Rainwater harvesting for irrigation for climate-resilient and circular food systems

The case of Ghana’s Bono East Region

Vincent Linderhof, Walter Rossi Cervi, Cora van Oosten, Confidence Duku, Emese Witte, Mercy Derkyi, Mary Antwi, Valerie Fumey Nassah, Vassileva Ralitsa, Seth Kankam Nuamah, Albert Damoah, Ama Acheampomaa Asiedu, Stephan Aning Kwadwo

WAGENINGEN UNIVERSITY & RESEARCH

Ministry of Agriculture, Nature and Food Quality

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P.O. Box 88, 6700 AB Wageningen, The Netherlands. T + 31 (0)317 48 68 00, E info.cdi@wur.nl, www.wur.eu/cdi.

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1 Introduction

To feed a word population of 9.1 billion people in 2050, the Food and Agricultural Organization (FAO) estimates that we will need an increase in food production of 70% globally (FAO 2009). If the current rate of land degradation is not halted, global food production can be reduced up to 12%. Additionally, the price of commodities may increase by 30% in the period 2010-2030 (De Pinto et al. 2020). This challenge needs an integrated approach as sectoral approaches have been shown to be inadequate, such as agricultural intensification (Sayer et al. 2013).

In Ghana, the major cause of deforestation is the human competition over land. There is a rising demand for food and other resources such as wood due to population growth (Acheampong et al. 2020). Agriculture and forests should no longer be approached as competing land uses, but more in terms of win-win. Farmers need to be able to rely on food production in a forest-farm mosaic (Acheampong et al. 2020). Besides, forests play an important role in the socio-economic status of people in Ghana, specifically in the rural areas. The rural population forms about 60% of Ghana's total population. Alongside the production of food, forests provide for wood, building materials along with different ecosystem servicers (PROFOR 2011).

Global climate change is putting pressure on natural resources, endangering livelihoods and food security. This is especially worrying in rural areas in countries heavily reliant on agriculture where land is degrading as result of deforestation and unsustainable agricultural practices, driven by the demand of food and energy supply. Ghana has set up different projects to rehabilitate forests and landscapes in order to increase food security and become more climate resilient. These so-called Forest Landscape Restoration (FLR) projects are meant to enhance economic opportunities and livelihood security equally important to ecological benefits (Miyuki 2013; Ministerie van Buitenlandse Zaken 2019; Kumar, Calmon, and Saint-Laurent 2015).

The Ghana National Climate Change Adaptation Strategy (NCCAS), developed for the period 2010–2020, has the primary goal of "enhancing Ghana's current and future development to climate change impacts by strengthening its adaptive capacity and building resilience of society and ecosystems" (Government of Ghana 2012). In particular, agriculture, which is the largest employer in Ghana, will be affected by the changes in the variability of rainfall, which makes yield and production more uncertain as well as farm income (Government of Ghana 2012). The temperature increases will result in prolonged droughts and more frequent incidences with bush fires, and environmental degradation (Government of Ghana 2012). The water availability largely depends on precipitation. Vulnerability to climate change in Ghana is spatially and socially differentiated. Each ecological zone has peculiar physical and socio-economic characteristics that define their sensitivity and resilience to climate change impacts.

Droughts are a major problem for the northern and coastal savannahs with increasing significance for the transitional zone. Climate variability in terms of fluctuating weather conditions increases the vulnerability of the bulk of the population who depend on natural resource based activities for their living. Variability of rainfall has serious consequences for farmers in the transition and forest zones where slight changes in weather conditions affect cocoa and fruits such as pineapples, mangos, papaya etc. (Government of Ghana 2012).

For crop production systems in Ghana, there are several management practices provided in the literature that enable smallholder farmers to adapt to climate change and variability, such as rainwater harvesting for irrigation (Olesen et al. 2013; Biazin et al. 2012). This study investigates the drivers of rainwater harvesting for irrigation in the Bono East Region. In this way, rainwater harvesting for irrigation can contribute to a climate-resilient and circular food system in Bono East Region and beyond. As Bono East Region is one of the food baskets of Ghana, the food production in this region should be preserved in the future as well. Based on a literature review, stakeholder workshops and field work, we identify the drivers of rainwater harvesting for irrigation in Bono East Region, Ghana.

Chapter 2 presents the history, typology of rainwater harvesting as well as the link with the food systems framework. Moreover, Chapter 3 summarizes the rainwater harvesting for irrigation examples in Ghana. Chapter 4 presents the drivers of rainwater harvesting for irrigation that should be considered when looking into the potential of rainwater harvesting for irrigation in Bono East Region. Chapter 5 concludes.

2 Bono-East Region

2.1 Topography

The Bono East region, is a part of the former Brong Ahafo region in Ghana, see Figure 1. The capital of Bono East Region is Techiman and the region comprises of 11 different districts. The region lies in the transitional zone from Savanna to temperate climate and the green vegetated belt in Ghana. The Northern and North-Eastern region are Guinea savannah woodland, transitioning to semi-deciduous (tree species with broad leaves which are leafless only for a very short period of time) forest in the South-West area. There are many forests and soils suited for agriculture. National reserves that are present in the area are the Boabeng Fiema Monkey Sanctuary and Digya national Park (Visit Ghana, 2021).

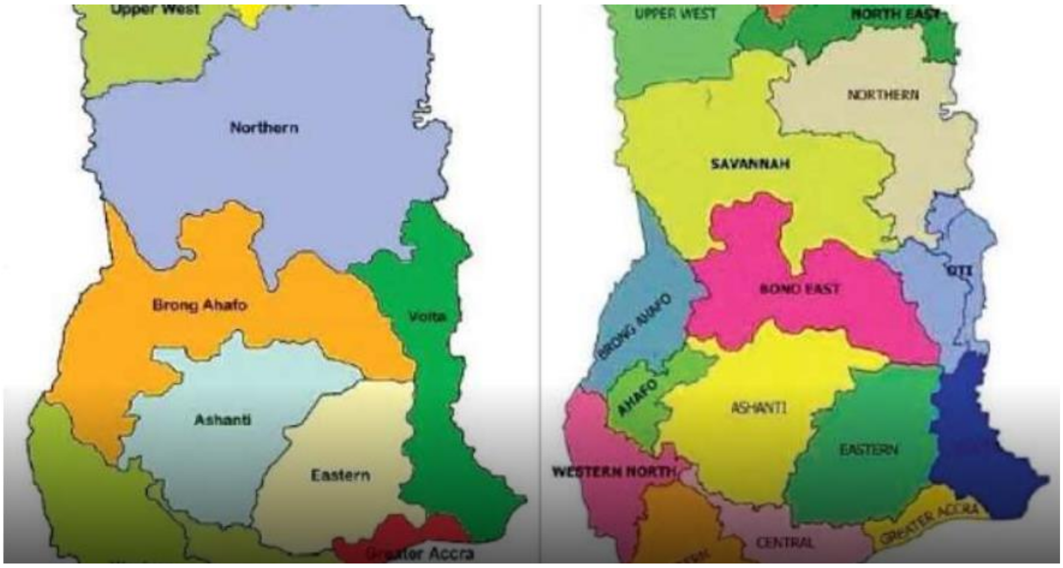


Figure 1 *Map of Bono East region as former part of Brong Ahafo Region (Okertchiri 2019).*

The East border of the region is at Lake Volta, one of the biggest fresh water reservoirs worldwide, with surface area of 8,462 km2 (ESA 2005). Furthermore, the Tano river flows through the region from 4 km away from Techiman towards Ivory Coast (Water Resources Commission, 2021).

2.2 Demography and economy

In 2019, the population of Bono East Region was approximately 1,200,000 in 2019 and it grows with 2.4% annually (The World Bank 2019; Ghana Statistical Services 2019). Over the last years, more and more people have migrated from the Bono East Region to urban centres. Youth looking for educational and employment opportunities are attracted by cities like Accra and Kumasi (Tanle et al. 2020). in the Bono East Region, agriculture is the dominant economic activity. This sector still has potential to expand in Bono East Region and contribute to food security of the population. The majority of the work force in Bono East Region (61%) is employed in the agricultural sector (‘Bono East Region – Bono East Regional Coordinating Council’ 2020). In 2015 72.6% or the employable population was employed in the Brong Ahafo region (Ghana Statistical Services 2016).

The Bono East Region has always been a region of food production. Although there are no data on the share of agriculture and related sectors in the GDP of the region, the development of the Agriculture, forestry and fishing sector in Ghana is presented. Figure 2 shows that the share of value added of Agriculture, forestry and fishing in total GDP of Ghana is declining. The importance of Agriculture, forestry and fishing in the Gross Domestic Product is declining. In 1990, the share of Agriculture, forestry and fishing in GDP was 45%, while in 2020 it was less than 20%. This decline of the share of Agriculture, forestry and fishing in GDP is much steeper for Ghana than for the aggregate of the countries in Western and Central African, see Figure 2.

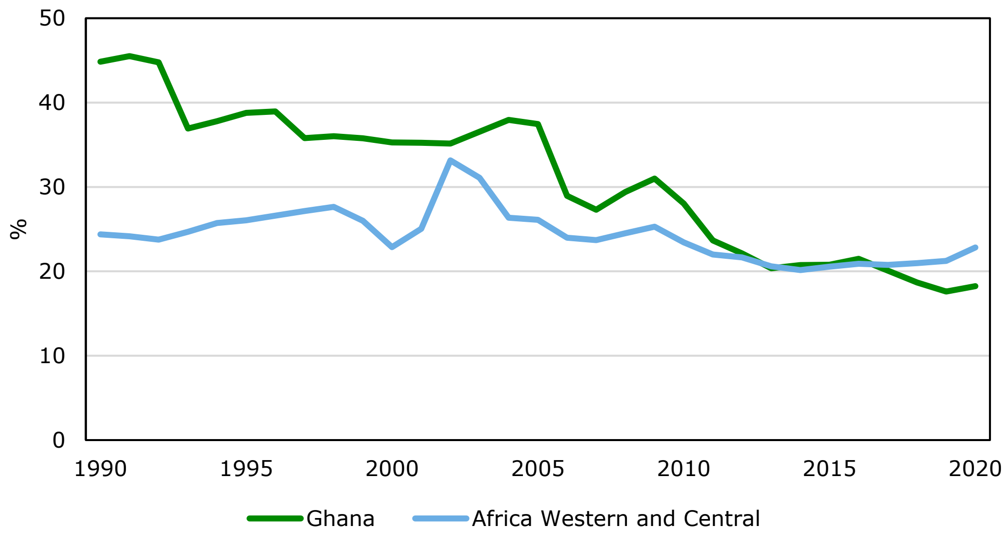


Figure 2 *Development of the share of the value added of the Agriculture, forestry, and fishing sector in total Gross Domestic Product (GDP) of Ghana and the region of Western and Central Africa, 1990-2020.*
Source: data.worldbank.org

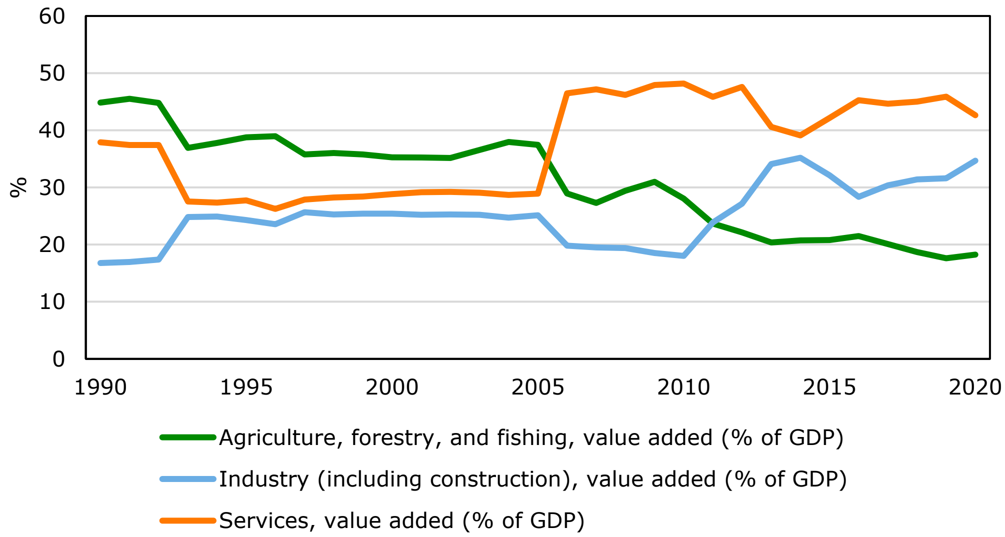


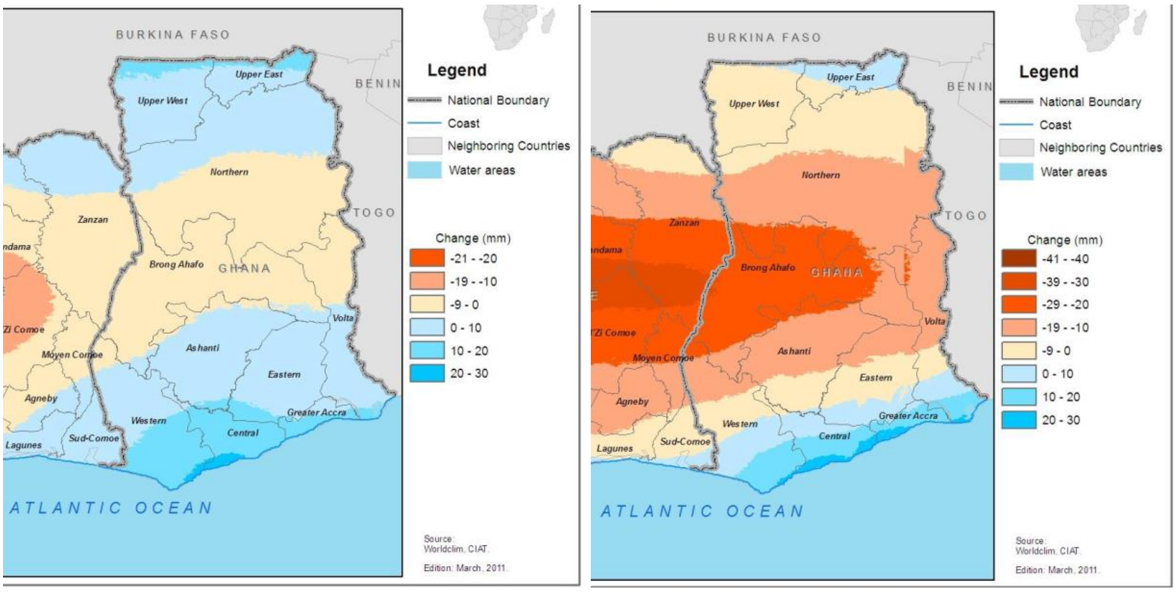
Figure 3 *Development of the share of the value added of three sectors in total Gross Domestic Product (GDP) of Ghana, 1990-2020.*
Source: data.worldbank.org

As the share of Agriculture, forestry and fishing gradually declines, the share of Industry sector increased form 2005 onwards, and the share of Services increased from 2010 onwards.

2.3 Climate and climate change

The annual rainfall is between 750 mm and 1050 mm, and falls mainly in the wet seasons from July to November. With temperatures ranging between 14 degrees Celsius at night and 40 degrees Celsius at day, the annual average temperature is 27 degrees Celsius (‘Kintampo Climate: Average Temperature, Weather by Month, Kintampo Weather Averages’, 2021).

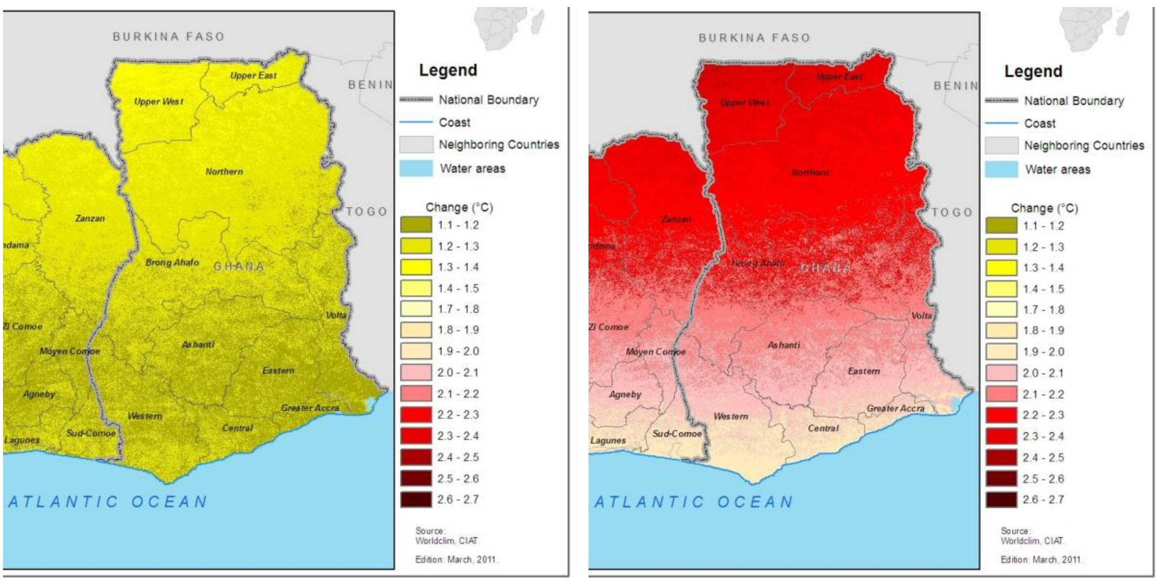
In future projections of the climate conditions, Bono East Region as part of the former Brong Ahafo region will suffice from unfavourable climatic conditions. It is expected that reductions in annual precipitation will emerge in 2030 which will double in 2050, see Figure 4.



2030 2050

Figure 4 *Change of annual precipitation in 2030 (left) and 2050 (right) compared to 2010 in the different areas of Ghana (Läderach et al. 2011).*

In addition, the mean annual temperature is expected to increase in 2030 which continues to increase in 2050, see Figure 5.



2030 2050

Figure 5 *Change of mean annual temperature in 2030 (left) and 2050 (right) compared to 2010 in the different areas of Ghana (Läderach et al. 2011).*

3 Rainwater harvesting

3.1 History of rainwater harvesting

Rainwater harvesting is defined as the management, control, and use of rainwater in situ or its storage for future use (Qadir et al. 2007). Rainwater harvesting is a practice that dates back to prehistoric times, and still forms an integral part of many domestic and agricultural systems in arid and semiarid regions (Qadir et al. 2007). There are many different ways of water harvesting and it has been done for several purposes (Velasco-Muñoz et al. 2019; Lasage and Verburg 2015).

In Ethiopia, for instance, RWHI is widely implemented in practice. There are different types of RWHI implemented, such as ponds, wells and micro-dams. All these types of RWHI collect rain water and use the soil to store water like ponds and wells, and/or use the geo-morphologic characteristics of area are used (slopes of the hills) to collect rain water. In all cases, some infrastructure by human intervention has to be provided. As mentioned above, RWHI is most often implemented to improve agricultural production, and nature and biodiversity might be affected as well, although the impact either being positive or negative is unknown. As a result, RWHI could be best classified as a "*measure can be intrinsic or inspired depending on the way how the NBS is designed*".

Rainwater harvesting has been adopted in arid and semi-arid areas in Ethiopia for decades. As RWHI has been applied for many years in Ethiopia, there are also farmers who stop using RWHI techniques. The main reasons to do so are, the number of rainfall shortage months, labor shortage, and shortage of plastic-sheet (Wakeyo 2012). Health issues, such as the potential increase of water-borne diseases like malaria due to the fact that people are more often expelled to surface water (Hagos et al. 2006), were not mentioned as a reason to stop using RWHI (Wakeyo 2012).

3.2 Typology of rainwater harvesting

Rainwater harvesting is a system designed to collect run-off water from outlying areas or from areas where it is not used, store it, and make it available where and when there is a scarcity of water. It can be used for several applications in urban and rural areas to tackle environmental, agronomic and socio-economic issues, such as urban floods, crop irrigation and human consumption. Panel A of Figure 4 shows an example from Ghana where rainwater is collected from roofs and stored in large tanks. Water collected from rooftops is often used for domestic use (cooking, cleaning, etc.). Panel B of Figure 4 shows an example of rainwater that is collected in basins, which can be used for flood protection as well as water for domestic use in cities. Panel C in Figure 6 demonstrates rooftop rainwater harvesting which is stored in tanks underground (or artificial water basins) and used for crop irrigation.

Rooftop with storage tank A | Community bassin B | Rooftop + underground storage C

Figure 6 *Rainwater harvesting examples.*

Rainwater harvesting can be strategically used to improve crop production. Many annual/seasonal crops have very narrow periods of high water demand during their growth phase. Nonetheless, irregular rainfall (boosted by the extreme events of climate change) must incur negative consequences in agricultural production, by increasing the yield gaps and many other environmental issues (e.g. erosion, soil carbon losses). To tackle these issues, RWHI should be seen as a strategy for climate adaptation in upstream stages of the food system.

The use of RWHI is a technique that is often used in production of high-value crops. Its rational and better use requires an assessment of the regional farming characteristics and the agro-ecological conditions of different sites. As an example, for very small (and flat) areas (e.g. less than 2 hectares), the use of roof collector (panel A of Figure 5) may be sufficient for application in crop production, whereas larger areas (up to 20 hectares) require more infrastructure and different terrain heights to run-off and store the rainwater either in underground tanks or open ponds (Panels B and C of Figure 5), depending on the lag between the rainfall and water demand. Nonetheless, the last two options may require several adaptations in the terrain, which demand investments and technical support from third parties (e.g. equipment, civil construction). Therefore, for a wide implementation of these systems at regional scale, a detailed spatial/stakeholder assessment of the study areas is key to identify suitable areas for RWHI. In addition, comprehending the current applicability status of these systems in Bono East (Ghana) and the willingness of the farmer (or any other investor) to invest in such a system is fundamental to disseminate this NBS for crop production.

Rooftop A | Collector of rainwater B | Bassin C

Figure 7 *Different systems for harvesting rainwater according to the size of agricultural production and the agro-ecological conditions of the area.*

As we are mainly interested in the linkage between nature-based solutions and the food system, we limit our focus of rainwater harvesting practices. On the one hand, rain water harvesting is also practiced for other reasons than food related activities (sanitation, industrial water use amongst others). On the other hand, rain water harvesting is not necessarily a nature-based solution, such as roof top water harvesting. Therefore, we focus on rain water harvesting for irrigation (RWHI) which implies harvesting, storing, and conserving rainwater directly in a farmed area or the run-off derived from a catchment area of a reservoir that is generally smaller than the size of the catchment area (Kiggundu et al. 2018). This is not only farm level rain water harvesting but it can also be at the level of catchments where several farmers can benefit from rain water harvesting like micro dams (Biazin et al. 2012). As Ethiopia is one of the countries with a long history of rain water harvesting for irrigation, we limit our geographical focus to Ethiopia.

RWHI is commonly practiced in arid and semiarid areas where the rainfall is insufficient for crop growing. It’s objective is to collect run-off from outlying areas or from areas where it is not used, store it, and make it available where and when there is a scarcity of water. As precipitation is often seasonal and variable within a season, rain water is stored throughout the year, so that it may be used at a later moment in time (Kiggundu et al. 2018; Qadir et al. 2007). This is one of the main reasons why RWHI is a nature-based solution, as it is based on the natural event of precipitation. In addition, the efficiency of RWHI also relies on characteristics of the landscape such as the slope of the land (Kiggundu et al. 2018) and the texture and structure of the soil (Tabor 1995).

3.3 Rainwater harvesting for irrigation (RWHI) for climate-resilient and circular food systems

3.3.1 Food security

The implementation of RWHI has potential benefits (Yosef and Asmamaw 2015):

i) RWHI makes agricultural production possible in dry areas which only rely on rain-fed agriculture,
ii) RWHI can increase agricultural productivity on in areas with high variability of precipitation by reducing the climate risk of droughts, and
iii) RWHI can also facilitate the cultivation of water-intensive, higher value crops at a commercial basis or for personal use in the home garden (Hagos et al. 2013).

From the perspective of the food system approach, RWHI are mainly linked to smallholders in rain-fed areas, where they are involved in the agricultural production, and own consumption of food. When RWHI is successfully bringing commercialization, then the impact of RWHI will also impact the value chain in a broader perspective.

In the literature, there is a debate on the benefits of investments in RWHI. Investments in RWHI has increased income opportunities and reduced income (Hagos et al. 2013), and it has reduced food security for smallholders farmer (Awulachew et al. 2005; Fitsume et al. 2014).

One of the disadvantages of RWHI is that farmers become more exposed to water-borne diseases due to the proximity of still water (ponds, shallow wells amongst others). This increases the health risks for these farmers and their community (Hagos et al. 2013). These health risks were not one of the reasons to stop using RWHI (Wakeyo 2012).

3.3.2 Climate change adaptation

The main purpose of RWHI is to reduce the risk of climate change (more extreme climatic events like less rain, longer periods of droughts and higher temperatures for instance) for smallholders. Among these risk-reducing investments are small-scale water-saving technologies that are often denoted as "water harvesting technologies (WHT)" (Wakeyo 2012).

RWHI is of utmost importance for improving agricultural conditions in dryland regions (Gelaw, Singh, and Lal 2014). In their study, the they highlighted that RWHI systems have significantly improved the soil water content in the root zone, leading to crop yield gains in Tigray/Ethiopia. Apart from being an important mean for increasing climate adaptation in Sub-Saharan countries, RHWI can also play important role in climate risk mitigation as it can indirectly lead an increasing C absorption by the vegetation and soil.

3.3.3 Circularity

RWHI have direct and indirect effect on circularity. Firstly, it is clear that the rainwater reuse plays a direct effect on circularity (Hagos et al. 2006). Secondly, it enables increasing biomass yield rates, which contributes to soil fertility and nutrient cycling in a long run.

3.4 RWHI in Ghana and Bono East Region

3.4.1 Ghana

The need for applying rainwater harvesting has been addressed before (Amu-Mensah, Yamamoto, and Inoue 2013). Although Ghana has sufficient water resources, it is becoming increasingly evident that the quantity and quality of the surface water resources of Ghana is decreasing (WARM Study, 1998). Rainwater harvesting is very crucial to the sustainable development of water resources and food systems which include water use for domestic, agricultural, industrial, aquaculture and ecosystems. Since rainfall incidence and amount is limited and unpredictable in many areas of its occurrence, any process that maximises the retention and collection of rainwater through minimising of the losses incurred is beneficial to the success of such resource development process (Amu-Mensah, Yamamoto, and Inoue 2013).

Figure 8 *Locations of rainwater harvesting examples from the literature.*

Why is rainwater harvesting (RWH) important for Ghana, now and in the future? (Stockholm Environment Institute and United Nations Environment Programme 2009; Boelee et al. 2013). RWH is considered to be one of the strategies to overcome impact of climate variability. Some observations of the literature and policy documents on RWH applications in Ghana:

- There is also a plead for RWH in Ghana due to expected impacts of climate change (Emmanuel and Napoleon 2019).
- There is a serious challenge for the usage of harvested and stored rainwater, which is the quality of the water (Rahman et al. 2014; Cobbina et al. 2015; Wiredu 2019).
- Rainwater is particularly a good option for rural communities to get safe water for domestic use given the limited access to public water supply (S. Owusu and Asante 2020).
- Rainwater harvesting as part of soil- and water conservation measures to increase agricultural productivity (Abdul-Hanan, Ayamga, and Donkoh 2014).
- In 2012, RWH for rural small holders was already advocated as a way to adapt Ghana's food production to climate change and reduce climate-vulnerability (Antwi-Aygei 2012).

In 2011, the Ministry of Water Resources, works and Housing (MWRWH) of the Republic of Ghana published the National rainwater harvesting strategy (MoWRWH 2011). One of the statements of this National Rainwater Harvesting Strategy is that the Ministry of Food and Agriculture (MoFA) and Ghana Irrigation Development Authority (GIDA) are responsible for developing irrigation reservoirs that harvest rainwater for agriculture (MoWRWH 2011). MoFA implements RWH for agricultural production through various irrigation schemes. On the GIDA website), there is no word on rainwater harvesting. However, upscaling of RWH is required but it faces challenges and opportunities (SINTEF 2015). Moreover, application of GIS approaches or landscape approaches (Hari 2019) and an application for Ghana (S. Owusu et al. 2017) can be helpful with upscaling to identify the potential implementation. This has been applied for roof top RWH. The results are derived from a review of the scientific and grey literature.

For Ghana, RHW is considered to be a potential intervention to overcome water shortages during growing season (Emmanuel and Napoleon 2019; Andoh, Gupta, and Khare 2018). There is an extensive literature study for RWH in Ghana which reviewed the scientific literature, the grey literature and the policy document in Ghana (Emmanuel and Napoleon 2019). Soil and water conservation adoption in Ghana (Abdul-Hanan, Ayamga, and Donkoh 2014).

There are several types of RWH uses that can be distinguished:
- Domestic use in cities like Kumasi (Bhavananda 2010; Awuah et al. 2014) and Accra (K. Owusu and Kofi Teye 2015), and rural communities (Opare, 2012);
- Industrial use, as in the case of Takoradi Polytechnic in Takoradi, a city at the coast in the Western region of Ghana. The company tried to quantify the roof top RWH potential (Boakye and Nsiah 2016);
- Agriculture use for irrigation (Bawakyillenuo et al. 2016; Kemeze 2020; Abdul-Hanan et al. 2014; Tambo 2016).

In the case of domestic use, water quality of collected water is an issue due to the roofs (Andoh et al. 2018; Wiredu 2019). In Northern Ghana, RWH is applied for agricultural purposes due to the climatic and hydrological circumstances, although large water sources are not available. Also in other regions RWH is being used, although not much. Table 1 provides an overview on the use of RWH in Ghana.

Table 1 *Locations of RWH applications in Ghana derived from the literature.*

Region	Location and/or target population	Reference
Central region	Assin South District of the Central Region of Ghana	(Wiredu 2019)
	Rural communities in Central Region	(Opare 2012; S. Owusu and Asante 2020)
	Rainwater Harvesting in the Region of Ghana	(Dorm-Adzobu 2012)
North Ghana	Selected villages in the rural northern savannah zone of Ghana	(Bawakyillenuo, Yaro, and Teye 2016)
	Northern Ghana, rural areas	(Barnes 2009; Kemeze 2020)
	North-east Ghana	(Tambo 2016)
	Central Gonja district	(Issaka 2011)
Western region	Urban areas Accra	(K. Owusu and Kofi Teye 2015)
	Kumasi, namely Ayigya	(Bhavananda 2010)
	Kotei, a suburb of Kumasi	(Awuah et al. 2014)
	Takoradi	(Boakye and Nsiah 2016)

3.4.2 Bono East region

With a 3-day field trip to Techiman North District, the circumstances of rain water harvesting, dams, canals and irrigation techniques for farming activities were explored (Derkyi et al. 2021). The Techniman North District is one of the districts of Bono East Region, which is favourable for applying rainwater harvesting techniques for farming. The field trip started with meetings with key stakeholders in the study area such as the District Director of Agriculture, extension officers, heads of farmers associations and community leaders. The results of the meetings with these stakeholders revealed that rainwater harvesting for irrigation is not a common phenomenon in the Techiman North District (Derkyi et al. 2021). However, being a vegetable growing district, farmers were involved in different forms of irrigation. Therefore, data collection instruments were modified to reflect the field's conditions and the data collection exercise conducted in the second and third day in communities such as Adutwie, Kyiridiagya, Ofuman, Bonya and Tanoboase. Irrigation investment decisions are dominated by men, although in farming households with irrigation equipment, the wives support their husband in irrigation activities. In Tonoboase, irrigation and vegetable farming were attractive practices for the youth, which reduced the emigration of the youth to other places in Ghana.

The farm sizes in the District were relatively small and range from 1-5 acres. And farmers grew a wide variety of crops including cassava, yam, maize, plantain, cocoa, cashew, pepper, watermelon, garden eggs, tomatoes, carrots, cucumber, cabbage, okra and green pepper. However, with the rise in cashew products' prices in recent years, many of the District farmers converted significant portions of their farms into cashew plantations. The remaining portions of land have been used for the cultivation arable crops. Farmlands near water bodies in the District were primarily reserved for producing vegetables such as garden eggs, tomatoes, carrots, cucumber, cabbage, okra and green pepper using irrigation. While these crops were used for both domestic and commercial purposes, farmers cultivate these crops, especially vegetables for commercial purposes with cabbage, tomatoes and garden eggs being the dominant vegetables produced in the District using irrigation.

According to people interacted with, the phenomenon of irrigation started around 2010, which was mostly influenced by factors such as

i) the less-profitable nature of formerly grown crops in the District, such as maize, cassava, yam;
ii) the erratic rainfall patterns;
iii) the profitable nature of vegetable farming in the dry season; and
iv) the market availability for vegetable products.

Additionally, the large number of water bodies surrounding the study communities and the availability of technologies such as tricycles (water pump) and pumping machines also affected the increase of irrigation practices in the District. However, these pumping technologies require high investment cost which demotivates low-income farmers interested in this technology and farming system.

Irrigation had contributed substantially to arable crops productivity in the Techiman North District. Most respondents estimated a growth rate of crop productivity between 30 to 60% due to irrigation. Moreover, the irrigation also contributed to the improved quality of crops. The extension officer in Ofuman claimed that most of the vegetable grown in the community during the dry season would not have survived without irrigation. Techiman North District has recently achieved become vegetable growing status of the District communities is mainly due to irrigation farming widely adopted by many farmers in the District.

Despite the positive impacts of irrigation on quantity and quality of vegetables grown, irrigation practices also contributed to a number of challenges in the Techiman North District, such as

- the overuse of water resources, i.e. drying up of some rivers and streams in the dry season;
- pest and disease infestation;
- the abuse of agrochemicals by vegetable farmers, and as a result the pollution of water bodies with chemicals used in farming; and
- pressure on water bodies due to increase in the population of farmers involved in dry season farming.

Farmers who depend on chlorinated water from homes for irrigation also reported the crops' reaction to the chemicals. The over-reliance on rivers and streams for irrigation during the dry season contributed to water shortage in downstream communities that depend on these water sources for their domestic activities.

To combat these challenges, extension officers, unit committee members and traditional authorities set rules to address the challenges:

- banning irrigation using river and stream water in the peak of the dry season; and
- training farmers on appropriate use of agrochemicals.

Both rules were enforced by community leaders in collaboration with security agencies. Also, extension officers in the various communities recommended to construct large community dams to serve farmers demand for irrigation water in the community. In particular areas, however, farmers were unwilling to congregate due to privacy issues in farming and land tenure issues in the communities undermine these recommendations.

To conclude, rainwater harvesting for irrigation is not yet a common practice in Bono East Region, although the number of irrigation practices have emerged in the last decade to maintain or to improve agricultural production under the unfavourable conditions of climate change and competition for land.

4 Potential of RWHI for climate resilient and circular food systems in Bono East Region

4.1 Introduction

The overall conclusion is that there is limited information available on RWH in Ghana. Wherever RWH is being used, the water is used for domestic purposes (drinking water, washing). Only in the Northern part of Ghana there is RWH being used for agricultural production. This is not surprising, as in Central and Southern Ghana water shortage has so far not been an issue. However, given the increasing impacts of climate change, water shortage is an issue, and increasingly hampering food production, threatening food and nutrition security in the entire country. Therefore, an important matter that should be understood together with partners in Ghana is the reason why RWHI is not widely adopted for agricultural production.

4.2 Driving forces

A literature review was conducted to identify key factors that influence land suitability for RWHI. Generally, factors that influence land suitability for RWHI can broadly be classified as biophysical and socioeconomic factors. Approaches to suitability mapping of RWHI sites were previously based solely on biophysical factors (Mbilinyi et al. 2007). However, in the last decade approaches that combine both biophysical and socioeconomic factors have increasingly been deployed (Haile and Suryabhagavan 2019) to capture the preferences of stakeholders. Nevertheless, the most important factors for the selection of suitable sites for RWHI are slope, land cover, soil type, rainfall distance to settlements and cost (Ammar et al. 2016).

Table 2 *Driving forces of rainwater harvesting for irrigation at farm level.*

Factor		Suitability	Indicator
Land use	Agriculture	High	Land cover
	Built-up area	Low	
Nature area	Reserved	Not suitable	Protected areas
	Off-reserve	High	
Slope of the area	Steep slope	Low	Elevation/Slope
	No/minor slope	High	
Soil structure; opportunity to construct wells	Minor depth	Low	Depth to bedrock
	Deep depth	High	
Annual rainfall	Little rainfall	High	Rainfall
	High rainfall	Low	
Area not available for ponds and wells	High tree cover	Low	Tree cover
	No/low tree cover	High	
Distance from pond to plot	Large distance	Low	Distance to farms
	Small distance	High	
Runoff potential	High runoff	Low	Runoff potential
	Low runoff	High	
	?	?	Hydrologic Soil Groups
	?	?	
Land use rights	Tenure secure	High	No data available
	Tenure insecure	Low	
Economic viability	High	High	No data available
	Low	Low	

5 Conclusions

Although rainwater harvesting for irrigation has hardly been applied in Bono East Region, there are several signs from practice that it could be a way to adopt to the changing climate in the future. First, water availability for agriculture will reduce due to the climatic changes (less precipitation and higher mean annual temperatures). Secondly, the pressure on land use for agriculture is increasing. Third, there is experience with using irrigation and due to this usage, the crop mix has changed from staple crops to higher value and higher water demanding crops like vegetables for instance. From a food security and a livelihood perspective, the change in crop mix has been beneficial, but it also faces higher water demands and higher climate risks. All-in-all, it urges for the exploration of the potential places and locations of implementing rainwater harvesting for irrigation in Bono East Region.

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Appendix 1

Available literature
There is not much literature on RWH in Ghana, although some interesting documents can be found on the internet. Table A1.1 shows the type of publications on RWH research in Ghana. There were 12 articles published, four MSc thesis, and two policy documents. The policy documents included the National Rainwater Harvesting Strategy (NRWS) and national strategy on irrigation.

Table A1.1 *Type of publications on RWH applications in Ghana derived from the literature.*

Type of publications	**Count**
Articles	12
MSc thesis	4
PhD thesis	
Policy documents	2
Total	18

The articles were all published in different journals, see list:
- African Journal of Agricultural Research
- Asian Journal of Environment & Ecology
- Current World environment
- GeoJournal
- International Journal of Disaster Risk Reduction
- International Journal of Science and Research
- International Journal of Water Resources and Environmental Engineering
- International Journal of Water Resources Development
- International Research Journal of Public and Environmental Health
- Journal of Water, Sanitation and Hygiene for Development
- Local Environment The International Journal of Justice and Sustainability
- Water Resources and Economics

The MSc theses were written as part of two Ghanaian universities (Kumasi and Tamale) and two foreign universities:
- Massachussetts Institute of Technology (MIT), Boston, US (Barnes 2009)
- Erasmus University Rotterdam, The Netherlands (Bhavananda 2010)
- Kwame Nkrumah University of Science and Technology, Kumasi, Ghana (Issaka 2011)
- University for Development Studies, Tamale, Ghana (Wiredu 2019)

Based on the research, several universities and research institutes in Ghana have been working on rainwater harvesting research, see Table A1.2. For the universities in Tamale, Sunyani, Kumasi, and Accra, research from hydrological, geographical and social studies have been working on the rainwater harvesting research. In most cases, the research was targeted at rainwater harvesting in general without a particular focus on rainwater harvesting for irrigation.

Table A1.2 *Affiliation of researchers in Ghana working on RWH applications research.*

Affiliation in Ghana	**Location**
CSIR Water Research Institute, Ghana	
Department of Agricultural and Resource Economics, University for Development Studies	Tamale
University for Development Studies	Tamale
Department of Environmental Engineering, University of Energy & Natural Resources	Sunyani
Office of the Vice Chancellor & University of Energy & Natural Resources	Sunyani
Department of Agricultural Engineering, University of Energy and Natural Resources (UENR) Sunyani, Ghana	Sunyani
Faculty of Mechanical and Agricultural Engineering, College of Engineering, Kwame Nkrumah University of Science and Technology	Kumasi,
Department of Civil Engineering, School of Engineering, KNUST, Kumasi, Ghana	Kumasi
Department of Geography and Resource Development, University of Accra, Legon, Accra, Ghana	Accra
Institute of Statistical, Social and Economic Research, University of Accra, Legon, Accra, Ghana	Accra
Department of Science Laboratory Technology, Wa Polytechnic	Wa
Koforidua Technical University	Koforidua

Wageningen Centre for Development Innovation
Wageningen University & Research
P.O. Box 88
6700 AB Wageningen
The Netherlands
T +31 (0)317 48 68 00
wur.eu/cdi

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Wageningen Centre for Development Innovation
Wageningen University & Research
P.O. Box 88
6700 AB Wageningen
The Netherlands
T +31 (0) 317 48 68 00
wur.eu/wdci

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