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Integrated Water Resource Management: Rethinking the Contribution of Rainwater Harvesting

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Abstract: Rainwater harvesting (RWH) is generally perceived as a promising cost-effective alternative water resource for potable and non-potable uses (water augmentation) and for reducing flood risks. The performance of RWH systems has been evaluated for various purposes over the past few decades. These systems certainly provide economic, environmental, and technological benefits of water uses. However, regarding RWH just as an effective alternative water supply to deal with the water scarcity is a mistake. The present communication advocates for a systematic RWH and partial infiltration wherever and whenever rain falls. By doing so, the detrimental effects of flooding are reduced, groundwater is recharged, water for agriculture and livestock is stored, and conventional water sources are saved. In other words, RWH should be at the heart of water management worldwide. The realization of this goal is easy even under low-resource situations, as infiltration pits and small dams can be constructed with local skills and materials.

Keywords: infiltration pits; Kilimanjaro concept; rainwater harvesting; storage tank; water management

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1. Introduction

In 2015, the United Nations (UN) Sustainable Development Goals (SDGs) were adopted to substantially improve the human well-being by 2030 [1,2]. The UN SDGs consist of 17 goals, of which two focus explicitly on water: (i) Goal 6, "Ensure availability and sustainable management of water and sanitation for all", and (ii) Goal 14, "Conserve and sustainably use the oceans, seas and marine resources for sustainable development". Both goals call for: (i) avoiding water pollution, (ii) improving and/or restoring water quality, and (iii) protecting and/or restoring water-related ecosystems worldwide. This implies a reconsideration of water management at all scales, including household, small community, city, and national and international levels. With such an approach, enhancing groundwater recharge and reducing aquatic pollution start at household level, with each individual world citizen being involved, including those living in the slums of Durban

(South Africa) and even in the best squares of Peking (China). Given the timeframe of only 10 years (2021–2030), progress towards fulfilling the two named SDGs requires that existing knowledge is effectively translated into practical solutions within this short time period [2–4].

Existing knowledge is not only scholarly, but also includes indigenous knowledge systems that have served communities long before formal scientific knowledge [5–9]. To recall this, the German word for science will be analyzed. Science is called Wissenschaft and is composed of "Wissen" (knowledge) and "schaffen" (to create). In other words, according to the German way of thinking, science is the "art to create knowledge". This communication advocates for the use of both indigenous and scholarly knowledge to boost and fast-track the achievement of both Goal 6 and Goal 14 of the SDGs. Clearly, it is about locally applying existing knowledge for: (i) making water available, (ii) avoiding water pollution, (iii) treating polluted water, (iv) harvesting, storing and infiltrating rainwater, and (v) gravity transporting the water in channels from the point of generation to the point of use (or treatment). Starting water management at the local level implies, for instance, that rainwater should be used where and when it falls [5], and not only be reused or managed where it is posing human health risks and disasters (e.g., generating floods) [3,10]. For example, harvesting and using rainwater in the hills of the highlands of Ethiopia immediately contribute to mitigating flooding in the Nile Valley in Egypt.

The present communication is focused on rainwater harvesting (RWH). It is considered that by using available water treatment technologies, and adsorption in particular, water and wastewater can be effectively treated everywhere and in an affordable decentralized manner [11–16]. Such affordable technologies for safe drinking water provision include filtration on beds filled with biochar [14,15] and metallic iron [16]. This implies that RWH should be regarded as a stand-alone technology for water supply, including safe drinking water provision. Clearly, this communication is not discussing whether rainwater (RW) is used as source of potable water or not, because RW is far cleaner than many other natural sources (e.g., lakes, rivers, wells), and can thus always be treated to meet drinking quality [3,17–22].

The objective of this communication is to demonstrate that despite the broad application of RWH worldwide, rainwater is still an underestimated and thus under exploited "help from above" [18,23,24] in integrated water management. RWH is acknowledged as an option for decentralized water provision, but debates exist about its benefits and costs [25,26]. Moreover, even in developed countries, there are still doubts about its relevance, mainly because the way of supplying water in many of these countries is based on a centralized infrastructure and a single use of water [27,28]. This centralized option results from a major historical development: RW has been downgraded to a disturbing resource or nuisance, augmenting the volume of greywater and causing/intensifying flooding [3]. Accordingly, channeling RW as quickly as possible to the next water course via drainage systems has been a noble objective for several decades [29]. A U-turn is now necessary to use the huge potential of RWH in integrated water management on a global scale [3,20,21].

The paper is organized as follows: Section 2 presents an overview on the current status of RWH in the literature, Section 3 introduces a new theory to manage rainwater, Section 4 answers the question whether or not RWH can globally address the issue of water scarcity, and finally, Section 5 presents concluding remarks.

2. The Status of RWH in the Scientific Literature

The current status of RWH is directly related to the development of European cities during the 19th century [29–31]. The outbreaks of water-borne diseases (e.g., cholera) had motivated the introduction of centralized wastewater management systems [30–33], and since then, rainwater is mostly regarded as disturbing factor for water management [29,31]. This view dominates the scientific literature on water management which can be regarded as the "extended" science of European urbanization, or the conventional or dominant paradigm. In this paradigm, everything else including indigenous knowledge systems on rainwater management is regarded as an alternative and not always part of the mainstream science [5,8,28].

Prior to the 1950s, the main sources of water supply were local, and included surface water, groundwater, and rainwater [3,5]. As the size of the cities grew and urban areas became populated, the concentration of human and animal feces in urban areas resulted in the contamination of surface waters and the outbreaks of devastating diseases such as cholera and typhoid fever. The solution to these unhealthy conditions involved the provision of piped water supply and the construction of a sewage network to evacuate human feces. As cities continually grew, more water was needed and distant water sources were sought and large-scale infrastructures were built [3,5]. Local water sources, including rainwater, were progressively abandoned and scientifically justified to the extent that today, there are efforts to pipe distant waters for centralized water supply in scattered small communities (non-densely populated) [14–16]. It is in this effort that decentralized safe water management arose as a novelty, mostly using so-called low-technology solutions.

Similar to water management, there is a recent global trend to decentralize the supply of energy (e.g., gas, electricity, oil) and telecommunication systems [28,32]. In this effort, technology transfer from developed countries to developing countries is expected to play a key role [2,34]. The decentralization of telecommunications in terms of decentralized finance and mobile phones can be regarded as already accomplished [35,36]. The decentralization of energy and water supply is far from accomplished, and the lack of appropriate technologies is certainly a key issue [34,37,38]. However, while special skills are required to transform all kinds of energetic raw materials (e.g., coal, sun, water) to electricity, water is available everywhere and sometimes already of drinking quality [33,39]. Moreover, affordable safe drinking water technologies (e.g., filtration on biochar and metallic iron) have been developed and used for decades [12,14–16,40,41]. Interested readers are referred to Kearns et al. [14,16] or Yang et al. [15], who give an excellent overview on the state-of-the-art knowledge on treating natural water using biochar and metallic iron, respectively. Therefore, the achievement of universal access to safe drinking water (Goal 6.1) through decentralized drinking water provision should be an easy task [16,41]. All what is needed is to revisit the approach, and the status of local water sources such as rainwater. It should be avoided that rainwater totally becomes stormwater (Figure 1). In other words, there is a need to both theorize and operationalize the management of rainwater.

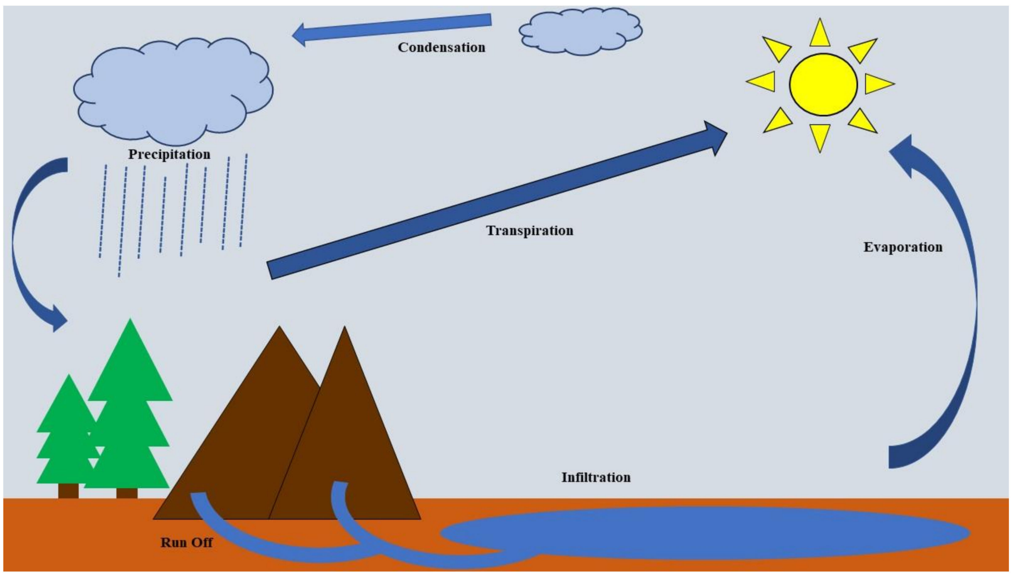

Figure 1. The simplified hydrological cycle depicting the main water reservoirs (groundwater, sea, soil) and the flow of water through the system (evaporation, infiltration, rainwater, runoff, groundwater recharge via deep percolation).

Banerji and Chaudhari [42,43] summarized the selection criteria for the suitability of technologies for decentralized safe drinking water supply as follows: (i) simple to operate (no special skilled personnel required), (ii) robust (gives consistent performance), (iii) low cost or affordable for villagers with low average incomes, (iv) able to function without electricity, (v) based on local resources and skills, and (vi) accessible to community and women's groups or the village elders. These criteria conventionally guide the selection of technologies to treat water made available from lakes, streams, rivers, springs, or wells. These water sources are usually more polluted than rainwater [21] that can be harvested and stored locally, even at a household level. In other words, it is not only about treating water in decentralized manner, but first locally making water available.

Increasing urbanization results in the removal of vegetation and the expansion of impermeable surfaces (including buildings, roads). The net result is an enhanced volume of runoff (e.g., increase soil erosion and flooding risks) and a reduced infiltration (e.g., less groundwater recharge) [3,44,45]. Because climate change will impact rainfall patterns, the need to maintain a sustainable water supply in future has motivated the development of new water management strategies in which recycling and reusing stormwater are key issues [46]. At least three different strategies have been developed to increase rainwater storage: (i) sponge city (China) [47,48], (ii) sustainable urban drainage systems (SUDS) (UK) [49], (iii) and low-impact development (LID) (USA) [10,26]. Interested readers are referred to Zabidi et al. [26], who give an excellent overview on the state-of-the-art knowledge on rainwater management. The same authors insist on the importance of ensuring water security in Sustainable Urban Drainage Systems (SUDS) by including a range of drainage techniques and devices. Related systems allow pollution mitigation, runoff attenuation, and water channeling to detention basins, infiltration trenches, treatment stations, and wetlands. However, the reasoning is still centered on urban areas and is thus not really holistic or universally applicable because it excludes rural areas and informal settlements such as slums and refugee camps. As Figure 1 presents rainwater as the source of all waters on earth, a truly holistic rainwater management should be applicable everywhere and address means to delay or minimize surface runoff, and increase water infiltration. It is recalled that surface runoff feeds rivers and water bodies supporting essential ecosystems. It is certain that the best infrastructures for RWH should not totally eliminate surface runoff. The aim of this concept is to mitigate flooding by maximizing the harvesting of surface runoff for eventual controlled infiltration [3].

3. The True Value of Rainfall

3.1. The History of RWH

RWH systems are designed and operated to collect, store, and use rainwater as a primary or supplementary water source. RWH systems are known in all cultures, and the simplest systems are easy to construct, operate, and maintain [3,5,50–53]. For a given climatic condition, the harvested water volume depends on the rainfall characteristics, catchment area, and the storage capacity of the artificial or natural reservoir [50,52]. Traditional RWH has the ability to operate independently of central water supply systems at a household level, but systems operating at the community and regional level are well-known [8,22]. This communication focuses on small-scale rainwater harvesting systems using rainwater collected primarily in individual compounds for use by the land's occupants or owners. The rationale is that each land's occupant is a critical part of the puzzle in the effort for systematic water management based on RWH.

RWH has a very long history, which is reviewed in detail for India by Pandey et al. [5]. The basic design of a community RWH system involves a large rock formed into a basin, with clay and rocks to seal it from leaking. Then, varying diversion tools are used to channel rainwater to the basin and stored water is used for agriculture, drinking, livestock watering, washing, and other household and productive uses. Gould and Nissen-Petersen [52] give examples of systems dating back to 2000 BC in Egypt, India, and Israel (Negev desert). Examples of household and community rainwater harvesting systems are found in almost all regions of the world [8,22,50–52]. According to Figure 1, flooding water is non-harvested (and non-infiltrated) rainwater and was already exploited in ancient Egypt. In those days, an annual 4-month period of the flooded Nile supplied water for all-seasons agriculture. Clearly, the ancient Egyptians developed skills to use irrigation canals and exploit flooding water for agriculture. This marked the starting point for the emergence of Egyptian civilization [54]. In other words, not knowing that flooding waters were from regions as far as Burundian hills and Ethiopian highlands, a sustainable agricultural system was built on their regular availability [54].

All ancient civilizations stored rainwater runoff and natural flow from hills and mountains to use at community scales (e.g., individual villages and groups of villages) [4,5,8]. In some regions (e.g., the Mandara hills in Cameroon and Nigeria, in hills of Mexico), underground reservoirs were used for collecting rainwater [3]. From the 16th century onwards, people began to preferentially use rainwater for laundry because it is naturally soft (low in minerals) [55]. As cities and communities were growing, the storage tanks and cisterns increased in size and harvested water became more and more contaminated with pathogens and suspended solids. The presence of pathogens led to the spreading of water-borne diseases [55]. Modern analytical tools for water analysis were not yet available and technologies to remove bacteria were lacking [56]. It is in this context that a centralized water supply was introduced as primary source for all water needs [32]. A negative side effect was that rainwater became a waste, augmenting urban stormwater, for example. This paradigm is still prevailing [26,32].

3.2. RWH Today

The presentation until now can be summarized in a short statement: "downgrading rainwater to a waste was a careless option". The simplest proof for this is that on many small islands and archipelagos around the world, rainfall has been the sole drinking water source for millennia [19,57–59]. In addition, in many cases where natural water is polluted by geogenic contaminants such as arsenic or fluoride, rainwater has been successfully used as a safe drinking water source [3,17,18]. In several low-income communities lacking access to centralized treated drinking water, rainwater harvested from roofs is used as the sole source of drinking water during rainfall events. This is because surface water and shallow groundwater sources are heavily contaminated with suspended solids and other contaminants during such rainfall events. In other words, there is no scientific reason to regard rainwater as a low-quality option. Even the absence of minerals in rainwater cannot justify the exclusion of rainwater from water supply because such minerals are often present in foods such as vegetables [55]. The improvement in the availability of water storage infrastructures [3,22] and the availability of affordable water treatment technologies [14–16] justify that RWH should be regarded as a good source of safe drinking water, not only under unfavorable conditions [3,60].

Current issues with collecting, storing, and using rainwater are all biased because of the century-old scholarly "knowledge" described above. This mistaken view is about to be corrected as RWH is now emerging as an option for water supply in residential, commercial, and agricultural applications [22,60]. This is a unique chance to cease relying on centralized water utilities or costly boreholes [28]. However, using harvested rainwater is not just "augmenting" water, but also saving a precious resource as local infiltration is improved and pollution of runoff is reduced, while minimizing flooding risks and associated human and environmental impacts [3,8]. There is no need to discuss the following issues herein: (i) efficiency of RWH systems, (ii) challenges on controlling and monitoring related systems, as well as (iii) reliability, resiliency, and vulnerability of RWH systems. In fact, compared to the current paradigm, the holistic approach just optimizes water management and all available tools will be applied on a site-specific basis. Furthermore, there are uncertainties due to climate change such as high temporal variability of rainfall which cannot be foreseen. Such uncertainties can be addressed by systematic rainwater harvesting, when and where it falls.

3.3. The Bright Future of RWH

The communication until now has demonstrated that rainwater is a valuable resource and that its collection and use should be intensified. The impressive advances in technology over the past decades now make likely the realization of King Parakramabahu of Sri Lanka (12th century), who wished for the building of a massive network of rainwater harvesting reservoirs in order to "*Let no drop of water flow to the sea unused by man*" [8]. Intensive RWH programs are currently being developed in India [8] and in a few other countries such as Ethiopia [9]. However, the perception persists as to whether this approach provides a sustainable alternative in the modern world [8]. In the developed world, despite the development of excellent strategies for stormwater management (e.g., LID, sponge city, SUDS) during the past two to three decades [26], their real implementation is still suffering from the lack of a regulatory framework [28,29]. However, as discussed herein, some existing regulatory policies are based on wrong scientific information on rainwater quality.

It is certain that RWH does not increase the overall water availability within a basin [8]. However, using modern storage and transportation tools, the distribution of water between upstream and downstream users as well as between socioeconomic and environmental demands can be regulated. Moreover, harvested rainwater can be transported from one basin to another through inter-basin transfers. The decision on where water should be transported from and to depends on the profound understanding of the water balances within the related basins, and on how the water resources shape the social and economic landscape (i.e., water uses).

Finally, using Figure 1, the way the bright future of RWH can be shaped through a number of measures as follows: (i) maximize RWH everywhere, such as through large storage devices (measure 1), (ii) maximize groundwater recharge everywhere such as through the construction of large infiltration systems (measure 2), (iii) minimize runoff volume (measure 3), and (iv) channel harvested rainwater to point of use, including water distribution tanks (measure 4) [23,24]. Measures 1 and 2 already reduce runoff, but stormwater ponds are needed even where infiltration is impossible. In reality, such ponds are evaporation pans, but help in avoiding/alleviating flooding.

Individually and collectively, measure 1 to 3 contribute to combat flooding, and all the four measures together correspond to "water augmentation" with the subtle but essential difference that treated rainwater can be piped into a central distribution network, as is already the case on small islands [22].

This communication advocates for global solidarity in water management through structured rainwater harvesting. The simplest and most common RWH system consists of a gutter, a bucket, and several storage containers in a residence. This domestic rainwater harvesting system, augmented with infiltration pits, is now to be implemented on a global scale, on a basin- by-basin level. In each basin, RWH is maximized and direct runoff minimized. Harvested rainwater can be infiltrated, transferred to other basins, or be locally evaporated. In all cases, flooding risks and soil erosion are minimized.

4. Can Rainwater Harvesting Address Problems of Water Scarcity?

Aquifer depletion and groundwater salinization are global problems, and RWH is considered to be a powerful countermeasure to address these crucial issues [20,61]. Accordingly, ancient RWH technologies have been revived and new ones developed to increase water availability by two main ways: (i) using harvested rainwater and thus limiting groundwater abstraction, and (ii) performing artificial groundwater recharge [62]. The hydrological cycle supports that these ancient technologies are a sustainable water management tool, even under modern socioeconomic and environmental pressures. This clear and simple answer may be regarded as simplistic in a context where understanding and quantifying the socioeconomic and environmental impacts associated with the installation and operation of these systems can be regarded as lacking [8,63]. However, rainfall is the main water source in the hydrological cycle. Considering the surface water balance as "Rainfall = Evaporation + Infiltration + Runoff" (Figure 1) implies that the best water management strategy should be rooted in how to take the maximum advantage of rainfall. In other words, wherever rain falls, affordable household and community-level water infiltration and storage (RWH) certainly play a valuable role in alleviating water scarcity, and thus improving food security even for small-scale farmers [3,5,8,24,64]. Accordingly, RWH is not just one part of an integrated plan to maximize water availability, but rather the heart of a new water management paradigm.

5. Conclusions

In ancient times, rainwater harvesting (RWH) was more common under all climatic conditions. RWH started to decline in Europe around 1850 and this state of affairs has been transferred elsewhere, including in China and India, where RHW has a very long and continuous history [5,50]. The present and changing climatic conditions call for a worldwide solidarity in avoiding water pollution and sustaining groundwater recharge through systematic RWH and controlled infiltration. From a local perspective, the advantages of RWH remain valid for small-scale farmers in semi-arid areas. However, on a small community scale, institutional and scientific support is needed to start related new projects. In realizing these projects, both indigenous and scholarly knowledge is needed. This paper calls for a global cooperation between scientists and practitioners involved in rainwater harvesting. In learning from available successes and improving them with transferrable aspects, a high degree of sustainability might be reached. Such a level of sustainability is similar to that which apparently existed in the past in many societies, and is regarded here as the cornerstone for the achievement of Goals 6 and 14 of the UN SGDs.

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References

1. Transforming Our World: The 2030 Agenda for Sustainable Development. Resolution adopted by the UN General Assembly, 25 September 2015. Available online: https://sustainabledevelopment.un.org/post2015/transformingourworld (accessed on 6 November 2015).
2. Hering, J.G.; Maag, S.; Schnoor, J.L. A call for synthesis of water research to achieve the sustainable development goals by 2030. *Environ. Sci. Technol.* **2016**, *50*, 6122–6123. [CrossRef]
3. Qi, Q.; Marwa, J.; Mwamila, T.B.; Gwenzi, W.; Noubactep, C. Making Rainwater Harvesting a Key Solution for Water Supply: The Universality of the Kilimanjaro Concept. *Sustainability* **2019**, *11*, 5606. [CrossRef]
4. Masten, S.J.; Harris, A.; Kearns, J.; Borrion, A.; Peters, C.A.; Gadhamshetty, V.R. Global environmental engineering for and with historically marginalized communities. *Environ. Eng. Sci.* **2021**, *38*, 285–287. [CrossRef] [PubMed]
5. Pandey, D.N.; Gupta, A.K.; Anderson, D.M. Rainwater harvesting as an adaptation to climate change. *Curr. Sci.* **2003**, *85*, 46–59.
6. Mbilinyi, B.P.; Tumbo, S.D.; Mahoo, H.F.; Senkondo, E.M.; Hatibu, N. Indigenous knowledge as decision support tool in rainwater harvesting. *Phys. Chem. Earth* **2005**, *30*, 792–798. [CrossRef]
7. Aikenhead, G.S.; Ogawa, M. Indigenous knowledge and science revisited. *Cult. Stud. Sci. Educ.* **2007**, *2*, 539–620. [CrossRef]
8. Van Meter, K.J.; Basu, N.B.; Tate, E.; Wyckoff, J. Monsoon harvests: The living legacies of rainwater harvesting systems in South India. *Environ. Sci. Technol.* **2014**, *48*, 4217–4225. [CrossRef]
9. Tolossa, T.; Abebe, B.B.; Girma, A.A. Rainwater harvesting technology practices and implication of climate change characteristics in Eastern Ethiopia. *Cogent Food Agric.* **2020**, *6*, 1724354. [CrossRef]
10. Eckart, K.; McPhee, Z.; Bolisetti, T. Multiobjective optimization of low impact development stormwater controls. *J. Hydrol.* **2018**, *562*, 564–576. [CrossRef]
11. Wakatsuki, T.; Esumi, H.; Omura, S. High performance and N, P removable on-site domestic wastewater treatment system by multi-soil-layering method. *Water Sci. Technol.* **1993**, *27*, 31–40. [CrossRef]

12. Ali, I.; Gupta, V.K. Advances in water treatment by adsorption technology. *Nat. Protoc.* **2006**, *1*, 2661–2667. [CrossRef]
13. Latrach, L.; Ouazzani, N.; Hejjaj, A.; Mahi, M.; Masunaga, T.; Mandi, L. Two-stage vertical flow multi-soil-layering (MSL) technology for efficient removal of coliforms and human pathogens from domestic wastewater in rural areas under arid climate. *Int. J. Hyg. Environ. Health* **2018**, *22*, 64–80. [CrossRef] [PubMed]
14. Kearns, J.P.; Bentley, M.J.; Mokashi, P.; Redmon, J.H.; Levine, K. Underrepresented groups in WaSH—The overlooked role of chemical toxicants in water and health. *J. Water Sanit. Hyg. Dev.* **2019**, *9*, 786–793. [CrossRef]
15. Yang, H.; Hu, R.; Ndé-Tchoupé, A.I.; Gwenzi, W.; Ruppert, H.; Noubactep, C. Designing the next generation of Fe^0-based filters for decentralized safe drinking water treatment. *Processes* **2020**, *8*, 745. [CrossRef]
16. Kearns, J.; Dickenson, E.; Aung, M.T.; Joseph, S.M.; Summers, S.R.; Knappe, D. Biochar water treatment for control of organic micropollutants with UVA surrogate monitoring. *Environ. Eng. Sci.* **2021**, *38*, 298–309. [CrossRef]
17. Roy, B.; Hartigan, J. Empowering the rural poor to develop themselves: The barefoot approach. *Innovations* **2008**, *3*, 67–93. [CrossRef]
18. Hartigan, M. Help from above: Considering rainwater harvesting as an alternative to filtration (Innovations Case Discussion: SONO Filters). *Innovations* **2009**, *4*, 103–106. [CrossRef]
19. Zhou, Y.-C.; Shao, W.-Y.; Zhang, T.-Q. Analysis of a rainwater harvesting system for domestic water supply in Zhoushan, China. *J. Zhejiang Univ. Sci. A* **2010**, *11*, 342–348. [CrossRef]
20. Marwa, J.; Lufingo, M.; Noubactep, C.; Machunda, R. Defeating fluorosis in the East African Rift Valley: Transforming the Kilimanjaro into a rainwater harvesting park. *Sustainability* **2018**, *10*, 4194. [CrossRef]
21. Ndé-Tchoupé, A.I.; Tepong-Tsindé, R.; Lufingo, M.; Pembe-Ali, Z.; Lugodisha, I.; Mureth, R.I.; Nkinda, M.; Marwa, J.; Gwenzi, W.; Mwamila, T.B.; et al. White Teeth and Healthy Skeletons for All: The Path to Universal Fluoride-Free Drinking Water in Tanzania. *Water* **2019**, *11*, 131. [CrossRef]
22. Byrne, H.; Cassar, S.; Humphrey, J.; Lowe, N.; Currell, M.; Brown, J.N. Enhancing access to safe drinking water in remote Fijian communities: Modeling and implementing a pilot rain-rank disinfection program. *Environ. Eng. Sci.* **2021**, *38*, 430–442. [CrossRef]
23. Bailey, R.T.; Beikmann, A.; Kottermair, M.; Taboroši, D.; Jenson, J.W. Sustainability of rainwater catchment systems for small island communities. *J. Hydrol.* **2018**, *557*, 137–146. [CrossRef]
24. Thomas, A.; Baptiste, A.; Martyr-Koller, R.; Pringle, P.; Rhiney, K. Climate change and small island developing states. *Annu. Rev. Environ. Resour.* **2020**, *45*, 1–27. [CrossRef]
25. Hafizi Md Lani, N.; Yusop, Z.; Syafiuddin, A. A review of rainwater harvesting in Malaysia: Prospects and challenges. *Water* **2018**, *10*, 506. [CrossRef]
26. Zabidi, H.A.; Goh, H.W.; Chang, C.K.; Chan, N.W.; Zakaria, N.A. A review of roof and pond rainwater harvesting systems for water security: The design, performance and way forward. *Water* **2020**, *12*, 3163. [CrossRef]
27. Dillon, P.; Toze, S.; Page, D.; Vanderzalm, J.; Bekele, E.; Sidhu, J.; Rinck-Pfeiffer, S. Managed aquifer recharge: Rediscovering nature as a leading edge technology. *Water Sci. Technol.* **2010**, *62*, 2338–2345. [CrossRef]
28. Vegas Niño, O.T.; Martínez Alzamora, F.; Tzatchkov, V.G. A decision support tool for water supply system decentralization via distribution network sectorization. *Processes* **2021**, *9*, 642. [CrossRef]
29. Jensen, D.M.R.; Thomsen, A.T.H.; Larsen, T.; Egemose, S.; Mikkelsen, P.S. From EU Directives to Local Stormwater Discharge Permits: A Study of Regulatory Uncertainty and Practice Gaps in Denmark. *Sustainability* **2020**, *12*, 6317. [CrossRef]
30. Ashley, P. The water, gas, and electric light supply of London. *Ann. Am. Acad. Pol. Soc. Sci.* **1906**, *27*, 20–36. [CrossRef]
31. Hillier, J. Implementation without control: The role of the private water companies in establishing constant water in nineteenth-century London. *Urban Hist.* **2014**, *41*, 228–246. [CrossRef]
32. Domènech, L. Rethinking water management: From centralised to decentralised water supply and sanitation models. *Doc. d'Anàlisi Geogràfica* **2011**, *57*, 293–310. [CrossRef]
33. Howe, K.J.; Hand, D.W.; Crittenden, J.C.; Trussell, R.R.; Tchobanoglous, G. *Principles of Water Treatment*; John Wiley & Sons, Inc.: Hoboken, NJ, USA, 2012; p. 674.
34. Wydra, K.; Becker, P.; Aulich, H. Sustainable solutions for solar energy driven drinking water supply for rural settings in Sub-Saharan Africa: A case study of Nigeria. *J. Photon. Energy* **2019**, *9*, 043106. [CrossRef]
35. Chen, Y.; Bellavitis, C. Blockchain disruption and decentralized finance: The rise of decentralized business models. *J. Bus. Ventur. Insights* **2020**, *13*, e00151. [CrossRef]
36. Chen, Y.; Pereira, I.; Patel, P.C. Decentralized governance of digital platforms. *J. Manag.* **2021**, *47*, 1305–1337.
37. Otter, P.; Malakar, P.; Sandhu, C.; Grischek, T.; Sharma, S.K.; Kimothi, P.C.; Nüske, G.; Wagner, M.; Goldmaier, A.; Benz, F. Combination of River Bank Filtration and Solar-driven Electro-Chlorination Assuring Safe Drinking Water Supply for River Bound Communities in India. *Water* **2019**, *11*, 122. [CrossRef]
38. Otter, P.; Sattler, W.; Grischek, T.; Jaskolski, M.; Mey, E.; Ulmer, N.; Grossmann, P.; Matthias, F.; Malakarh, P.; Goldmaier, A.; et al. Economic evaluation of water supply systems operated with solar-driven electro-chlorination in rural regions in Nepal, Egypt and Tanzania. *Water Res.* **2020**, *187*, 116384. [CrossRef] [PubMed]
39. Ndé-Tchoupé, A.I.; Crane, R.A.; Mwakabona, H.T.; Noubactep, C.; Njau, K.N. Technologies for Decentralized Fluoride Removal: Testing Metallic Iron-based Filters. *Water* **2015**, *7*, 6750–6774. [CrossRef]
40. Shannon, M.A.; Bohn, P.W.; Elimelech, M.; Georgiadis, J.G.; Marinas, B.J.; Mayes, A.M. Science and technology for water purification in the coming decades. *Nature* **2008**, *452*, 301–310. [CrossRef]

41. Naseri, E.; Ndé-Tchoupé, A.I.; Mwakabona, H.T.; Nanseu-Njiki, C.P.; Noubactep, C.; Njau, K.N.; Wydra, K.D. Making Fe0-Based Filters a Universal Solution for Safe Drinking Water Provision. *Sustainability* **2017**, *9*, 1224. [CrossRef]
42. Banerji, T.; Chaudhari, S. Arsenic removal from drinking water by electrocoagulation using iron electrodes-an understanding of the process parameters. *J. Environ. Chem. Eng.* **2016**, *4*, 3990–4000. [CrossRef]
43. Banerji, T.; Chaudhari, S. A cost-effective technology for arsenic removal: Case study of zerovalent iron-based IIT Bombay arsenic filter in West Bengal. In *Water and Sanitation in the New Millennium*; Nath, K., Sharma, V., Eds.; Springer: New Delhi, India, 2017.
44. Steinel, A. *Stormwater Reuse via Aquifer Storage and Recovery: Risk Assessment for Sandy Aquifers. Climate Change and the Sustainable Use of Water Resources*; Springer: Berlin/Heidelberg, Germany, 2012; pp. 17–42.
45. Liu, C.; Lu, J.; Liu, J.; Mehmood, T.; Chen, W. Effects of lead (Pb) in stormwater runoff on the microbial characteristics and organics removal in bioretention systems. *Chemosphere* **2020**, *253*, 126721. [CrossRef]
46. Rai, R.K.; Neupane, K.R.; Bajracharya, R.M.; Dahal, N.; Shrestha, S.; Devkota, K. Economics of climate adaptive water management practices in Nepal. *Heliyon* **2019**, *5*, e01668. [CrossRef] [PubMed]
47. Zevenbergen, C.; Fu, D.; Pathirana, A. Transitioning to Sponge Cities: Challenges and Opportunities to Address Urban Water Problems in China. *Water* **2018**, *10*, 1230. [CrossRef]
48. Liang, X.; Liang, Y.; Chen, C.; van Dijk, M.P. Implementing Water Policies in China: A Policy Cycle Analysis of the Sponge City Program Using Two Case Studies. *Sustainability* **2020**, *12*, 5261. [CrossRef]
49. Iglesias, A.; Quiroga, S.; Moneo, M.; Garrote, L. From climate change impacts to the development of adaptation strategies: Challenges for agriculture in Europe. *Clim. Chang.* **2012**, *112*, 143–168. [CrossRef]
50. Prinz, D. Water Harvesting: Past and Future. In *Proceedings of the Sustainability of Irrigated Agriculture, NATO Advanced Research Workshop, Vimeiro, Balkema, Rotterdam, The Netherlands, 21–26 March 1994*; Pereira, L.S., Ed.; Springer: Dordrecht, The Netherlands, 1996; pp. 135–144.
51. Evenari, M.; Koller, D. Ancient masters of the desert. *Sci. Am.* **1965**, *194*, 39–45. [CrossRef]
52. Gould, J.; Nissen-Petersen, E. *Rainwater Catchment Systems for Domestic Supply*; IT Publications Ltd: London, UK, 1999.
53. Fewkes, A. A review of rainwater harvesting in the UK. *Struct. Surv.* **2012**, *30*, 174–194. [CrossRef]
54. Bell, B. The oldest records of the Nile floods. *Geogr. J.* **1970**, *136*, 569–573. [CrossRef]
55. Davis, F. *An Elementary Handbook on Potable Water*; Silver, Burdett & Co: New York, NY, USA; Boston, DC, USA; Chicago, IL, USA, 1891; p. 118.
56. Hamlin, C. *A Science of Impurity: Water Analysis in Nineteenth Century Britain*; University of California Press: Berkeley, CA, USA, 1990.
57. Han, M.; Ki, J. Establishment of sustainable water supply system in small islands through rainwater harvesting (RWH): Case study of Guja-do. *Water Sci. Technol.* **2010**, *62*, 148–153. [CrossRef]
58. Waite, M. Climate-change mitigation and adaptation in small island developing states: The case of rainwater harvesting in Jamaica. *Sustainability: Sci. Pract. Pol.* **2012**, *8*, 81–87. [CrossRef]
59. Donohue, M.J.; Macomber, P.S.H.; Okimoto, D.; Lerner, D.T. Survey of Rainwater Catchment Use and Practices on Hawaii Island. *J. Contemp. Water Res. Educ.* **2017**, *161*, 33–47. [CrossRef]
60. Staddon, C.; Rogers, J.; Warriner, C.; Ward, S.; Powell, W. Why doesn't every family practice rainwater harvesting? Factors that affect the decision to adopt rainwater harvesting as a household water security strategy in central Uganda. *Water Int.* **2018**, *43*, 1114–1135. [CrossRef]
61. Khayan, K.; Husodo, A.H.; Astuti, I.; Sudarmadji, S.; Djohan, T.S. Rainwater as a source of drinking water: Health impacts and rainwater treatment. *J. Environ. Public Health* **2019**, 1760950. [CrossRef]
62. Dillon, P.; Fernández Escalante, E.; Megdal, S.B.; Massmann, G. Managed Aquifer Recharge for Water Resilience. *Water* **2020**, *12*, 1846. [CrossRef]
63. Parsons, D.; Goodhew, S.; Fewkes, A.; De Wilde, P. The perceived barriers to the inclusion of rainwater harvesting systems by UK house building companies. *Urban Water J.* **2010**, *7*, 257–265. [CrossRef]
64. Van Dijk, M.P.; Zhang, M. Urban water management paradigms in chinese cities. *Sustainability* **2019**, *11*, 3001. [CrossRef]