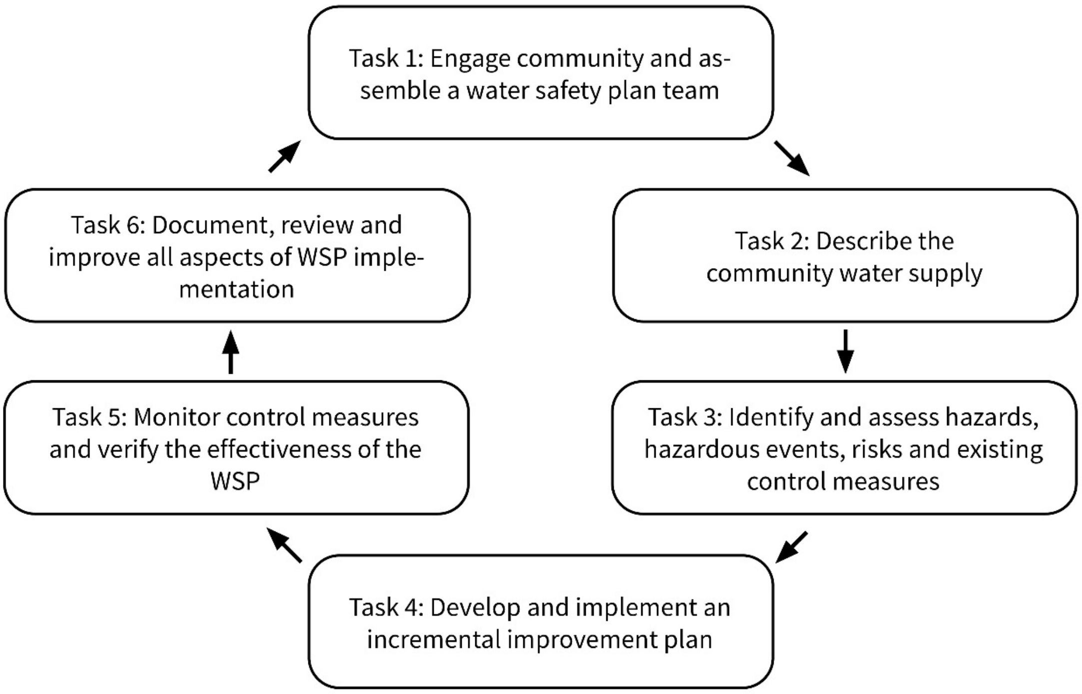

Figure 2. Tasks to develop a Water Safety Plan (WSP) for small communities (adapted from World Health Organization (WHO) [44]).

These socio-technical regime factors, thus, significantly influence the adoption and implementation of technologies, processes, and management tools, such as WSPs. Socio-technical regime factors can be summarized into five dimensions of (1) policy and regulation, (2) institutions, (3) science and technology, (4) user and market dynamics, and (5) socio-cultural considerations [76–78]. Addressing a complex system, therefore, requires careful consideration of both technical and socio-institutional factors influencing the challenge. The WSP process has been implemented in Uganda, Ghana, and Tanzania within the last decades [42,50,51], with varying levels of enabling and inhibiting regime factors, as reviewed in the next section. In assessing a given socio-technical system, it is important to understand the system boundaries or geographical scale [79]. This review focuses on small community groundwater-based supplies in peri-urban areas, which may be part of larger aquifer systems.

4. Challenges of IWRM and Attributes of TM in Implementing WSPs to Reduce Peri-Urban Groundwater Contamination by On-Site Sanitation in SSA

Like many countries in SSA, the existing water regime in Ghana, Uganda, and Tanzania generally follows the principles of IWRM [34,37,38]. IWRM promotes a multi-stakeholder approach to water resources management through a framework of creating an enabling environment, developing management instruments, and defining institutional roles for action [29]. IWRM promotes integrated management of water and land resources through four principles, namely; (1) fresh water is a finite and vulnerable resource, essential to sustain life, development, and the environment; (2) water development and management should be based on a participatory approach, involving users, planners, and policymakers, at all levels; (3) women play a central part in the provision, management, and safeguarding of water; and (4) water has an economic value in all its competing uses and should be recognized as an economic good [29]. These principles have been adopted in the policy and regulation framework, institutional set-up, and influence practices within the water sector in most of SSA. While the explicit implementation of WSPs in SSA is still growing [42,51], there is extensive documentation on implementation of the constituent tasks of the WSP process (Figure 2), influenced by the IWRM regime.

Transition Management, on the other hand, is still unexplored in the context of SSA, despite promising attributes at addressing persistent societal challenges [56,57]. TM has been explored, especially in the global north, in addressing sustainability problems in the transport, energy, water, and environment sectors, among others [56,80,81]. Rotmans and Loorbach [55] summarized eight principles of TM as; (1) creating space for niche developments; (2) empowering the niches; (3) focus on frontrunners; (4) guided variation and selection (system flexibility); (5) radical change in incremental steps; (6) learning by doing and doing by learning; (7) multi-domain approach; and (8) anticipation and adaptation. Transition Management, in practice, is usually implemented through concepts of Transition Management Cycle (TMC), Multi-Level Perspective (MLP), Multi-Phase Perspective (MPP), and Multi-Pattern Approach (MPA), among others [82–84]. The normative attributes of these TM approaches towards re-enforcing the principles and application of IWRM in implementing WSPs for reducing groundwater contamination in peri-urban areas in SSA, are further discussed.

4.1. Policy and Regulation

Ghana enacted the Water Resources Commission Act in 1996, which was the first legislation to embrace IWRM principles of managing water resources through a multidisciplinary and participatory approach [34]. Uganda developed the Water Action Plan in the period 1993–1995, basing on IWRM principles, culminating into the Water Policy of 1999 [85]. Adoption of IWRM principles in Tanzanian legislation can also be dated to as early as 1991, with the first river basin organization (Pangani River Basin Office, Moshi), and later entrenched in the Water Resources Management Act 2009 and the Water Supply and Sanitation Act 2009 [86]. The improved policy and legislation recognized holistic management of activities within a catchment and the interlinkages with the hydrological cycle, including groundwater, within overall sector objectives and documentation. This improved the appreciation of effects of human activities in the catchment on the quality of groundwater, and thus provided a holistic approach for groundwater contamination risk analysis, assessment, and management. This improved policy framework, thus, provided an enabling environment for the introduction of WSPs. Due to this holistic policy framework, Uganda was one of the first countries to adopt WSPs in SSA, undertaken in Kampala in 2005, which resulted in the national framework and guidelines for water source protection in 2013 [47,51]. In Ghana, the first WSPs were implemented in 2014, leading to the national drinking water quality management framework in 2016 [42]. In Tanzania, the first WSPs were undertaken in Dar es Salaam in 2014, and development of national guidelines is still underway [42].

However, in an attempt to include multiple stakeholders and multiple sectors towards water and land resources management, IWRM policies are conceptually diverse, without clear boundaries nor guidance to address specific societal challenges [32,33,87,88]. As a result, groundwater-specific issues have not been adequately addressed in policy and strategic sector direction [32]. Komakech and de Bont [89] pointed out that while the water management policies in Tanzania refer to groundwater protection, anthropogenic contamination of groundwater in urban areas continues unregulated, as depicted in Table 1. Within the maze of many issues affecting water resources management, it is therefore difficult to have sufficient scope analysis for the problem of peri-urban groundwater contamination, thus insufficient risk management strategies. Several pilot interventions on WSP implementation have been undertaken in Uganda, Ghana, and Tanzania, however, they are not specific to groundwater, despite the wide use of groundwater by the peri-urban majority, albeit, a low-income population [42,51,82]. Low funding for WSPs is also a manifestation of low prioritization to water safety, which is even more severe for the groundwater resources [90].

Transition Management approach is a prescriptive, stepwise, approach usually intended for a particular societal persistent (wicked) problem [91]. Loorbach [52] described the Transition Management Cycle to transition society from an undesirable state to a desired equilibrium state through; (a) establishing a transition arena, (b) establishing a transition agenda, (c) experimenting, and (d) monitoring and evaluating progress. Considering the extensive use of groundwater in peri-urban areas, the persistent hazards identified (Table 1) constitute a societal challenge that deserves particular attention. Through a TMC, the problem can be critically analyzed through its historical perspectives, identifying the critical formal and informal stakeholders and thereby addressing all socio-technical aspects. Through incremental steps and effective monitoring, the process is adapted until sustainability on this particular issue is achieved. The Multi-Phase Perspective (MPP) is a tool proposed under TM approaches for monitoring a transition process through stages of pre-development, take-off, acceleration, and finally stabilization, but aiming to avoid undesired scenarios of system lock-in, backlash, or system break down [92]. It is not clear to what extent WSPs have contributed to the elimination of contamination to public water supply systems in SSA, due to limited audits and follow-up processes [47,50]. Specific WSPs for sustainable protection of the groundwater resources against contamination by on-site sanitation in peri-urban areas could also be formulated, and implemented through small incremental steps until sustainability is attained by reduced contamination levels.

The need for prescriptive, flexible policy and regulation arrangements to groundwater management can be drawn from hydropolitics experiences in transboundary aquifer management in the Disi and Guarani aquifers, among others [22,23]. In an effort to address water scarcity in Jordan, a co-operation agreement was negotiated, with several geopolitical tradeoffs, between Jordan and Saudi Arabia for exploitation of the Disi aquifer to supply drinking water to the Jordanian capital, Aman, and other towns [23]. The co-operation agreement between Argentina, Uruguay, Paraguay, and Brazil towards improved management of the shared Guarani aquifer, reached after a decade of negotiations, also shows the benefits of policy specificity to handle a particular problem [22]. These examples from transboundary groundwater management show that specific and flexible policy and regulation instruments are required to address particular groundwater challenges. Thus, specific policies and regulations, within the local hydropilitics of the urban/peri-urban areas, could be helpful towards improved adoption and implementation of WSPs for reducing groundwater contamination.

4.2. Institutions

The IWRM principle of subsidiarity, management of the water resources at the lowest level, has been mainly constructed around catchment/basin organizations. Uganda, Tanzania, and Ghana have all made progress towards operationalizing of the catchment-based institutions, with varying degrees of success [40,85,86]. However, the adequacy of catchment/ basin organizations for groundwater management has been severely contested [37,38,40]. Foster and Ait-Kadi [32] argued that for effective groundwater management, the hydrogeological delineation would serve better than river/lake basin delineation. The effectiveness and coordination between various institutions and governance entities, including town authorities, has not been well addressed [37,93]. Effectiveness of the basin organizations in Uganda, Ghana, and Tanzania is as well in infancy stages, trying to establish legitimacy in the already existing institutional framework [37,40,85]. 'Top-down' centralized planning and control of resources has also remained prevalent in all the countries reviewed, leaving the created basin institutions deprived of technical and financial resources to make meaningful contributions to issues affecting peri-urban areas [37,89,94]. This institutional conundrum, therefore, has resulted in failure to address groundwater contamination challenges in peri-urban areas, among other challenges.

Implementation of WSPs has not been shielded from these institutional challenges. The WSPs developed in Uganda have mainly been undertaken within the National Water and Sewerage Corporation (NWSC), with minimal involvement of external stakeholders in the process [51,95–97]. In Ghana, the implementation of a WSP for a small-town water supply system (Assin Fosu), not operated by the national utility company, showed limited capacity of the local government and community beneficiaries to participate in a formal WSP process effectively [98]. Adoption and implementation of an effective WSP process for community water supplies in a peri-urban area requires a diverse section of actors, owing to the complex interlinkages required to make a sustainable societal change [99]. In Tanzania, Herslund and Mguni [100] argued that the water utility in Dar es Salaam city, the Dar es Salaam Water and Sewerage Corporation (DAWASCO), had done little to improve sanitation in low-income areas, despite high levels of contamination of the groundwater used by the peri-urban communities. This is evidenced by the microbial and nutrient contamination reviewed in Table 1, with a similar situation in urban centers in Uganda and Ghana. From all the cases, there is an institutional vacuum to supporting peri-urban communities in implementing WSPs for water supply options, which are usually off the conventional water supply network.

From TM concepts, the multi-domain principle encourages multiple pathways through both 'top-down' and 'bottom-up' approaches towards realizing an intended societal goal, as advanced by the Multi-Pattern Approach (MPA) [94,99]. The MPA advances a systematic analytic framework for review of different interrelated processes (patterns) aimed at achieving a desired societal goal by a different configuration of structures, cultures, and processes [84,99]. A specific system and its goal must first be defined, and then the relevant stakeholders and actors identified. In this regard, the societal goal is universal access to safe water (SDG 6). Through this approach, the tensions between different agencies in the water management initiatives can be minimized by exploring the most feasible and practical institutional constellation (formal and informal) for achieving the desired goal. De Haan and Rotmans [99] described that transitions could occur along three patterns of empowerment (bottom-up), re-constellation (top-down), or adaptation (internally induced change). Thus, this may include a co-existence of 'bottom-up' approaches aimed at improving community water sources in un-served low-income areas, while advances are also being explored by the existing regime (through public water utilities) for universal network coverage.

The concept of frontrunners can also be helpful to identify individuals from any pertinent organization, with commitment and capacity to contribute to the WSP process. This would ensure diversity of representatives in the process and thus improved community ownership of the processes. This approach is also supported by the attribute of guided variation and selection, which advocates for system flexibility, to devise alternative system configurations where a problem persists. De Haan and Rogers [84] documented several socio-institutional constellations that have been explored to address water management challenges in Melbourne (Australia), emphasizing the need for system flexibility to emerging challenges. Such a flexible institutional configuration, which may involve formal and informal agents towards a particular objective, is also supported by the growing literature on polycentric governance approaches [24–26]. Polycentric structures include multiple, interdependent autonomous agents (formal and informal), with a defined conflict resolution mechanism, working towards a common goal [25,26]. It is argued that polycentric governance approaches offer advantages of a context-specific institutional fit, enhanced system adaptability to emerging challenges, eliminate redundant actors, and improve local participation and accountability [26]. There is therefore sufficient theoretical grounding for an alternative institutional configuration to support community level initiatives for implementation of WSPs to protect their groundwater sources, with collaboration with the local governments and utilities providing water and sanitation services.

4.3. Science and Technology

Through IWRM, research has also been supported to develop and promote groundwater quality management instruments and processes in SSA such as groundwater quality/risk mapping, modelling, and protection/zoning [8,15,94,101]. However, extensive risk analysis for emerging organic and inorganic contamination from on-site sanitation is still limited [71,72]. Aquifer vulnerability assessments have been conducted, mainly through DRASTIC approach (representing parameters of depth, net recharge, aquifer media, soil media, topography, impact of vadose zone and hydraulic conductivity), as a step in the risk management process [15]. Risk assessment tools, mainly Quantitative Microbial Risk Assessment, have also been explored in SSA [67]. However, most of the management instruments/tools developed under the IWRM regime are still techno-centric, being water-sector specific, with limited integration with socio-institutional parameters [1,101,102]. Management instruments that integrate the socio-institutional aspects and hydrogeological assessments are limited, which complicates holistic decision making.

Water professionals have mainly been responsible for the WSP processes in Uganda, Tanzania, and Ghana, where the process tends to focus on the water treatment processes [95,97,98]. For instance, Howard et al. [95] noted that the WSPs should be based on health-based targets and independent surveillance conducted to ensure water safety by the health sector, but in practice, the WSP processes are usually implemented by the water sector. The limited capacity of local governments in participating in the WSPs process in Ghana could also be reviewed as a process left to the water sector [98]. Integration of traditional and non-traditional approaches, from various sectors and actors, could result in new, improved socio-technical approaches [103,104].

Transition Management concepts stem from complex systems theory trying to represent the complex relations between nature, science, society, and technology [55]. Complexity theory contends that such systems tend to be non-linear, continually evolving with changes in the environment and adapt to new situations. It is, thus, usually impossible to generalize or predict system behaviors [99]. Practical experimentation and learning from each experiment to adapt the system to an improved configuration is one of the prime attributes of TM. Peri-urban communities are usually served by groundwater supplies which are off the primary water supply network, thus not included in municipal physical models. Implementation of WSPs for such communities would be implemented in an experimental approach, learning lessons from incremental steps, which can be assimilated by the regime upon demonstrated successes. Such experimentation can be led by any relevant stakeholder, especially in the domain neglected by the primary grid, such as peri-urban areas. This variable approach could result in novel approaches, which could be adopted by the water regime. In analyzing requirements for a transition to sustainable urban wastewater management principles in Stellenbosch Municipality (South Africa), Malisa et al. [103] recommend for adoption of both traditional sources and alternatives such as rainwater harvesting, aquifer storage, and stormwater and wastewater reuse.

4.4. User and Market Dynamics

It is also argued that stakeholder participation under IWRM has been largely focused to institutional and high-level stakeholders, with limited active involvement of lower-level community stakeholders (usually economically vulnerable) in decision making processes [37,87,105]. Stakeholder participation has been promoted through Multi-Stakeholder Platforms (MSPs), in the form of Catchment Management Committees, which are decision making bodies (voluntary or statutory) comprising different stakeholders aimed at interdependence in solving water resources management problems [106,107]. Stakeholders in groundwater should encompass all entities (institutional, individual, association), whose actions directly or indirectly affect groundwater, with or without there consciousness [107]. However, it is noted that individual households are vital sources of peri-urban groundwater contamination, and thus their involvement in key decision-making is crucial to the resolution of the problem. Water User Associations in Uganda were an attempt to involve the communities at the lowest level, but these structures were not supported to grow and remained inactive, especially in urban areas [85]. In Tanzania, Pantaleo et al. [12] showed that despite the high level of microbial contamination in shallow wells in Babati town, the local community was not aware of the contamination, nor the potential risks. The involvement of individual households or local communities in WSP process in SSA has equally been limited [43,51].

The Multi-Level Perspective (MLP) has gained prominence in structuring transition processes at different levels of influence, structured as landscape, regime, and niche levels [82,83]. The landscape level encompasses the external environment, which puts pressure on the regime processes to create space for niche innovations to emerge towards the desired sustainability [82]. In this regard, international commitment to the attainment of SDGs can be regarded as one of the vital landscape pressures influencing national processes to develop innovations at all levels towards the attainment of SDG targets. Such innovations may include implementation of WSPs to improve community water sources in peri-urban areas, which have previously been abandoned by the urban water utilities. The national processes (socio-technical regime) need to allow for protected spaces (niches) for various innovations to incubate, which can be assimilated by the regime upon successful demonstration [83]. Creating space for niches and empowering them significantly improves community participation at the lowest level of society, as emphasized by the TM approach. Niches are created at the local level, with the participation of willing individuals. Frontrunners, as well, could be derived from the community, which offers an opportunity for individual participation in vision creation and decision making. Poustie et al. [80] shared experiences in designing a transition experiment for leapfrogging to sustainable urban water management in the city of Port Vila through niche experiments. Through a TM process, it was analyzed that unsustainability of the urban water infrastructure in Port Vila was as a result of the focus on technical and institutional capacities, with limited stakeholder networks and collaborations. Participation in a new vision creation and transition pathways analysis was achieved through a transition arena composed of community members, state actors, and private sector actors. Individual households could, therefore, through such an approach, be engaged to champion sustainability transition towards improved on-site sanitation facilities to reduce the risk of peri-urban groundwater contamination.

Implementation of the IWRM economic principle (polluter-pays-principle) also remains to be effective in SSA and almost non-existent for peri-urban groundwater context, which is affected by communities with limited economic capacity to pay. Groundwater management strategies should take into consideration the socio-economic position of the community [20,27]. Even in the conventional utility networks, raising resources for WSPs is a cross-cutting challenge [47,51,96]. Komakech and de Bont [89] attested to the inability of peri-urban communities in Tanzania to pay for such services. The principle would essentially imply that individual households owning the on-site sanitation facilities would meet the costs of implementing the WSP. While the principle may be applicable to industrial discharges, it is impractical to implement for community-level sources, such as unlined pit latrines and illicit municipal waste dumping by impoverished communities. Through the system flexibility principle of TM approach, "polluter-pays-principle" in the context of peri-urban groundwater management can be assessed depending upon the community characteristics such as willingness and ability to pay for such services; the level of existing public sanitation infrastructure in the area and settlement (housing) patterns. An alternative framework for compensating polluting activities could be assessed and recommended for the peri-urban areas depending upon the economic vulnerability of the population. An example of promoting resource recovery approaches to a circular economy in the Dutch wastewater system transition demonstrates a policy shift from "polluter-pays-principle" [108]. In this regard, a WSP process that advocates for resource recovery from the on-site products would be recommended. The recovered products could then be marketed for nutrient recovery in agricultural production and energy recovery, which benefits the society [6,61], in comparison to requesting the community to pay for the pollution. The economic principle of IWRM has found limited application to groundwater, especially in low-income communities, thus, system flexibility is required to find alternative remedies.

4.5. Socio-Cultural Considerations

Under IWRM, adequate consideration of socio-cultural aspects in the prevention of groundwater contamination in peri-urban areas in SSA has been rather limited [105,109]. Yeleliere et al. [110] highlighted the immense challenges of implementing integrated water resources policies in regulating peri-urban groundwater pollution in Ghana due to a disconnect with the customary practices in the region, which regulated equitable access to water resources and prevented community contamination of water resources. Such customary practices (like customary rights over water and gender customs in water utilization) are usually addressed by informal stakeholders such as traditional leaders, community elders, and unregistered well drillers (and diggers), who are unregulated by the regime, yet influential to a certain extent considering their high numbers in the SSA context [105,109]. Mapunda et al. [111] estimated that over 68% of the population from 20 cities in Tanzania is covered by informal providers, mainly from unregulated groundwater sources, which are not part of the city public water infrastructure. Such informal services are, thus, operated through social-cultural arrangements for water pricing, pollution control, operational schedules, and protection against vandalism. Culture (socio and institutional) issues have found limited space in the WSP processes to date [112]. Van Koppen et al. [86] argued that the implementation of IWRM in Tanzania removed the customary rights to water enshrined in previous arrangements. Consideration of socio-cultural factors in the implementation of WSPs in SSA has equally been limited, primarily focused on the technical factors [112].

Creating space for niches and empowering the niches to develop at the community level, as advocated by TM approaches, provides for an opportunity to incorporate and address socio-cultural issues, particular to the society [57]. These may include customary rights and practices to water and sanitation, and customary land ownership, which may influence groundwater protection zoning and community mobilization towards water source protection [57,105]. In assessing strategies for developing the transformative capacity of the urban water management sector in the city of Melbourne (Australia), Brodnik and Rebekha [113] emphasized the inclusion of organizational and socio-cultural factors in the transition process. Geels [82] also stressed the relevance of niche level innovations in achieving a transition process, usually emanating from the community, well grounded in the societal socio-cultural practices. Mukherji and Shah [28] also present strong arguments for active involvement of community users in groundwater management, drawing on experiences from India, Pakistan, Bangladesh, China, Spain, and Mexico, which have intensive use of groundwater.

However, the TM approach is also faced with unresolved socio-institutional challenges, including limited regard of "politics, power, and conflicts" in achieving democratic participation and ensuring equal and influential participation of weaker members of society in transition processes [56,114]. Other noted challenges include uncertainty in the framing of regimes and system boundaries, low legitimacy of frontrunners, concern for individual perspectives, and inadequate capacity for steering and monitoring societal changes [56]. Considering the complexity of the problems addressed in TM, the development of appropriate management instruments is a work-in-progress [84]. Globally, there are also still limited empirical prescriptive interventions by TM. In view of these limitations, TM alone, as well, may not be the "silver bullet" to addressing the complex dynamic challenge of peri-urban groundwater contamination in SSA. A complementary approach harnessing attributes of both IWRM and TM could offer complementarity towards improved uptake and implementation of WSPs for peri-urban groundwater management.

5. Proposal for a Risk-Based Management Framework towards Reducing Peri-Urban Groundwater Contamination by On-Site Sanitation in SSA

Remedies to complex problems need an interdisciplinary and multifaceted approach [33]. While several studies have advocated for alternative approaches to IWRM [33,39,88], in light of the achievements and gains realized in the global efforts in the implementation of IWRM, others have argued for the strengthening of the concept with attributes of emerging frameworks in order to address emerging challenges [30,38,40]. From the achievements of IWRM in Uganda, Tanzania, and Ghana, this review advocates for strengthening of IWRM towards addressing the challenge of peri-urban groundwater contamination by on-site sanitation. From the analysis of attributes of IWRM and TM, a unified risk-based management framework is proposed towards improved adoption and implementation of WSPs for reducing groundwater contamination from peri-urban areas in SSA (Figure 3).

The socio-technical regime factors that influence groundwater contamination in peri-urban areas in SSA are presented in Figure 3, described with a simplified Entity-Relationship Diagramming (ERD) approach. These factors must be taken into consideration when designing the WSP process for protecting peri-urban groundwater sources against contamination from on-site sanitation. The tenets of natural resources sustainability are hinged on the balance between economic efficiency, social equity and environmental (ecological) sustainability, as advocated by IWRM. TM approach emphasizes a prescriptive approach, which should target a particular persistent societal problem. The proposed framework is, thus, envisioned to contributed to reduce peri-urban groundwater contamination by on-site sanitation. The attributes of this vision are hinged on the sustainability tenets of ecological sustainability, social equity, and economic efficiency. Simultaneous maximization of the three attributes, as suggested by IWRM, has not been practical, leading to ambiguity in actions [33,36]. Giordano and Shah [88] advocated for context-specific approaches in consideration of the attributes. In this context, considering the social-economic marginalization of peri-urban communities, it can be argued that the proposed framework maximizes social equity, while taking into reasonable consideration the economic and ecological attributes. The focus on social equity is also in accordance with the transformative principle of the SDGs of "leave no one behind" [5].

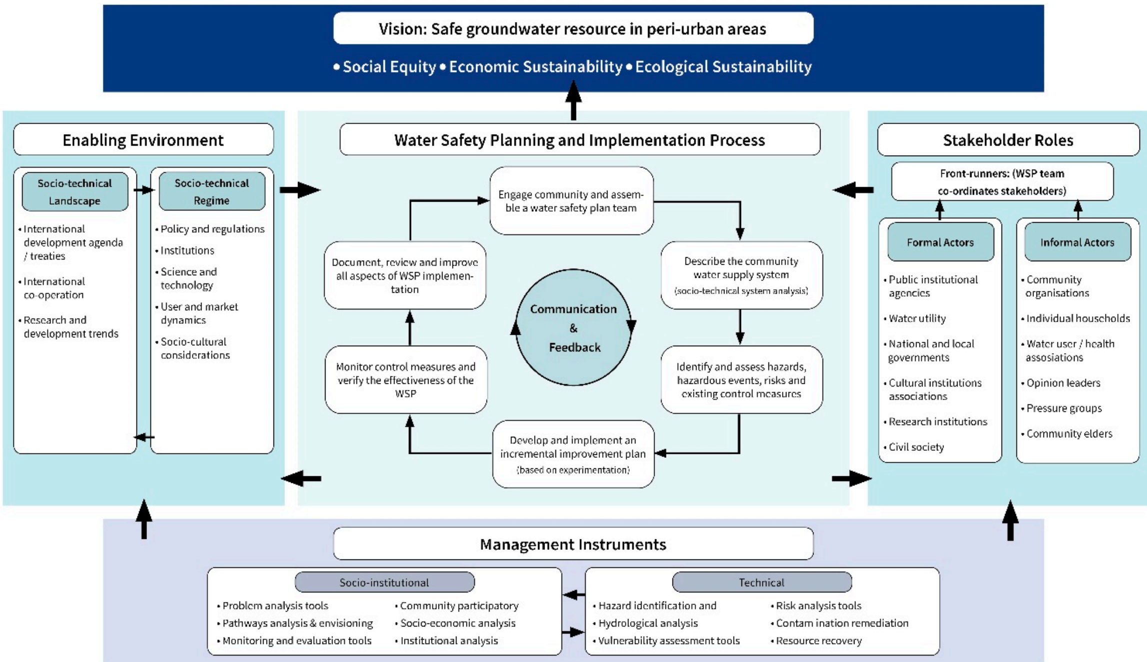

Figure 3. Proposed risk-based management framework for reducing groundwater contamination by on-site sanitation peri-urban Sub-Saharan Africa (SSA) (Adapted from [29,44,52,82]).

The WSP process is in line with the WHO process for small communities [44]. The WSP team may represent the frontrunners, according to TM approach, who follow the process through. The team should be composed of stakeholders from diverse background, different sections of the community, institutions, and leaders, with willingness and ability to participate in the process [56]. In describing the water supply system, both technical and socio-institutional factors affecting community water supply need to be critically analyzed. The Catchment Management Committees, developed under IWRM approaches, have been critiqued for the limited representation of vulnerable community members, power imbalances in decision making, and high cost of operationalizing the committees [106]. The MLP perspective offers a structured approach in analyzing the system components at landscape, regime, and niche levels, ensuring effective representation from all levels. The niche level initiatives at community level, to some extent, address representation and power imbalances. Improved socio-technical management processes and instruments should be used to comprehensively identify and assess hazards, hazardous events, risks, and existing control measures. Experimental measures should be explored, including radical steps, which may not be in the main system configuration, but demonstrated to improve water safety of the peri-urban communities. The process and activities should be monitored, along the MPP approach, with a focus on the sustainability goal [83]. All aspects of the WSP process are continually reviewed and adapted to emerging situations and the process is repeated continuously to achieve sustainable reduction of groundwater contamination from on-site sanitation. Throughout the WSP process, communication and feedback to and from all stakeholders is emphasized, while continually adapting tools, processes, and focus to emerging hazards and events. This continuous influence and adapting of processes are reflected in the bi-directional influence arrows between the various entities in Figure 3.

As postulated by IWRM, the process is influenced by a framework of 'enabling environment', 'management instruments', and 'institutional roles' [29]. Using concepts of TM approach, these elements are re-enforced for practical analysis and formulation of strategies for reducing groundwater contamination in peri-urban areas by on-site sanitation. In the enabling environment, the MLP differentiates between the socio-technical landscape and socio-technical regime to influence transitions towards sustainability. The landscape pressures, including international development agenda (SDGs), multinational development agencies, and international political/trade treaties are avenues for influencing regimes towards the sustainable achievement of groundwater quality. IWRM has been strong at mobilizing the international agenda towards holistic management of water resources [30,36]. The socio-technical regime, comprised of national level policies, structures, political dynamics, user preferences, national development, and cultures, can be rallied towards the support of groundwater protection initiatives. While the external environment influences the contamination risk management process, emerging innovations should equally impact the external environment for improved adaptation of the entire system. This provides for the possibility of upscaling promising niche level experiments to be adopted by the system regime and subsequently, the landscape level. This also ensures continuous adaptation of the landscape and regime forces towards emerging situations.

An array of stakeholders from both formal (under regulation by the regime) and informal (unregulated by the regime) settings, derived from the individual level, the national level, and the international level, are required for driving the transition towards the reduction of peri-urban groundwater contamination by on-site sanitation in SSA. This polycentric arrangement would enable a resilient and accountable institutional framework to support the particular challenges faced by peri-urban communities in managing groundwater resources. Management boundaries need to be specified between different stakeholders to avoid scenarios of inaction and conflicts. While IWRM advocates for catchment-based boundary systems, TM advocates for flexibility in setting the boundary of assessment, depending upon a given challenge. The peri-urban areas could be assessed as a specific sub-system, with particular socio-economic characteristics, within the overall urban water supply system. TM advocates for an approach that starts at the lowest community level, within the existing societal arrangements for change action. The informal arrangements with the community need to be given due consideration for any management arrangements proposed for implementation of the WSP.

Appropriate socio-technical management instruments are required to manage the entire process, stakeholders, and the environment towards realization of the sustainability objective. Prediction and modelling tools and techniques developed under IWRM could be strengthened, which could be used to study the overall system, including the technical and socio-institutional aspects and the complex interactions towards achieving the desired sustainability goal. Such management tools may include laboratory analysis techniques, problem analysis tools, pathways analysis tools such as back-casting, and vulnerability assessment tools. The process of tools development is continuous with knowledge advancement. Experimentation with various processes and adaptation of the WSP process to emerging issues from the peri-urban communities is an integral part of the process.

6. Conclusions

Groundwater is a vital resource for most of the population in low-income peri-urban areas in SSA. However, the resource is threatened by increasing contamination arising from on-site sanitation facilities, in light of a growing population. From the review of literature, it is evident that microbial and chemical contamination is prevalent and well documented in SSA. The WHO introduced WSPs to assist communities to manage such contamination by managing the technical and socio processes from catchments to the water user. However, adoption and implementation of the WSPs have been met with several successes and challenges influenced by the existing management framework (regime), which is aligned to the IWRM principles [36,37,85].

IWRM introduced improved holistic water resource management policies, improved public participation, improved management tools, and gender-sensitive approaches, which provided an enabling environment for the adoption of WSPs, which were multi-stakeholder by design [44]. However, implementation of IWRM has had a low focus on groundwater-specific problems and implemented through an incoherent institutional framework based on catchment management structures within already existing governance structures. The practicality of such structures to address groundwater-specific issues has been severely questioned [34,37]. The management instruments developed under IWRM have also, to date, remained techno-centric, with limited integration of socio-technical factors. There has also been limited regard for socio-cultural aspects and the economically vulnerable society segments, reflected in low financing of WSPs initiatives [51,98]. These limitations have affected the adoption and implementation of WSPs for groundwater interventions in peri-urban areas in SSA. The WSPs have been mainly implemented by urban water utilities for the conventional piped water supplies, with no consideration to community sources within the peri-urban areas.

TM advances normative strengths of long-term planning for societal transformation and implementation of the plan through incremental short-term measures, which has shown promise at addressing such complex adaptive systems. It provides a prescriptive approach, which targets a particular societal concern and works towards a shared vision, guided by frontrunners, which addresses the challenge of system diversity. TM processes are also multi-domain and flexible to institutional and actor dynamics, with emphasis on community-level (niche) initiatives [82]. These attributes can eliminate institutional tensions, ensure incorporation of community vulnerable persons, and integration of socio-cultural elements in a transition process towards the elimination of groundwater contamination. The process is improved through learning by doing and doing by learning, through a multi-domain approach, further adapting the system in light of increased pressures like increased urbanization and climate change. The normative strengths proposed by TM are consistent with emerging approaches in polycentric governance approaches, postulated to improve system adaptability to emerging challenges and accountability for results to the local population in attainment of set goals.

Based on the normative strengths of IWRM and TM, a unified risk-based management framework is advanced by this review towards the improved adoption and implementation of WSPs for reducing peri-urban groundwater contamination from on-site sanitation in SSA. The framework strengthens the vision of the WSP process, illuminates the enabling environment along landscape and regime aspects while refining the WSP process at the community level for incremental steps towards sustainability. Socio-technical management instruments are identified, which could be strengthened and applied in improved WSP implementation. The stakeholders, coordinated by a specific team of frontrunners, are also structured into formal and informal stakeholders towards improved WSP process implementation to emphasize community-level interventions. Experimentation of the proposed framework is recommended for empirical validation, which could then be adopted towards the improved implementation of WSPs for reducing groundwater contamination by on-site sanitation in peri-urban SSA, in the effort towards attaining sustainable development goal number 6 for universal access to safe water.

Key research gaps identified by the review include; the need for a further understanding of emerging contaminants in peri-urban groundwater, in light of increased urbanization, which have not been addressed by the WSP processes. There is also need for further assessment of the context and regional specific socio-institutional factors influencing adoption and implementation of WSPs in addressing the persistent challenge of groundwater contamination by on-site sanitation in SSA, such as cultures, power imbalances, societal practices, which differ between various socio-technical settings. While the integration of TM and IWRM approaches for improved implementation of WSPs is recommended, tensions between attributes of the approaches may also arise, which need further study through experimentation. There are also limited management instruments that incorporate analysis of socio-technical aspects of groundwater contamination, in the light of emerging challenges.

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