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Community-based rainwater harvesting (CB-RWH) to supply drinking water in developing countries: lessons learned from case studies in Africa and Asia

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ABSTRACT

This paper uses pragmatic findings and lessons learned from three case studies to deduce that community-based rainwater harvesting (CB-RWH) is an innovative solution to develop sustainable drinking water supply systems in developing countries, especially in Africa and Asia. Taking advantage of traditional community-based activities in African and Asian villages, the water supply system can be significantly improved with the introduction and implementation of CB-RWH systems. Furthermore, sustainable, safe water sources in Africa and Asia can be brought to fruition when transparent self-regulatory management systems are supported through comprehensive design and maintenance guidelines and funded from private and public sources. To this end, the potential for CB-RWH to lead toward greater resilience and sustainability was investigated. Based on case studies of three successful demonstration projects in Africa and Asia, this paper identifies 14 innovative solutions resolving technical, economic, and social problems which have been barriers preventing the wide implementation of CB-RWH in developing countries, especially in Africa and Asia. It also recommends strategies to promote CB-RWH in African and Asian villages, which include the following: implementation of more pilot projects at local levels; promotion of and education in rainwater preservation and harvesting at all levels of the education system; and innovation in micro-funding systems in cooperation with corporate social responsibility activities. These strategies will promote the implementation of CB-RWH as a mainstream and high-priority technique for national, regional, and global water strategies.

Key words | community-based rainwater harvesting (CB-RWH), corporate social responsibility (CSR), developing countries, drinking water, one company for one community (1C1C) movement, sustainable drinking water supply

INTRODUCTION

Africa and Asia are suffering physical and economic water scarcity, which will become increasingly severe due to urbanization and climate change. Studies conducted by the United Nations Environment Programme (UNEP) in 2008 (UNEP 2008) and Asia Development Bank (ADB) in 2011 noted that freshwater resources in Africa and Asia are already facing serious threats, with the situation expected to worsen in the future. Africa’s extreme temporal and spatial variability of rainfall is reflected in an uneven distribution of surface and groundwater resources, from areas of severe aridity with limited freshwater resources such as the Sahara and Kalahari Deserts in the north and south, to the tropical belt of mid-Africa that contains abundant freshwater resources. One of the greatest water issues in Africa is the unequal
distribution of resources; 30% of Africa’s water drains into the Congo Basin where only 10% of Africa’s population lives (Shinn 2012). The continent’s vast deserts and savannas are notably dry. The uneven distribution of freshwater is exacerbated by high population growth rates, extreme variability in rainfall, climate change, and environmental degradation. In response to this threat, the African Union (AU), in cooperation with the United Nations Economic Commission for Africa (ECA) and the African Development Bank (AFDB), developed the Africa Water Vision 2025 (ECA, AU & AFDB 2011). The report addresses the potential disastrous consequences of water-related threats to the continent and how to create a paradigm shift in water management for a future in which the full potential of Africa’s water resources can be readily unleashed to stimulate and sustain growth in the region’s economic development and social well-being. The Vision also addresses the critical health and economic impacts of shortages in safe drinking water resources in Africa. However, the Vision is limited in addressing the fundamental targets as well as the consequences of safe and adequate drinking water supply by 2025. In particular, rainwater is treated as an unreliable water resource with limited use for human consumption due to its unpredictability and chaotic nature.

Asia has also been suffering from water resource problems. Home to 60% of the world’s population, Asia needs a clean water supply system not only in rural areas but also in the fast-growing cities where rapid urbanization is exerting strains on this precious resource. It is estimated that one in five people (700 million) do not have access to safe drinking water; 22 of 32 Indian cities face daily water shortages. In Kathmandu, the capital of Nepal, many residents have grown accustomed to waiting in queues for hours to obtain drinking water from the city’s ancient, stone waterspouts. The UN estimates that the population of Asia will grow by 700 million people between 2010 and 2025. The Water Operational Plan 2011–2020 for Asia, which was developed by the ADB (ADB 2011), reported that growing populations, rapid urbanization, increasing water pollution, and competing demands for water have left water resources in many Asian countries in a critical state, i.e., the gap between demand and supply is widening and competition is increasing between water users, including farmers, energy producers, households, and businesses.

Around 70% of Asia’s water is used to irrigate crops, but much of it is used inefficiently, while many water-stressed countries lose large volumes of treated water through leakage from urban water supply systems. Asia’s supply of water to meet future needs is rapidly decreasing.

If water is collected safely from catchment systems situated atop buildings, rainwater can be a free, quality source of drinking water with no added energy requirement or exacerbation of territorial conflicts (Mwenge Kahinda et al. 2007; UNEP 2009; Amin & Han 2009a, 2009b; Song et al. 2009; Tabatabaei & Han 2010; Julius et al. 2013). Recently, innovations in sustainability were applied to school buildings in Africa and Asia with successful and measurable results (Nguyen et al. 2013; Mwamilla et al. 2015; Temesgen et al. 2015). In this regard, the Africa Water Vision 2025 and the Water Operational Plan 2011–2020 need to be improved by addressing the specific potential of rainwater harvesting in developing a safe and clean domestic source of drinking water.

Through case studies of three successful demonstration projects in Africa and Asia, this paper investigates the potential of community-based rainwater harvesting (CB-RWH) in the establishment of a sustainable drinking water source in developing countries, particularly in Africa and Asia, which would lead to greater resilience and sustainability. The objectives of this paper are as follow: to identify innovative solutions resolving technical, economic, and social problems that have been barriers to the wide implementation of CB-RWH in developing countries; and to recommend strategies to promote CB-RWH within developing countries, which can be reflected in national, regional, and global water strategies.

**DRINKING WATER CHALLENGES AND THE CURRENT STATUS OF RWH IN AFRICA AND ASIA**

**Drinking water systems in Africa and Asia**

In Africa and Asia, it is traditional for each family to develop its own water catchment system by either digging a shallow well or building a crude rainwater harvesting system. Both methods offer some benefits; however, the drawbacks are many: they are unreliable decentralized sources of water,
they are subject to the whims of nature, water quantities collected during the dry season are insufficient, the quality of water collected could be hazardous, and structures suffer due to a lack of expertise.

As African and Asian countries become increasingly industrialized and urbanized, large and centralized infrastructures are being developed to manage water resources. As can be expected, rivers and reservoirs (natural and man-made) are being utilized to capture water that is then purified in large treatment centers and finally delivered via pipelines or other means of transport. However, these large-scale systems require an even larger infrastructure and support system to work effectively and efficiently, including a huge network of pipelines, a significant maintenance crew (maintenance costs are prohibitive for many communities in Africa and Asia), and experts to operate the system. In addition, most small communities and villages in Africa and Asia hardly benefit from the centralized water supply system because of distance and geographical impediments.

To overcome the shortcomings of both systems, community-based groundwater (CB-GW) systems are a suitable alternative. The intent of CB-GW is to establish wells for communities, as is the current practice in many rural African and Asian villages. In a CB-GW system, a well is constructed in the middle of a village, from which villagers can draw water for domestic purposes. The village leader is responsible for maintaining the water supply system. However, research has shown that villagers find it difficult to use the wells freely because most village leaders generally manage the well very conservatively, undemocratically, and sometimes in an ad-hoc manner. Additionally, water shortages are likely to occur sporadically throughout the CB-GW system due to the overexploitation of groundwater, water contamination, power interruptions, and/or system malfunctions. When water shortages have occurred, villagers have been excluded from the decision-making process and have not had an opportunity to voice their concerns or to contribute to a collaborative solution. ‘Tragedies of the commons,’ as defined by Garet (1968), may occur because there is no reasonable self-regulatory mechanism. Although the CB-GW system can solve many problems for both large and centralized systems and the traditional decentralized water supply system, its use has been very limited because of the aforementioned challenges. Therefore, new, innovative ideas are required to solve the problems of CB-GW, retaining the idea of a community-based approach as a core principle. Traditionally and historically, African and Asian villages are constructed on the concept of community, from which they conduct activities such as business, hunting, or agriculture under the leadership of a village head. Tradition should be respected and applied when it comes to water management.

Therefore, this research explored the possibility of CB-RWH as a supplement to the current shortcomings of CB-GW and as a promising solution to the drinking-water challenges in developing countries. This research also proved that the CB-RWH system, once it has a self-regulatory and transparent operating system based on reasonable methods, could lead to water quantity and quality that is predictable, sustainable, and achievable with more regularity and self-determination than the three methods described above: the decentralized and disorganized system, the centralized system requiring a large infrastructure, and CB-GW. Moreover, this paper identifies the steps necessary to make the best use of the benefits of CB-RWH through successful demonstration projects in Africa and Asia.

**Current status of RWH in Africa and Asia**

Rainwater harvesting systems have not been used as a primary tool in supplying a safe source of drinking water. The key barriers for the rainwater harvesting system can be analyzed from three perspectives: technical, economic, and social.

Technically, most rainwater holding tanks in operation experience problems with both water quality and water quantity. The water quality is turbid with suspended solids or sometimes with insects easily observable with the naked eye within the water tank. At times, the poor design of the rainwater system becomes an obstacle to its utilization in harvesting rainwater for consumption. Another barrier is irregular rainfall throughout the year. Rainwater is not considered a reliable source because of the lack of precipitation during the dry season. In most rural areas, local rainfall data, which is essential input data for determining an efficient design, is unavailable. Technical capacities for developing rainwater harvesting systems are low because there are not
sufficient business opportunities, nor technical standards, for building such a system.

From an economic perspective, the cost of parts is high and the quality of workmanship is poor due in part to an immature market for rainwater harvesting. The cost of a rainwater system is economically prohibitive for most individual households, and economically insignificant and of no value for donor agencies to construct. Donor countries or agencies have funded very few rainwater harvesting systems because of a preference for a centralized water supply system.

Socially, due to apparent poor performance in water quantity and quality, and a lack of successful rainwater demonstration projects, rainwater harvesting is not a high priority for beneficiary developing countries or of high priority in water management policies. Additionally, the manager of a rainwater catchment system is likely to act conservatively for fear of dry-season water shortages; therefore, the operation of rainwater catchment systems is not transparent to villagers. Moreover, the operational mechanism of a rainwater system is not likely to be democratic. On top of all these barriers, system training and knowledge of the proper maintenance and usage of the system is very limited or non-existent.

Current progress in science and technology has led to a new opportunity for CB-RWH to become an innovative solution as a safe source of drinking water. Rainwater is clean when it is collected properly. The poor quality of rainwater, which has been reported in many publications, is not native to the rainwater itself, but is caused by either an inadequate design or poor maintenance of equipment (Dobrowsky et al. 2014), or an incorrect sampling method from the rainwater tanks. The only contaminants are particles and microorganisms, which originate from the atmosphere (Kaushik et al. 2012), bird droppings, or the roof catchment (Ahmed et al. 2012), which requires minimum treatment before use as drinking water. Many studies have also reported rainwater as a good quality water source that can be used as drinking water without any other treatment if the catchment and rainwater tank are managed well (Coombes et al. 2006; Lee et al. 2012).

Recently, there has been technical progress in collecting rainwater and maintaining high quality in holding tanks. Specific examples, some of which were collected by the authors, are as follows:

- The basic premise for particle separation is to maximize the sedimentation capability of the rainwater-holding tank (Han & Mun 2007). Biofilm inside the tank can maximize the microbial activities needed for self-purification (Kim et al. 2012; Kim & Han 2013, 2014). Finally, the most useful methodology for removing possible pathogens is to expose rainwater in 2-L polyethylene terephthalate bottles in a solar collector to sunlight for 4–8 hours; complete disinfection can be achieved even under weak weather conditions by adding inexpensive food preservatives such as lemon juice and vinegar (Solar Disinfection, SODIS) (Amin & Han 2009a, 2009b, 2011).
- In order to cope with water shortages during dry periods, careful design can be made through simulation modeling (Mun & Han 2012). Optimum tank volume can be calculated with the input of rainfall data, catchment area mapping, and water consumption. A strategy to restrict water consumption based on the remaining water in the tank can reduce the number of no-water days (NWDs) (Mwamilla et al. 2015). Another method is to develop a site-specific water supply system with dual sources; for example, rainwater for drinking purposes and groundwater for other domestic purposes at an area contaminated by arsenic (Nguyen & Han 2014).

Although rainwater offers potential as a clean, sustainable, and free water source without territorial conflict, it has not been widely adopted in water policies in Africa and Asia, nor taught in school curricula. A more proactive approach to enhance CB-RWH is required to solve drinking water problems in Africa and Asia.

LESSONS LEARNED FROM CASE STUDIES

Three RWH case studies were recently conducted at schools in Africa and Asia, as shown in Figure 1. Schools were selected for the case studies of CB-RWH for three reasons: water is needed in schools; schools are a good place to find social interaction among many stakeholders; and schools will be a good point of origin for further promotion and education. Usually, a school is the optimal location for a CB-RWH system because it offers a relatively secure and large roof. In addition, villagers generally respect teachers, who serve as a conduit between the project and the village.
Many community members gather as parents at the school where communication and knowledge transfer can easily transpire. Moreover, students who benefit from RWH at school can hopefully transfer their experience to their villages when they become active members of their community.

Tanzania, Mnyundo Primary School (10 m³ rainwater system)

Mnyundo Primary School is located in Mtwara, Tanzania. The school has 300 pupils and 15 teachers; five buildings have roofs suited for RWH. As is typical in Africa, students and teachers experience water shortages because they do not have a reliable water supply system. In January 2013, a team from Seoul National University (SNU) constructed a site-specific rainwater system funded by NGOs, Rain for All (RFA) and the Korean Society of Civil Engineers (KSCE). They helped the locals build a rainwater tank system that consisted of a 160 m² roof catchment (the limitation of a catchment site), gutter, first flush tank, two 5 m³ rainwater holding tanks, and a water distribution system in the form of water fountains (Figure 2). In addition, a

Figure 1  The locations of three case studies: (a) Tanzania, Mnyundo Primary School, (b) Vietnam, Cukhe Elementary School, and (c) Ethiopia, Chemical Engineering Building at AUST.

Figure 2  Rainwater tank at Mnundo Primary School in Tanzania.
simple water gauge constructed from transparent plastic tubing was installed. In this project, the following special considerations were made.

**Capacity building**

Construction used local materials and local labor based on designs by the SNU team. Following construction, a maintenance manual with the description of the system and details of contact personnel was made available at the school and for the children in both English and the local language (Swahili). In doing so, locals could independently repair or build additional RWH facilities.

**Operation based on self-regulation**

Water shortages during the dry season can be mitigated by using a larger holding tank; however, this option is sometimes too expensive. Thus, this project employed a self-regulating rule; the school was able to reduce the number of NWDs through a simple plastic tube that was used to monitor water levels. For example, if the water level fell within the first, second, or third quarter from the bottom, people would regulate water consumption by a quarter litre, a half litre, and 1 litre, respectively (Mwamilla et al. 2015). Therefore, they were able to reduce dry-season hardships. The lessons learned from this case study include the importance of capacity building and the mutual understanding of the benefit of a self-regulating operation rule according to the water level by which everyone can transparently monitor water levels.

**Replication potential**

After the first year in operation, the system satisfied residents and the local government wanted to establish another facility at a nearby school. The second rainwater system was successfully built and installed using acquired knowledge, local skills, and materials; RFA contributed half of the funds for the project and the other half came from the local government. The physical presence of the SNU team was not necessary; instead, communication was made by simple social network service messages during the design and construction stage. It was clear that the local population knew how to build the system and could install another tank through self-determination. The only remaining issue would be how to mobilize the financial resources and how to make the facilities, including holding tanks, cheaper.

**Vietnam, Cukhe Elementary School (12 m³ rainwater tank)**

Cukhe Elementary School is located at Cukhe, in the southern part of Hanoi, Vietnam. The school has 300 students, 15 teachers, and 3 buildings with relatively secure and suitable roofs. In the past, they had to use expensive bottled water for drinking water because the local groundwater is heavily contaminated by arsenic. In July 2014, a new approach to the donation system was introduced. The Lotte Department Store donated money for the rainwater system as part of its corporate social responsibility (CSR) commitment. The SNU team designed the rainwater system that consists of a 180 m² roof catchment, gutter, first flush tank, two 6 m³ rainwater-holding tanks, and UV filters near the tap (Figure 3). Locals using locally sourced materials constructed the project. Following construction, residents and the donor company were satisfied with the outcome. Here, water level gauges and water meters were installed to monitor remaining water supplies and cumulative water consumption. Money saved from the RWH facilities and not having to buy bottled water is equivalent to building another CB-RWH system every two years.

Another issue was insufficient rainfall data for the area. Most rainfall data are primarily collected in urban centers. Therefore, Cukhe Village did not have adequate rainfall data to make a precise RWH design. The solution was to install a simple rainfall gauge and to work with a science student group to maintain rainfall records via a website (Figure 4). They can use the rainfall data for future designs.

The lessons learned from this case study are threefold: the importance of building local residents’ capacity to design, build, and operate rainwater harvesting systems; the importance of involving industry through CSR activities as a win-win strategy; and the benefit of local data collection by students, which resulted in a democratic decision of operation that can be used as reference for future designs and operations.
Ethiopia, chemical engineering building at Adama University of Science and Technology (8 m³ rainwater tank)

The chemical engineering building at Adama University of Science and Technology (AUST), located in Adama, Ethiopia, was built in 2011. Due to delays in construction of the water supply infrastructure, students suffered from a shortage of water for consumption, as well as for practical and educational purposes. Essentially, the water supply was insufficient to run university laboratory experiments, to be used for sanitation purposes, and even for many emergency situations. In June 2014, an SNU team together with a professor at AUST helped make two rainwater systems that consist of 528 m² of roof, gutters, first flush, a 4 m³ rainwater holding tank, and connections (Figure 5). The system was built using local materials and labor. The project was funded by the Institute of Global Social Responsibility (IGSR) at SNU.

The unique aspect of this project as compared to the other projects comes from an engineering perspective; the sheer quantity of water needed and the degree to which the water had to be ‘clean’ required distinct expertise. Using hydrologic

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**Figure 3** | Schematic of rainwater tank at Cukhe Primary School in Vietnam.

**Figure 4** | The rain gauge installed at Cukhe Primary School in Vietnam.
modeling, the SNU team was able to predict water availability based on daily water consumption. At the same time, they had to incorporate the theories of particle separation and disinfection to maintain the water quality.

At the time this demonstration project began, the benefits of CB-RWH were not widely known to the faculty and student body at AUST. Therefore, the SNU team organized a seminar to share sound practices and to transfer knowledge on RWH. After the seminar, the participating AUST groups understood the benefits of rainwater harvesting and engineering necessities, and acquired proper knowledge for implementing RWH systems. In addition, the president of AUST recognized the importance and potential of rainwater, and planned to modify the campus into a rain harvesting-friendly campus. He also added rainwater harvesting studies into the engineering curriculum for enrichment and employment purposes.

The lesson learned from this case study is the benefit of involving an engineering college where they can make the system reliable in terms of water quality and quantity. Through proper training and education, all engineering students were able to acquire a new set of skills and knowledge. Such knowledge transfer, based on an education system, can be used for nationwide promotion of rainwater harvesting.

**Potential of RWH as a drinking water solution in developing countries**

Based on the three case studies in Africa and Asia, this paper found that technical, economic, and social innovations, as well as combinations of the three, can solve the problems that have served as a barrier to the wide implementation of CB-RWH in developing countries. Based on the solutions to these problems, this paper advocates CB-RWH as the most innovative method to ameliorate insufficiencies in freshwater and drinking water supplies through continent-wide rainwater harvesting movements in Africa and Asia.

A special fundraising system was successfully executed with the three case study projects on a win-win basis. They were funded from sector entities such as SNU, Lotte Department Store, RFA, and KSCE. Relatively small funds can realize success depending on the size of the beneficiary community, eventually satisfying all parties involved. Therefore, a new donation system, the one company for one community (1C1C) movement, is suggested, in which one company donates money to make a rainwater system for one community.

Figure 6 summarizes the relationship between the problems and the innovative solutions derived from the three case studies.

There are solutions to the problems impeding the wide usage of CB-RWH in developing countries.

The technical problems include water shortages during the dry season, poor water quality, poor workmanship, and a lack of local data. The solutions to these problems are as follows:

- Three possible solutions to handle water shortages during the dry season include: the development of a dual water system; the use of rainwater for drinking purposes and groundwater for other purposes; and the modeling of water quantity and quality followed by the installation
of a device to measure local rainfall data and monitor the water volume remaining in the rainwater tank.

- For poor water quality, possible solutions include the development of design and maintenance guidelines, conducting modeling of water quantity and quality, providing engineering and technical education, and strengthening the capacity of local citizens.
- To mitigate poor workmanship, there are three technical solutions: developing guidelines for design and maintenance, providing engineering and technical training, and encouraging technical transfer.
- Where local data are lacking, there are two technical solutions: modeling water quantity and quality and monitoring the volume of rainwater.

From an economic perspective, suggested solutions are as follows:

- To handle the notion that the economic outlay is not sufficient for donor agencies’ consideration, yet is too high for individuals to undertake, solutions include: getting industries involved as a CSR activity, establishing co-financing among donor agencies and local citizenry, and boosting business opportunities in rainwater harvesting.
- To handle the high cost of parts due to the immaturity of the market, there are two solutions: involving industry using CSR activities and increasing business opportunities in rainwater harvesting.

The solutions to problems from a social perspective include the following:

- To get community leaders to adhere to conservative operations for dry-season water shortages, a self-monitoring and regulation system should be implemented to reduce the number of NWDs.
- To solve the lack of ‘sense of ownership’ in the case of free donations, this paper proposes creating a ‘sense of ownership’ by implementing a partial self-funding scheme.
To ensure rainwater harvesting is included in the education system, two suggestions are to conduct public seminars for educational purposes, and to get the media involved for promotional and educational purposes.

To improve the perception of rainwater harvesting, due to a lack of successful demonstration projects, solutions include developing public education seminars and involving media outlets to help promote benefits and activities.

Once a CB-RWH system is successfully installed and implemented using the 14 innovative solutions recommended in this paper, it will fill in the gaps of a CB-GW system in terms of water quantity and quality and maintenance, which are described in the section ‘Drinking water challenges and the current status of RWH in Africa and Asia’. First, in terms of water quantity, CB-GW may experience a sudden water shortage without prior notice due to overexploitation of groundwater and system failure for various reasons, such as power shortages, parts, equipment, and lack of skilled labor. Leaders should be strict and conservative in managing the CB-GW system. However, CB-RWH can predict the number of NWDs from the model that is based on rainfall, tank volume, and usage. By monitoring rainfall data, the volume of remaining water, and daily consumption, a community can democratically self-regulate water consumption. Second, in terms of water quality, groundwater may be subject to contamination by fecal coliform or heavy metals such as fluoride or arsenic. However, roof-harvested rainwater does not contain such contaminants because it has a decreased chance of coming into contact with such pollutants after the rain has fallen, if the system is designed and maintained according to proper guidelines. Finally, in terms of maintenance, because GB-RWH is not dependent on power and chemicals, when problems do occur, it is very easy and cheap to make repairs using local labor and materials.

This research established that most barriers to the wide use of RWH in developing nations could be overcome by recent technical, economic, and social progress. The effective starting point of CB-RWH could be a school or another place serving an educational purpose, such as a showcase and data gathering hub. In addition, management and maintenance decisions need to be made through a democratic process with transparent data gathering or via localized rain gauges, water meters, or micro-data catchments. The CB-RWH can be a good model for the ‘governing of the commons,’ as proposed by Ostrum (1990).

**STRATEGIES FOR PROMOTING CB-RWH**

When it comes to water resources, most villages in developing countries have relied on traditional methods and community-based hierarchical leadership and have not benefitted from large and centralized water infrastructures. For water resilience and sustainability, a paradigm shift is required, keeping in mind the long tradition of self-reliance and community culture. This paradigm shift, however, should not be accomplished by adopting a method that is formulated by disregarding the needs and expectations of the community; it should instead be achieved via a bridge that will bring knowledge and innovative technologies to a village in an economical and agreeable manner. That bridge is CB-RWH. Through the three successful RWH projects in Africa and Asia, we have learned that the direct and indirect benefits of a CB-RWH system are monumental.

In order to promote CB-RWH in developing countries, the following strategies are recommended:

- First, more local pilot projects need to be implemented across the entire African and Asian continents. Because water problems are site-specific, so should be the solutions. More successful demonstration projects in different areas, where rainfall conditions are unique, need to be implemented, monitored, and evaluated. Those places must include coastal slums and mountainous areas, which have different building techniques and traditional building materials. Thus far, several small- to mid-size CB-RWH demonstration projects and careful follow-up monitoring systems have been suggested.
- Second, the promotion and education of rainwater preservation and harvesting should be done at all levels of the educational system, from elementary schools to universities. Especially, engineering schools should foster CB-RWH as a new discipline for increasing students’ knowledge and employability. One or two universities in each country should establish a rainwater research center that will develop RWH technology and expedite
the transfer of knowledge gathered to the local community, with the added benefit of creating rainwater-related employment opportunities.

- Last, but not least, an innovative micro-funding system should be created in cooperation with CSR activities of the public sector as a win-win tool. Together with seed money from the public sector, villagers can develop a localized business via spinoff effects. The 1C1C rainwater donation movement needs to be promoted under the leadership of the UN and developed countries.

**CONCLUSION**

Problems with the current water supply systems in developing countries have been examined, such as traditional decentralized water supply systems, centralized systems, and CB-GW. Although rainwater harvesting has been practiced traditionally, technical, economic, and social barriers prohibit the wide use of mainstream rainwater harvesting in policy. Therefore, innovative solutions of CB-RWH were identified for the promotion of CB-RWH in developing countries on the basis of lessons learned from the three rainwater harvesting case studies in Africa and Asia. When the system possesses a transparent self-regulated management system that is supported by comprehensive designs and built with expert guidance and maintenance guidelines, then the spinoff effect for the community, the educational system, and the country as a whole benefits everyone involved.

In addition, a win-win situation can be created when the 1C1C couples with local efforts to create a resilient and sustainable supply of drinking water. To this end, strategies have been recommended to promote CB-RWH systems around Africa and Asia, which include the following: more pilot projects will be implemented at local levels; the promotion and education of rainwater preservation and harvesting will be conducted at all levels of the education system; and an innovative micro-funding system will be made in cooperation with CSR activities of the public sector. These strategies will promote the implementation of CB-RWH as a mainstream high priority technique in national, regional, and global water strategies.

This paper lays the foundation for further research on water problems in developing countries, especially in Africa and Asia, which have varying climatic and cultural conditions.

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**REFERENCES**

ECA, AU & AFDB 201 The Africa Water Vision for 2025: Equitable and Sustainable Use of Water for Socioeconomic Development. UN Water.
Han, M. & Mun, J. 2007 Particle behavior consideration to maximize the settling capacity of rainwater storage tanks. Water Science and Technology 56 (11), 73–79. DOI:10.2166/wst.2007.778.
Shinn, D. H. 2012 Water Crisis in Africa: Remarks before the GWU International Affairs Society. Elliott School of International Affairs, George Washington University, Washington, DC.

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