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Initiating rain water harvest technology for climate change induced drought resilient agriculture: scopes and challenges in Bangladesh

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Abstract: Bangladesh is primarily an agrarian economy. Agriculture is the single largest producing sector of the economy since it comprises about 18.6% of the country's GDP and employs around 45% of the total labor force. The performance of this sector has an overwhelming impact on major macroeconomic indicators like employment generation, poverty alleviation, human resource development and food security. The agriculture sector is extremely vulnerable to disaster and climate induced risks. Climate change is anticipated to aggravate the frequency and intensity of extreme weather events in Bangladesh. Drought is one of the major setbacks for the agriculture and its development. Therefore, disaster and climatic risk, especially drought management in agriculture is a major challenge for Bangladesh in achieving sustainable agricultural development. There are some regions in Bangladesh where every steps of agricultural activities from field preparation to harvesting of crops dependents on rainfall. Consequently, drought affects annually 2.5 million ha in wet season and 1.2 million ha in dry season. Another 1 million ha is saline affected. Water is a natural resource with spatial scarcity and availability. Additionally, cross-country anthropogenic activities caused a severe negative impact on water resources and eco-systems of Bangladesh in the recent years. The rivers and cannels dry-up during the dry season and make the people completely dependent on groundwater. Accordingly the contribution of groundwater as a source of irrigation has increased and surface water has declined. It is now inevitable to look for alternate water source for agriculture. Water harvest technologies (WHTs) can play an important role in this regard. WHTs can provide an additional source of water for crop production at the most critical stages of the growing season, thereby increasing yields and food security. The study is consists of drought scenario analysis, GIS based drought mapping and systematic literature review on RWHTs as drought mitigation option in Bangladesh. Locations of twenty eight (28) weather station of

Bangladesh Metrology Department (BMD) were considered for the analysis and mapping of drought. Standardized Precipitation-Evapotranspiration Index (SPEI) data were classified for severe and extreme drought event. Inverse Distance Weight (IDW) method was used to interpolate the point data for spatial mapping of drought severity using standard GIS procedure. There are potentials for conserving and utilizing rain water for agriculture use but it is still far from being utilized as unresolved challenges including absence of business model for the upscaling of WHTs for wide scale adoption are persists.

Keywords: Drought, Resilience, Rain Water Harvest, SPEI, Climate Change, Bangladesh.

Introduction

Bangladesh is situated at the interface of the two contrasting settings with the Bay of Bengal to the south and the Himalayas to the north hence land characteristics with low and almost flat topography, multiplicity of rivers and the monsoon climate render Bangladesh highly vulnerable to natural disaster. Increasing climatic variability as a result of climate change harshly affects agriculture of the country which has a key role in tackling the challenges of the growing population viz. poverty alleviation, maintaining food security, creating improvements in terms of people's well-being (IPCC, 2012; Thornton *et al.,* 2011) and assist people to better adopt to climate change (BCCAAP, 2010). Agriculture is an important sector of the Bangladesh economy where adaptation to climate change could be usefully applied. Despite a declining share in the gross domestic product (GDP), agriculture remains the pillar of the Bangladesh economy. It represents the critical source of income for the majority of the population, and directly employing about half the total labor force (GoB, 2011). Furthermore, rural communities, that represent the vast majority of the population, will continue to depend on agriculture even with structural change in the economy (World Bank, 2013). Recently Bangladesh achieves a position of being able to produce enough rice not only to meet its food, feed, and seed requirements, but also to be left with some exportable surplus (Abdullah *et al.,* 2014). Yet, the agriculture sector is extremely vulnerable to disaster and climate induced risks. Climate change is anticipated to aggravate the frequency and intensity of extreme weather events in Bangladesh (Xenarios *et al.,* 2013). Drought is one of the major problems for the agriculture and its development in the country (Abdullah *et al.,* 2014). On average, droughts affect about 47% of the total area of Bangladesh and 53% of the population (WARPO, 2005). Levels of drought severity, constituting 7.4% at very severe (0.58 Mha), 21.7% (1.7 Mha) at severe, and 27.8% (2.18 Mha) at moderately severe of Bangladesh's net cropped area in 2012 (MoA, 2013). Thus, severe to very severe drought-prone areas accounted for 29.1% of the net cultivated area. In general drought is categorized into three types (Dai, 2011): (1) meteorological drought is a period of months to years with below-normal rainfall. It is often accompanied by above-normal temperatures and precedes and causes other types of droughts. (2) Agricultural drought is a period with dry soils that causes from below normal precipitation, intense but less frequent rain events, or above-normal evaporation, all of which lead to reduced crop production, plant growth and yield. (3) Hydrological drought occurs when river stream flow and water storage in aquifers, lakes, or reservoirs fall below long-term mean levels. Hydrological drought develops gradually because it involves stored water that is depleted but not replenished. A lack of precipitation often triggers agricultural and hydrological droughts, but other factors, including more intense but less frequent precipitation, poor water management, and erosion, can also cause or enhance these types of droughts. It is one of the main natural causes of agricultural, water resources, natural ecosystems, society and environmental damage (Burton *et al.,* 1978; Wilhite, 1993). Since Agricultural productivity still remains far below compared with other developing economies hence accelerated adoption of innovative systems and knowledge that allow for agricultural intensification and improved efficiency in the use of land, water and labor continues to be of critical importance for strengthening food and income security (Pretty *et al.,* 2011). Particularly for the rainfed agricultural systems that are associated with low production as compared to the potential that can be achieved with good crop and soil management (Ray *et al.,* 2012). Rainfall availability and distribution is a limiting factor for agriculture as water is the key driver for crop production. High seasonal variability can further lead to significant water deficits at critical stages during plant growth that can contribute to disruptions in smallholder farming activities (Rockström *et al.,* 2014). Water scarcity can lessen crop production and adversely impact food security. Water is a natural resource with spatial scarcity and availability. Additionally, cross-country anthropogenic activities (Barrage/Dams on the upstream) caused a severe negative impact on water resources and eco-systems of Bangladesh in the recent time (Abdullah *et al.,* 2014). The rivers and cannels dry up during the dry season and make the people completely dependent on groundwater. Accordingly the contribution of groundwater as a source of irrigation has increased and surface water has declined leading to ground water depletion (Abdullah, 2014). Additionally the process of ground water uptake makes the country vulnerable to Arsenic contamination. It is now inevitable to look for alternate water source for agriculture. That's why there is a growing realization that conventional irrigation practices are less suitable for these resource-constrained subsistence small holder farmers (Senay and Verdin, 2004; Kahinda *et al.,* 2007) and that the potential for improving their productivity and family incomes lie with technologies for instance rainwater harvesting technologies (RWHTs). RWHTs are a suite of approaches to improve on-site soil water infiltration capacity, enhance and create storage of water, making use of local surface run-off and maintain soil moisture during extended periods of dry-spells and drought (Karpouzoglou and Barron, 2014). RWHTs can play an important role in this regard. RWHTs can provide an additional source of water for crop production at the most critical stages of the growing season, thereby increasing yields, nutrition and food security. But scopes and challenges of RWHTs in climate change induced drought adaptation/mitigation is not clear and less documented particularly in Bangladesh situation. Hence, the objective of the study is to understand the drought scenarios and scopes, challenges of RWHTs for drought resilience in affected areas of Bangladesh.

Materials and Methods

The study is based on combination of drought scenario analysis, GIS based drought mapping and systematic literature review on RWHTs as drought mitigation option in Bangladesh. In the study drought scenario was analyzed for the whole of Bangladesh but detailed drought assessment was done for the Mymensingh district only due to its vulnerability. However, RWHT as a drought mitigation option was considered for the whole country. A new drought index, the Standardized Precipitation–Evapotranspiration Index (SPEI), developed by (Vicente-Serrano *et al.*, 2010) was used for drought mapping and scenario analysis. The SPEI is based on a monthly climatic water balance (i.e., precipitation minus evapotranspiration). It can be calculated for different time scales to monitor droughts. The SPEI is based on monthly precipitation totals and temperature means and follows a simple approach to calculate the PET based on a normalization of the simple water balance (Thornthwaite, 1948). In developing the SPEI, Vicente-Serrano *et al.* (2010) followed the same conceptual approach that McKee *et al.* (1993) devised to develop the SPI. Mathematically, the SPEI is similar to the SPI, but it includes the role of temperature. The SPEI combines the sensitivity of the PDSI to changes in evaporative demand (related to temperature fluctuations and trends) with the multi-temporal nature of the SPI. The SPEI's main advantage over other widely used drought indices lies in its ability to identify the role of evapotranspiration and temperature variability with regard to drought assessments in the context of global warming. Twenty eight (28) weather station locations of Bangladesh Metrology Department (BMD) were considered for the analysis and mapping of drought. SPEI data were classified for severe and extreme drought event. Inverse Distance Weight (IDW) method was used to interpolate the point data for spatial mapping of drought severity. The IDW interpolation is a method which is largely a reflection of Waldo Tobler's first law in geography which state that "everything is related to everything else, but near things are more related than distant things" (Tomislav, 2009). In this study IDW was utilized as a mapping technique which is an exact, convex interpolation method that fits only the continuous model of spatial variation. The IDW derives the value of a variable at some new location using values obtained from known locations (ESRI, 2005). Bar graph of SPEI data were prepared to understand the evolution of drought at different lag (3, 6, 24 and 48 month). All the graphs were prepared using R statistical software. SPEI graph and its spatial mapping were done to identify drought prone area, severity, duration, onset, extent and end. Scopes on rain water harvesting for crop production that are currently unfolding within multiple challenges were also discussed. This study therefore complements existing research on RWHTs in Bangladesh. The analytical approach further offers greater scope for understanding the institutional, political and policy pre-conditions for connecting agricultural innovations e.g. RWHTs. RWH used for decades in Bangladesh, but it is still far from being utilized to its full potential as unresolved challenges prevent its wide scale adoption.

Results and Discussions

Analysis of drought scenario and mapping

Drought is among the most detrimental, and least understood, of all "natural" hazards. Though some droughts last a crop calendar and affect only small areas, the instrumental and paleoclimate records show that droughts have occasionally continued for decades and have impacted wide areas. The negative societal consequences of drought include extreme economic losses, famine, epidemics, and land degradation (Beguería *et al.*, 2010). SPEI based spatial temporal mapping of drought shows (Figure 1) that Bangladesh is prone to both extreme and severe drought event. Considering the agricultural drought; north-western and middle-eastern part are most vulnerable to extreme drought. However, middle of the country and south-eastern part are vulnerable to severe drought. This is due to regional high temperature and its influence on evapotranspiration. As some time evapotranspiration exceeds the amount of rainfall. The country is highly depending on monsoon due to its geographic location. So, pattern of monsoon rainfall determines the nature of drought intensity. Every year Bangladesh experiences a dry season for 7 months, from November to May, when rainfall is normally low. Hence, drought mostly occurs in pre-monsoon (March to May) and post-monsoon (October to November) seasons in Bangladesh (Banglapedia, 2006). Beside this, inadequate pre-monsoon showers, a delay in the onset of the rainy season or an early departure of the monsoon may create drought conditions in Bangladesh. It is also evident that number of severe drought event occurs more than that of extreme drought event. Different SPEI series were obtained for different time scales (lag) representing the cumulative water balance over the previous n months. Short lag time scales display a strong relationship with variations in soil moisture that determine water availability for vegetation and agriculture, whereas water resources in reservoirs are mostly related to longer time scales (Beguería *et al.*, 2010; Vicente-Serrano *et al.*, 2011). SPEI value at different lag shows the intensity of drought related to different ecosystem e.g. seasonal lag (3, 6 month lag) for agricultural drought and long-term (24, 48 month lag) for hydrological drought (Figure 2 and 3) in the Mymensingh district of Bangladesh. In the bar graph red color represents the drought intensity and the blue color represents the wet intensity. Mymensingh is an agriculturally important but a drought prone district having above average rainfall in Bangladesh. In Mymensingh drought intensity and frequency does not have distinct pattern in the 3 and 6 month lag due to recurrent drought in a short time. Both the intensity and frequency is clear for the period of 24 and 48 month lag representing the hydrological drought. Intensity of drought was classified in Table.1. So, the SPEI is mostly suited for detecting, monitoring, and assessing the drought conditions. Long-term SPEI shows a spatial temporal pattern of drought. It also gives information on past global change event related to climate change induced drought in Bangladesh. SPEI derived drought shows the longest duration and highest severity was occurring during the 1970s, 1985s, 1995s and 2010s. These periods correspond to highest temperature and lower precipitation anomalies as observed by residual rainfall and residual temperature (Figure 4). The main reason for rainfall variability in Bangladesh due to it situates in the monsoon region of South Asia and surrounded by the Bay of Bengal and Indian Ocean to south, iced cap Himalayan range to the north. Hence, any change of monsoon climate makes Bangladesh sensitive to different natural calamities. More precisely, it could be said that the north-west region is just south of the foothills of the Himalayas, where monsoon winds turn west and north-west. The mean annual rainfall of Bangladesh is about 2,300 mm. But, the average annual rainfall in north-west region is 1,329 mm, whereas the north-east part of the country is 4,338 mm. Moreover, in terms of space and time, there has been observed wide fluctuations, with about 80 % of the annual rainfall occurs during July to October and almost no rainfall during winter season (October to March) at national level (Hossain *et al.*, 1987). This also justifies the need for RWHTs as a tool for drought adaptation and mitigation for agricultural development in Bangladesh.

Table 1 - SPEI based drought intensity classification.

Range	Condition
$SPEI \leq -2$	Extreme dry
$-2 < SPEI \leq -1.5$	Severely dry
$-1.5 < SPEI \leq -1$	Moderately dry
$-1 < SPEI \leq 1$	Near Normal
$1 < SPEI \leq 1.5$	Moderately wet
$1.5 < SPEI \leq 2$	Severely wet
$SPEI \geq 2$	Extremely wet

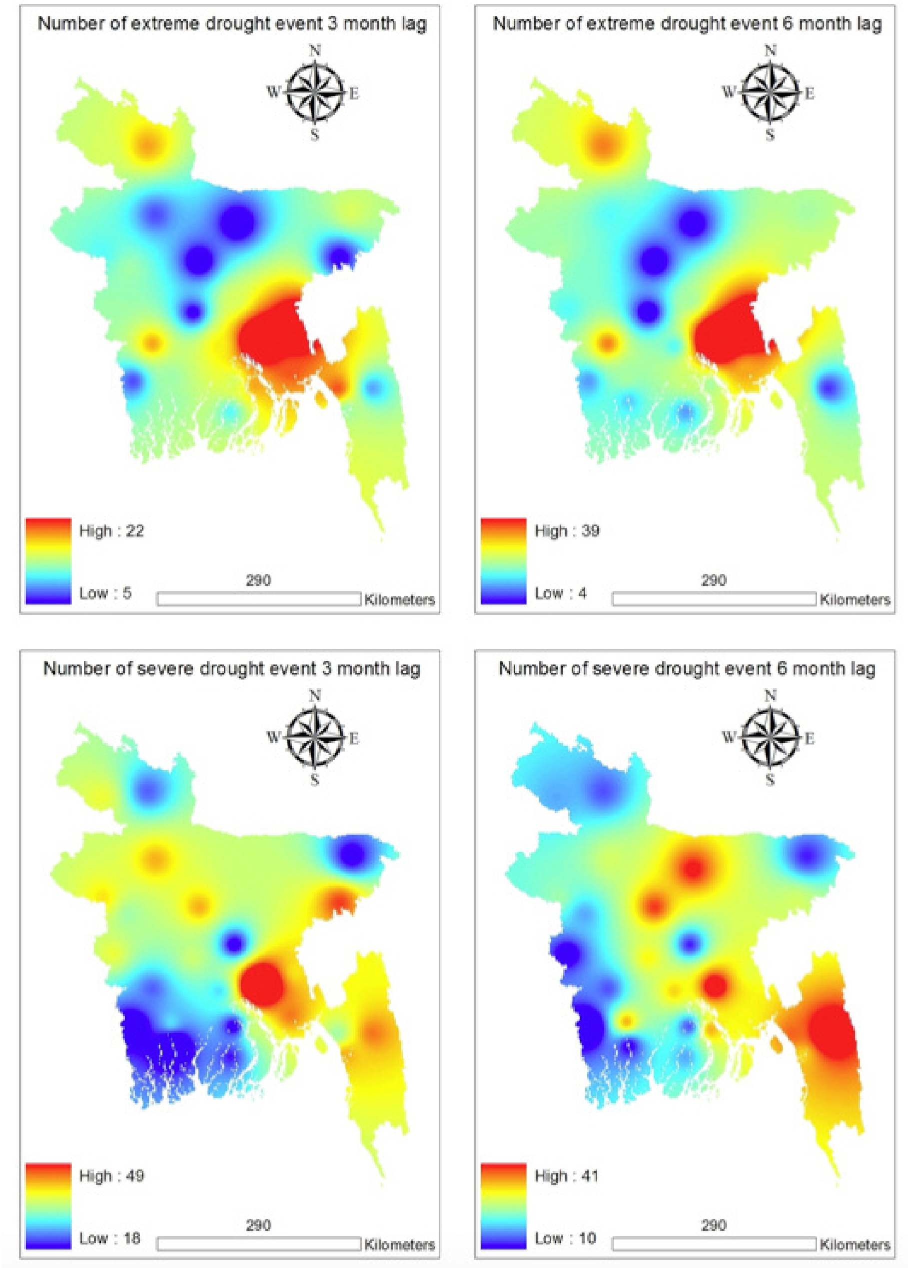

Figure 1 - Number of agricultural drought events – extreme at 3 and 6 month lag (top) and severe at 3 and 6 month lag (bottom) since 1970-2011 showing the saptial temporal pattern of drought in Bangladesh.

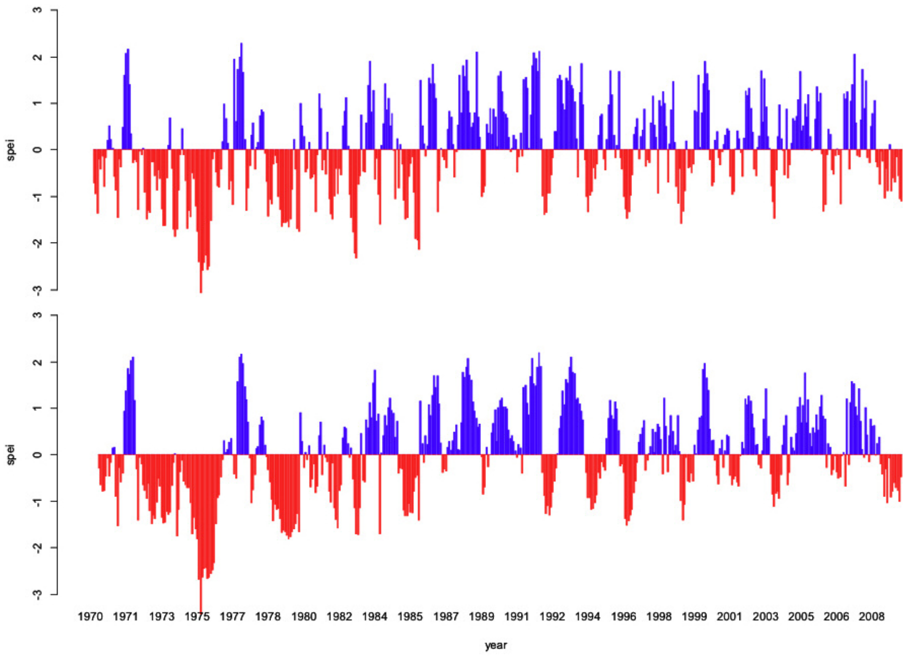

Figure 2 - SPEI based agricultural drought 3 month lag (top) and 6 month lag (bottom) in Mymensingh (24.73º lat and 90.42º lon), a drought prone district in Bangladesh.

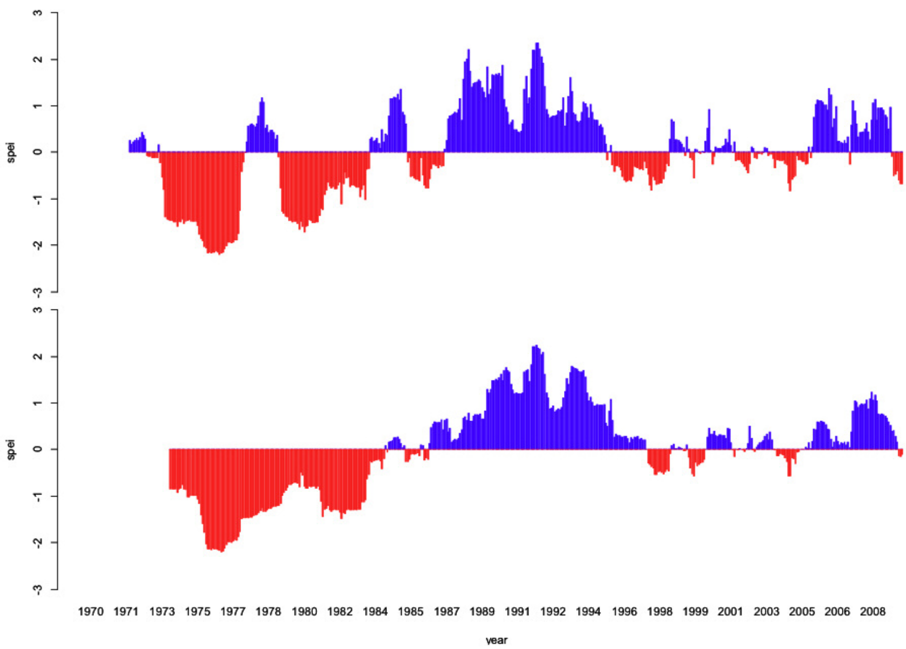

Figure 3 - SPEI based hydrological drought 24 month lag (top) and 48 month lag (bottom) in Mymensingh (24.73º lat and 90.42º lon), Bangladesh.

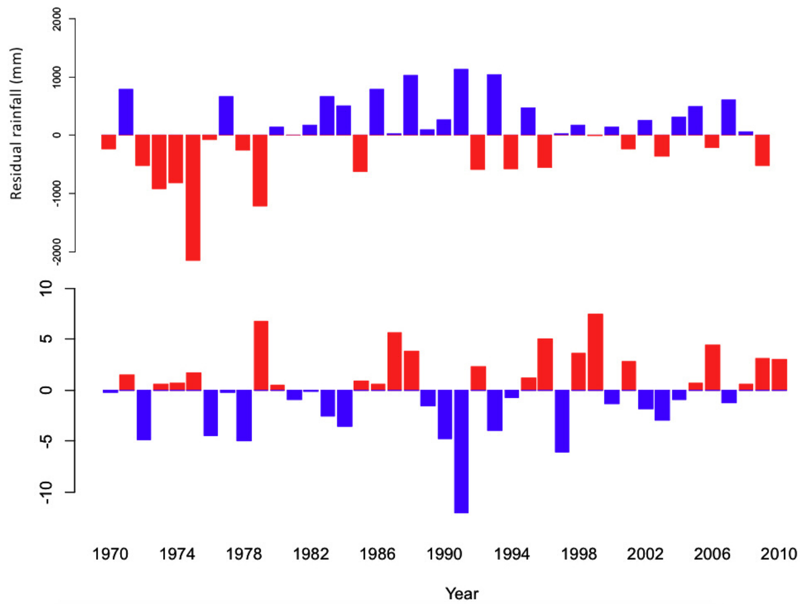

Figure 4 - Residual rainfall (top) and temperature (bottom) of Mymensingh (24.73º lat and 90.42º lon), showing the driver of drought in Mymensingh, Bangladesh.

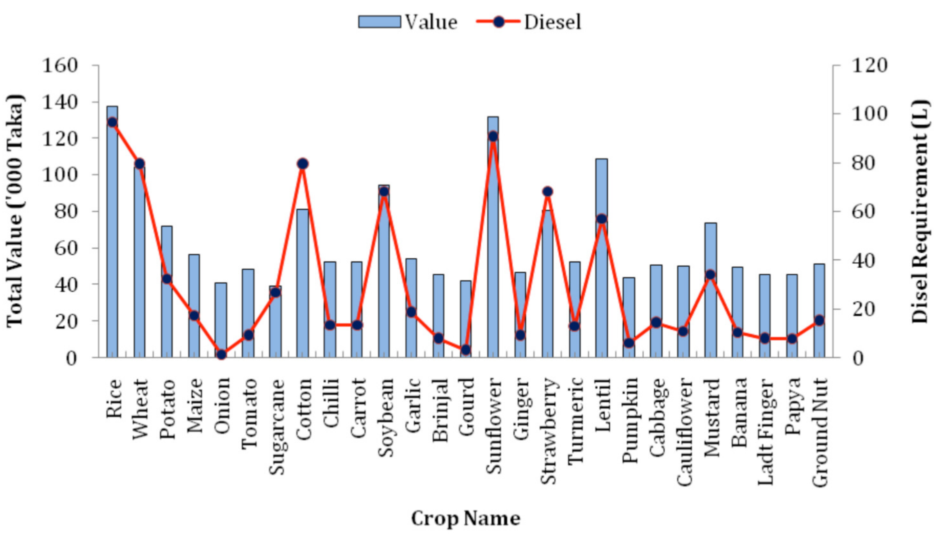

Figure 5 - Cost calculation of diesel powered irrigation (cost includes initial pump cost and number of irrigation in a crop cycle) (Modified from Tareek et al., 2013).

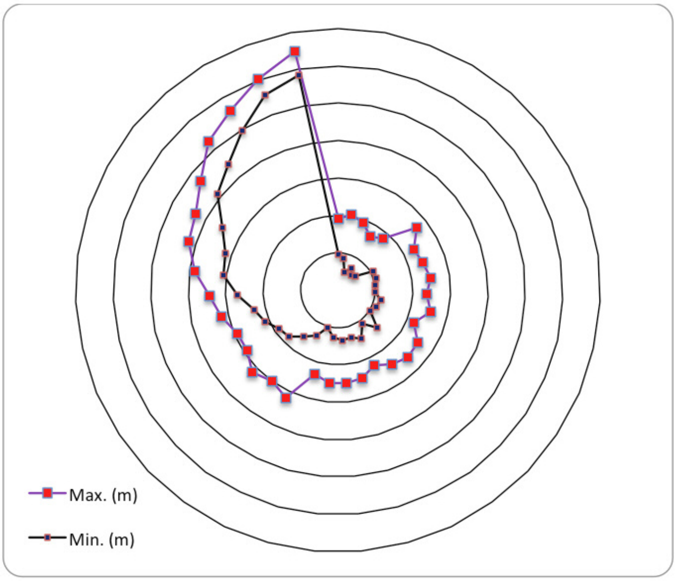

Figure 6 - Year wise groundwater depletion near Mymensingh (BRRI 2014) since 1979-2013.

Scopes

Bangladesh has been blessed with huge amount of rainfall. Every year there is about 2320 mm of rainfall (Murshed *et al.*, 2011) which replenish ground water a key source of irrigation and serve as drivers to make the country self sufficient in food production as well as for climate change adaptation leading to sustainable agricultural intensification (BADC, 2003). But due to heavy extraction of groundwater for irrigation during cropping season triggers water table depletion which is the main constraint for the development of dependable irrigation water supply (Zahid and Ahmed, 2006). Therefore, rainwater harvest offer a viable alternative for smallholders farmers (Getnet and Macalister, 2012; Kassie *et al.*, 2013) since it provide enough water to boost agricultural yields and outputs in drought and saline affected environments and stabilized food production (Hanjra *et al.*, 2009) and the revenue from the agriculture sector (Sampath, 1992). Additionally, RWHTs are a suite of approaches to improve on-site soil water infiltration capacity, enhance and create storage of water, making use of local surface run-off and maintain soil moisture during extended periods of dry-spells and drought (Critchley and Scheierling, 2012). In Bangladesh the rate of growth in agriculture and per capita cultivable land came down gradually over the past few years due the combined effect of shrinking acreage and rising population (Unnayan Onneshan, 2014b). As a result, the pressure on land is immense, often with detrimental implications on productivity (Rahman, 2010). Though, production of crops in Bangladesh has been gradually increasing over the last few decades which are assumed one of the good indicators for food security, but future sustainability in this sector may be plagued due to high scarcity of irrigation water (Unnayan Onneshan, 2014a). The shortage of water in coastal areas is becoming severe in the South Western Coastal parts of Bangladesh (Harun and Kabir, 2013). As a result of water scarcity, communities are facing high food insecurity (Yu *et al.*, 2010) as they are not being able to explore and produce food through agricultural interventions.The burden of livelihood security has been largely threatened by the loss of productions due to the saline intrusion and significant transformation from rice-based farming systems to shrimp aquaculture (Ahmed *et al.*, 2009), with numerous adverse effects on the food security of the coastal population. There is a decline in vegetable production and homestead gardening practice due to high salinity and scarcity of irrigation water especially in summer season (Habiba *et al.*, 2011; Shahid, S., 2011). This problem can be overcome by wise adoption of RWHTs. In Bangladesh, about 56% crop land is under irrigation. It signifies that, roughly 44% cropland is rainfed either partly or full (Unnayan Onneshan, 2014b). Moreover, climate change, particularly the higher temperature increases the evapotranspiration resulting in more water demand and exploitation of groundwater, scarcity of groundwater resources. Significantly high rainfall variability is observed in the drought-prone areas, with different types of seasonal droughts (initial, mid and terminal) posing major threats to agricultural production. Yet, often, high intensity of rainfall is wasted due to non-availability of proper storage structures (Gould and Nissen-Petersen, 2003). So, it is needed to concentrate on WHTs, recycling and conservation. Harvesting rainwater is not only water conserving, it is also energy conserving since the energy input requires to operate water pump throughout the growing season. By capturing water directly, it can significantly reduce reliance on electricity and diesel driven water pumping system. It can reduce the cost of crop production involve in irrigation purpose (Figure 5) and reserve foreign currency for buying fosilfuel. Rainwater harvesting lessens local soil erosion and flooding (Solh and Ginkel, 2014) caused by the rapid runoff of water from impervious cover such as pavements and roofs as some rain is instead captured and stored. A reduced level of storm water requires smaller sized storm water drainage systems and also helps in reducing soil erosion into the waterways, preventing damage to the surrounding areas. The concept of rainwater harvesting varies from region to region however, the overall concept for adoption RWH is precised well by Southface Energy Institute (2002), mentioned as; Save money, avoid the increasing economic and environmental costs associated with irrigation water. Save energy, by reducing water use, energy demands to pump water. It is further demonstrated, that rainwater harvesting can contribute to the realization of larger agricultural transformations with simultaneous ecosystem services, environmental, economic and societal benefits (Table 2). Apart from the increasing yields, RWHTs provide smallholder farmers with an essential climate adaptation mechanism for dealing with climate variability as well

Table 2 - Rainwater harvesting technology relevance to different transformation domains and ecosystems services.

Transformation domain	Rainwater harvesting technology relevance	Relevant study
Societal	Climate change adaptation Food security Water availability	Deressa *et al.*, 2009 Tesfaye *et al.*, 2008 Falkenmark and Rockström (2004)
Economic	Household income improvement Staple crop yield increase	Hatibu *et al.*, 2006 Fox and Rockström (2003)
Environmental	Restoration of degraded landscapes Soil structure and fertility	Barron (2009) Stroosnijder (2009)
Ecosystems Services		
Provisioning	Can increase crop productivity, food supply and income. Can increase water and fodder for livestock and poultry. Can increase rainfall infiltration, thus recharging shallow groundwater sources and base flow in rivers. Can regenerate landscapes increasing biomass, food, fodder, fibre and wood for human consumption.	Poverty-Environment Partnership (PEP). 2006.
Regulaing	Can affect the temporal distribution of water in landscape. Reduces fast flows and reduces incidences of flooding Reduces soil erosion. Can provide habitat for harmful vector diseases bridges water supply in droughts and dry spells.	Hobbs *et al.,* 2008
Cultural	Rain water harvesting and storage of water can support spiritual, religious and aesthetic values. Creates green oasis/mosaic landscape which has aesthetic value.	Malesu *et al.*, 2008
Supporting	Can enhance the primary productivity in landscape. Can help support nutrient flows in landscape, including water purification.	World Resources Institute (WRI), 2005

as improving resilience against droughts and dry spells (Mapfumo *et al.*, 2013). By increasing water availability, RWHTs contribute to reducing the risk of crop failure, and securing other crop management investments (nutrients, weeding, pest and disease management) while also improving water utilization at the individual crop level (i.e. more yield per drop of water) (Rockström, 2003; Welderufael *et al.*, 2008). RWHTs have also been proposed as a measure to improve degraded land and production capacity in saline affected soil systems and have desired impacts on hydrological processes (Bouma *et al.*, 2012). Improved on-farm water management, based on a scenario of increased adoption of rainwater harvesting has been projected to increase global crop production by almost 20% (Rost *et al.*, 2009).

Challenges

It is now widely recognized that Bangladesh represents one of the most sensitive hotspots for climate change and climate-related extreme events (World Bank, 2013). Frequent local droughts in Northwestern Bangladesh cause greater yield losses relative to flooding and submergence (World Bank, 2013). It also justified the World Bank (2013) reports that, Bangladesh's water security threat was extreme, varying between 0.8 and 1 (0 – no apparent threat, 1 – extremely threatened). This poses a great threat for current and future water demand for agricultural intensification. Empirical evidence manifest that, with increasing irrigation area towards food production, groundwater irrigation coverage area also increases i.e. from 41% in 1982/83 to over 80% in 2010/11, while surface irrigation declined from 59% to less than 20% over the same period (BADC, 2011; Planning Commission, 1997). Drastic reduction of surface irrigation area (pond, cannel, and river) reveled that potential natural area for rain water storage decline over time. It forces the farming community towards pumping irrigation leading to depletion of ground water table. Long-term ground water table record showed that the useable water layer is going downward over the years (Figure 6). Each farm in the country had ponds in the past which usually serve as a water reservoir but with time those pond and wells are disappeared. This lead to increase cost of RWHTs as some RWH techniques require infrastructure development and high labor input during their implementation phase (DTI, 2001). The cost of implementation becomes a burden for drought vulnerable poor farmers as approximately 31.5 percent of the population is living below the poverty line (Unnayan Onneshan, 2014a) thereby rural communities have limited resources for the establishment of RWHTs. Unfortunately, to date, public agricultural development schemes (supported by both bilateral and multilateral aid programmes) or international NGOs financing RWHTs is very limited. However, this funding stream is not the most efficient means for consistent and successful up-scaling; as smallholder farmers may decide to abandon RWHTs once the funding period comes to end. While

RWH increases water availability at the root zone and help reduce the risk of crop failure, like traditional dry land agriculture, it still relies on rainfall. But, climate change induced erratic pattern of rainfall is another challenge to popularize RWHT. Despite some occasional research on RWHTs in Bangladesh, there is still poor knowledge and data on critical drivers and processes, alongside those that shape RWHTs adoption at a local level that can accelerate the spread and utilization of different RWHTs. In addition, there are few studies that address specific knowledge gaps associated with factors influencing RWHTs adoption beyond the scale of the homestead, including appreciation of the wider farmer capacity, environment, access to markets and fair pricing mechanisms, the importance of the political context and the existence of supportive institutions and policies (Boelee *et al.*, 2013). Additionally, extension services are especially lack for RWHTs up-scaling.

Conclusion and recommendation

Introducing water harvesting to improve soil health, productivity in crop production promises large social, economic, and environmental paybacks, principally in poverty reduction, economic development and environmental conservation in Bangladesh. WHTs present a low-cost approach for mediating dry spell impacts in rainfed agriculture. WHTs are a traditional practice in certain regions, but the transferability of these models and practices has so far been very limited. There are some barriers/drivers to upscale WHTs. In this regard, rainwater harvesting in rainfed agricultural systems has the potential to strengthen climate adaptation and resilience, while contributing to the production of adequate food for growing population in Bangladesh. An important research priority that emerges from this study, therefore, is the need to adopt a system perspective and to consolidate processes of change at different spatial and temporal scales. Such a perspective can enable better-targeted investments and a deeper understanding of the opportunity context for facilitating accelerated adoption of rainwater harvesting. Rainwater harvesting seems to be a beneficial method for minimizing water scarcity in developing countries. It is essential that local materials and man- power is to be used to spot catchment areas and build up harvesting systems. Nevertheless, RWH is used for centuries in Bangladesh, but it is still far from being utilized to its full potential therefore awareness on RWH should be increased by technocrats, practitioners and policy makers, to appreciate its potential and ecosystem benefits for human well-being. Key recommendations resulting from this research are:

1. Essential policy should be formulated by the policymakers emphasizing the RWHT as a recognized method of irrigation which is currently absent in Bangladesh;
2. Awareness building program should be initiated to motivate smallholder farmer to introduce RWH system in the farm;

3. Design a business model to ensure adequate fund through microcredit, cooperative farmer group and government subsidy to install RWH system by small holder farmer;
4. Pilot RWH system could be scale-up first at garden scale (homestead) then to field scale;
5. Related extension activities should be undertaken to spread information regarding technical knowhow;
6. Conduct more research on limits and barrier of RWH system adoption in Bangladesh.

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