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Feasibility of managed domestic rainwater harvesting in South Asian rural areas using remote sensing

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ABSTRACT

Rainwater harvesting is a simple, low-energy and cost effective solution for meeting drinking and domestic water demand in rural communities. In this study, the feasibility of Domestic Rainwater Harvesting (DRH) in South Asia region was assessed using rainfall climatology, remote sensing and water balance concept to improve the rural public health condition. Long term satellite precipitation data was used for analyzing the precipitation climatology as in situ stations are sparsely located in this region. The study area was divided into smaller regions and average roof area for each region was approximated from the satellite visible imagery. It was found that DRH is a viable option in most of Bangladesh, Sri Lanka, Himalayan range, North-Eastern, Central, Eastern and coastal parts of Southern India as the rainfall and household architecture can satisfy potable (7.5 liters per capita per day-lpcd for drinking and cooking) water demand for significant portion the year even in worst case scenario. The study demonstrated that DRH system is not a realistic option in most parts of Pakistan, Northern and Western India. DRH would not a feasible option to fulfill the domestic (20 lpcd for drinking, cooking and basic hygienic needs) water demand for significant portion of the year except North-Eastern India. This study is perhaps the first comprehensive assessment of rainwater harvesting potential in rural South Asia using satellite-precipitation climatology and can inform the policy makers on where to invest geographically for building distributed rainwater harvesting systems.

1. Introduction

Water supply, sanitation and hygiene (WASH) are foundational issues related to public health. Development of water supply is a prerequisite for robust sanitation system and hygiene practice (Hunter et al., 2010). The world has met the Millennium Development Goal target for safe drinking water coverage in 2010 (UNICEF and WHO, 2015). However, 748 million people still lack access to improved drinking-water (WHO/UNICEF, 2014) and 1.8 billion people drink water from a source with fecal contamination (Bain et al., 2014). Children under five years old in the low and middle-income countries are the major victims and account for more than 90% death from water-related diseases such as diarrhea caused mainly by drinking fecally contaminated water (UNICEF, 2003). Safe water at households prevents waterborne disease like diarrhea, typhoid and cholera (Bartram and Cairncross, 2010). Cutler and Miller (2005) claimed that clean water was the key reason behind the decline of half of the observed mortality in U.S. cities.

Water demand will increase substantially with increasing population to maintain the economic growth and meet the food demand (Vorosmarty et al., 2000). Estimates show that 60% people may face water scarcity by 2025 (Qadir et al., 2007). Developing countries of South Asia are particularly vulnerable to lack of safe drinking water due to development activity lacking coordination with water management policies. Almost 134 million people in this region do not have access to safe drinking water (UNICEF and World Health Organization, 2015). Other apparently safer sources of water, such as groundwater, have problems too. A recent study demonstrated that 60% of the shallow groundwater of the Indo-Gangetic Basin are not suitable for drinking due to salinity and arsenic contamination (MacDonald et al., 2016). The International Bank for Reconstruction and Development/The World Bank (2003) showed that more than one third of water infrastructures in South Asia are not functional. Due to these reasons people are forced to fetch water from surface water bodies which are highly contaminated with fecal organism (Luby, 2008).

Most of the developed and industrialized countries have the centralized pipe network based safe water supply system. This kind of large scale infrastructure with water treatment facility to purify the surface water will not be suitable for the rural communities of developing countries due to socio-economic constraints (Mara, 2003). Developing

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this kind of water supply system for the rural regions would require huge investment which is a major constraint for developing countries. It is also unrealistic to expect the proper maintenance of this kind of system in rural communities towards sustainability of the system. Large water supply system using surface water body might also require impoundment of water which often causes social, environmental and ecological disruption.

Compared to the centralized water supply infrastructure, Domestic Rainwater Harvesting (DRH) is more cost effective, simple to manage and socially acceptable in most of the regions (Thomas, 1998). These unique features make it very suitable for rural areas of the developing countries. According to World Health Organization (WHO) rainwater is free from major impurities. However, there is possibility of mineral contamination from roof materials and microbial contamination from the feces of birds (Magyar et al., 2014; Owusu-Boateng and Gadogbe, 2015). Simple point-of-use water treatment facilities like filters or chlorination can solve this complication in-situ though. Point-of-use water treatment was found to be the most effective intervention to reduce waterborne disease like diarrhea (Fewtrell et al., 2005; Quick et al., 1999). A study on the urban water supply system of Chennai showed that rainwater harvesting combined with efficiency improvement is the best policy to meet the skill, fairness, reliability and economic criteria. (Srinivasan et al., 2010).

In most rural areas, there are two types of water supply systems: community based and household water supply system. The community based water supply system is typically built in a suitable location of a community and shared by the all people of the community. Household level water supply system can be piped network based or a tube well that supplies water within the house. In case of communal point source, safe water can get contaminated during collection and storage due to bad handling (Han et al., 1989). Studies have shown significant fecal contamination of water between source and point-of-use storage (Pickering et al., 2010; Wright et al., 2004). Supplying water to the individual household will lessen the chance of drinking water contamination during collection and storage. People's willingness to pay for water infrastructure is also likely to wane after a short period which in turn compounds the sustainable maintenance of such systems (Zwane and Kremer, 2007). On the other hand, individual household rainwater harvesting develops a sense of ownership in the consumer (Cain, 2014). Sense of ownership has a positive correlation with the user's confidence and system management (Marks et al., 2013).

DRH can also improve the overall standard of living of the rural people. Improved water supply to individual household can substantially decrease the coping cost (collection time, financial water cost, capital cost, diarrhea treatment cost) which has huge impact on the diarrhea prevalence, child nutrition condition and mortality rate (Pickering and Davis, 2012). The median coping cost of poor water supply can be equal to 12.5% of reported cash income which is higher than the utility cost in water supply in USA (Cook et al., 2016). Improvement of water supply and sanitation also has greater economic benefit. An estimation showed that every dollar invest in water supply and sanitation gives $4.3 in return (World Health Organization, 2012). Different studies have demonstrated notable water saving potential and economic gain from domestic rainwater harvesting (Imteaz et al., 2011; Rahman et al., 2012).

People have been utilizing the rainwater harvesting technique to store and supply water since ancient civilizations. Evidence of rainwater harvesting construction has found in southern Jordan which is believed to be 9000 years old (Boers and Ben-Asher, 1982). Despite huge benefits, rainwater harvesting still lacks proper recognition in water policy or investment plan (United Nations Environment Programme and Stockholm Environment Institute, 2009). The potential of domestic rainwater harvesting for supplying potable and non-potable water has been shown in many studies (Basinger et al., 2010; Chiu et al., 2015). Imteaz et al., 2013 analyzed the performance of different combinations of storage tank and catchment area for different climatic condition in Melbourne. Akter and Ahmed (2015) have assessed the rainwater harvesting potential for an urban community in Bangladesh using multi-criteria decision analysis techniques. One study indicated that rainwater harvesting system in Goa University recharged 260 m^3 of water using a 400 m^2 catchment area in 2008 (Centre for Science and Environment, 2014). Despite high population density in the capital of Bangladesh, Karim et al., 2015 showed the potential of DRH system to fulfill partial domestic demand (up to 15–20% of the time of a wet year) using 140–200 m^2 catchment area.

Most of these studies have analyzed rainfall data from gauge networks limited in sampling to test the feasibility of rainwater harvesting. Traditional gauged measurement provides the magnitude of rainfall only at a point location. In developing countries, the in-situ stations are sparsely located and often have short, incomplete records (Cowden et al., 2008). Due to poor institutional capacity and lack of collaboration between meteorological agencies, it is challenging to get long term freely available in-situ meteorological data of south-Asia with good areal coverage (Hossain and Katiyar, 2006; Hossain et al., 2007; Balthrop and Hossain, 2009). For large scale regional feasibility analysis of DRH, spatial distribution of climatology of rainfall data for whole region is required. High resolution satellite rainfall data have the potential to provide us with the spatial and temporal coverage needed for such analyses. Rainfall estimation using remote sensing is therefore more appropriate for hydrological applications in developing countries (Hossain, 2015). High resolution satellite images can be used to approximate the roof area which is a key design component of domestic rainwater harvesting.

In this study, the feasibility of domestic rainwater harvesting in South Asia was assessed by using the following: i) long-term monthly rainfall climatology from high resolution satellite data; ii) approximate roof area derived from remote sensing images, and iii) concepts of water balance used in conventional water management. Imteaz et al., 2012 indicated that monthly water balance model overestimates the size of storage tank while daily water balance model evaluates it more precisely. However, as this study focuses more on the spatial variability of a large area in a very fine resolution, the use of monthly water balance model is reasonable.

The specific science question that is addressed in this paper is – *What is the geographic variability of feasibility of domestic rain water harvesting for meeting the potable and non-potable water demand in South Asia?*

2. Study area and data

Six developing countries (Bangladesh, India, Pakistan, Nepal, Bhutan and Sri Lanka) from South Asia were selected as the study region for this paper (Fig. 1). South Asia is a densely populated region with more than 500 million people earning than a US$ 1.25 daily income (World Bank, 2013). The precipitation pattern of this region is mainly dominated by the Indian monsoon resulting huge amount of rainfall during the summer monsoon.

The Climate Hazards Group InfraRed Precipitation with Stations (CHIRPS) version 2.0 dataset was used for analyzing gridded precipitation climatology (Funk et al., 2015). The dataset covers the area from 50°S to 50°N along all longitudes. CHIRPS dataset was prepared by incorporating 0.05° resolution InfraRed (IR) satellite imagery with in-situ station data from 1981 to present. Infrared Cold Cloud Duration (CCD) observations were used to calculate the satellite precipitation and these estimates were calibrated against the Tropical Rainfall Measuring Mission Multi-satellite Precipitation Analysis version 7 (TMPA 3B42 v7). The resolution of CHIRPS (0.05°) data is much finer than the more popular precipitation datasets like Global Precipitation Climatology Project (GPCP) (2.5°), Global Precipitation Climatology Centre (GPCC) (0.5°) and TRMM Multi-satellite Precipitation Analysis (TMPA) (0.25°). Funk et al., 2015 demonstrated that bias ratio (using GPCC precipitation as baseline) of CHIRPS was less than TMPA 3B42 v7

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