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176

Adapting Aquifer Storage and Recovery Technology to the Flood-prone Areas of Northern Ghana for Dry-season Irrigation

Seth Owusu, Olufunke O. Cofie, Paa Kofi Osei-Owusu, Vincent Awotwe-Pratt and Marloes L. Mul

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International Water Management Institute

The authors: Seth Owusu is a consultant, Olufunke O. Cofie is Head of Office and Principal Researcher – Soil Science, and Marloes L. Mul is a Senior Researcher – Hydrology and Water Resources, all at the West Africa Office of the International Water Management Institute (IWMI) in Accra, Ghana; Paa Kofi Osei-Owusu is a Manager at Conservation Alliance, Accra, Ghana; and Vincent Awotwe-Pratt is a Senior Technical Consultant at Rural Support Network, Accra, Ghana.

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Contents

Summary

Limited access to water, droughts, floods and other climatic conditions are major challenges to food security in Ghana. Over 70% of smallholder farmers in the country practice rainfed agriculture, which is highly vulnerable to rainfall variability. Flooding and waterlogging of farmlands limit land use and crop productivity. The Bhungroo Irrigation Technology (BIT), a system designed to infiltrate excess 'standing' floodwater to be stored underground and abstracted for irrigation during the dry season, was piloted in three sites in northern Ghana. Two BITs were installed in the Jagsi and Kpasenkpe communities in the West Mamprusi District, while the third was installed in the Weisi community in the Builsa South District. This paper documents the implementation of BIT, the operating principles and criteria for selecting appropriate sites for the installation of such systems, as well as the potential benefits complementing existing irrigation systems in Ghana. Based on experiences from Asia, we identified the essential requirements for installation of BIT. Biophysical features such as land-use type, soil type, surface hydrology and slope of the terrain should be suitable for implementation of BIT, as well as support agricultural activities. The hydrogeological characteristics of the subsoil are also vital, and must exhibit high storage capacity and potential for groundwater accessibility. To be profitable and generate benefits for farmers, the technology needs to be situated in close proximity to markets and must have public acceptance. Reports on the use of the technology in India have shown the capacity of BIT to utilize floodwaters from farmlands for dry-season farming, generating good income and improving the livelihoods of smallholder farmers.

1. INTRODUCTION

Increasing water challenges in Ghana have significant effects on agriculture and food security. Extreme climatic conditions such as droughts and floods have devastating effects on people's livelihoods and the economy of Ghana. The agriculture sector employs over 60% of the economically active population and contributes to around 38% of the foreign exchange earnings (ISSER 2008). However, poverty is prevalent with strategies to reduce it being less effective, especially among the inhabitants of northern Ghana (Hesselberg and Yaro 2006; Quaye 2008), who are the largest contributors to the nation's agriculture sector.

Agricultural Water Management (AWM) is needed to address challenges of water access for smallholder farming systems. Ghana's agrarian economy is highly dependent on rainfed agriculture. So, the growing vagaries in rainfall pattern pose a serious problem for national development, and have a direct effect on food security and income generation for farmers and their families. Moreover, many smallholder farmers in the region are affected by waterlogging and flooding, as well as drought and dryspells (Conservation Alliance 2015a). Such challenges make land unsuitable for farming and restrict the varieties of crops that can be grown. Also, extreme flooding could destroy crop production entirely, especially fast-running or high-rising water. Overall, these challenges reduce the agricultural potential and productivity, affecting income, and food and nutrition security at household and regional levels.

In spite of the above, there is clear potential for irrigation expansion in Ghana, as currently less than 2% of the total cultivated land area is under irrigation (Namara et al. 2011). The Millennium Development Authority (MiDA) estimates that improved water and land management practices could increase agricultural productivity in northern Ghana between 100 and 200% (MiDA 2012). A large area (186,000 ha) of irrigated farms is managed by local communities, in comparison to about 15,000 ha of 22 irrigation schemes managed by the Ghana Irrigation Development Authority (GIDA) (Gumma et al. 2011). However, this is still a fraction of the irrigation potential in Ghana, which is estimated at 2 million hectares (Mha) (FAO 2005). These small-scale irrigated areas use traditional water-lifting technologies, such as water cans, ropes and buckets, and motor pumps, which are usually not efficient AWM options (Namara et al. 2014). To maximize the potential of irrigable areas in northern Ghana, new and innovative technologies have evolved that provide better AWM solutions for farmers.

This working paper presents a newly introduced water storage and irrigation system, BIT, which has thus far mostly been applied in India (Paul 2013). BIT is an artificial recharge method that infiltrates excess runoff in a deeper aquifer layer to be used for crop production during the dry season. Storing water in the subsurface minimizes evaporation, which tends to be an issue when storing water above the ground. However, the system requires energy to lift water from the aquifer onto the fields. Water-lifting technologies to accompany such systems include solar, motorized, electric and manual pumps, while water application measures include drip, overhead and surface irrigation systems. In particular, BIT has proved to be successful in flood-prone areas and useful for dry-season farming, especially in India, with evidence of income benefits to farmers and implications for poverty reduction and national growth (Paul 2013; UNFCCC 2014).

In view of this, the CGIAR Research Program on Water, Land and Ecosystems (WLE) supported the introduction of BIT in northern Ghana. The pilot, led by Conservation Alliance (CA), Ghana, and its partners, involved installation of the Bhungroo technology in the Jagsi and Kpasenkpe communities in the West Mamprusi District of the Northern region, and in the Weisi community in the Builsa South District of the Upper East region. This paper provides a general background of the Bhungroo technology and a method used for selecting appropriate pilot sites, considering the hydrogeological characteristics and potential socioeconomic impacts of the technology.

2. ARTIFICIAL RECHARGE METHODS

Limited access to water resources for domestic use and agricultural purposes led to the implementation of practices such as ***Aquifer Recharge (AR)***, ***Aquifer Storage*** and ***Recovery (ASR)*** or ***Managed Aquifer Recharge (MAR)***, which seek to better manage and conserve water (Gale and Dillon 2005). More specifically, these practices have been used to "intentionally" replenish groundwater from various sources such as rainwater, storm water runoff and reclaimed water (Pyne 1995). There are different objectives for implementing ASR or MAR schemes: to store water for future use, improve water quality, impede storm runoff and soil erosion, or to reduce loss through evaporation and runoff (Gale and Dillon 2005). In doing so, various methodologies have been adopted, which include the following:

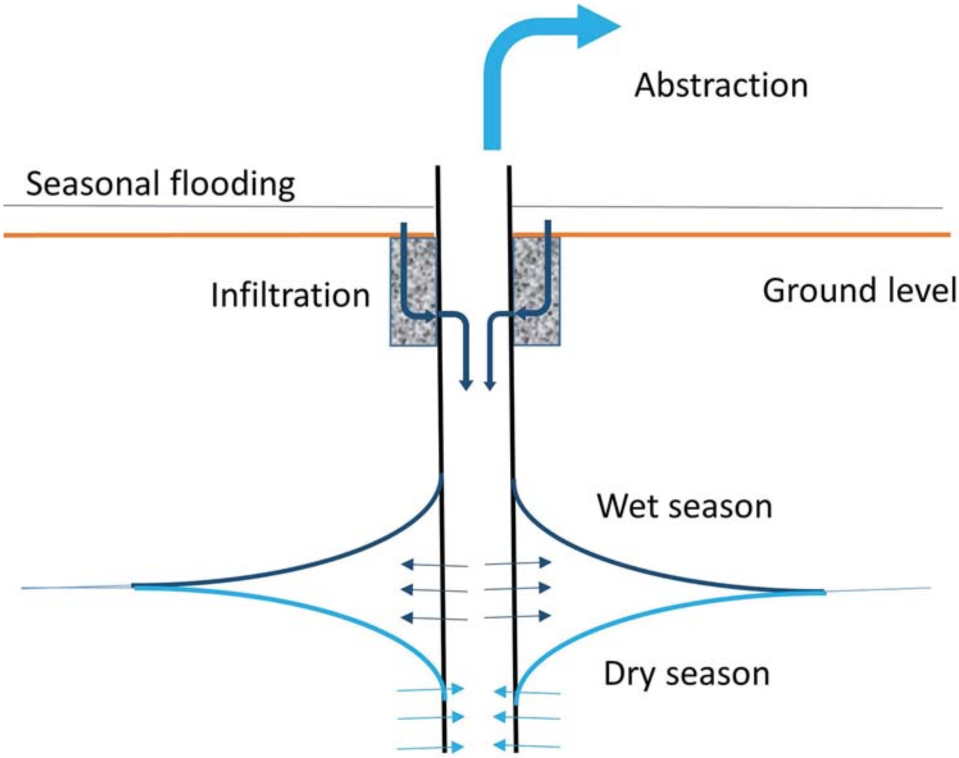
- ***Direct surface techniques (e.g., surface infiltration):*** this approach involves the spreading of water on the land surface, and it requires permeable soils at the surface for effective infiltration of water to the unconfined aquifer that is being recharged (Bouwer 2002; Gale and Dillon 2005). Examples of this method include the use of surface infiltration basins, swales, lagoons, and soil aquifer treatment (Bouwer 2002; Gale and Dillon 2005).
- ***Direct subsurface techniques (e.g., well, shaft and borehole recharge):*** these are subsurface techniques and the first of this method is infiltration of the vadose zone (i.e., unsaturated zone), which involves dug trenches (5-15 m deep) or wells in the vadose zone for vertical infiltration of water (Bouwer 1989, 2002; Edwards et al. 2016; Gale and Dillon 2005). It is usually inexpensive and suitable where there are insufficient lands or impermeable soils for the surface infiltration described earlier. The direct recharge well is suitable in areas where techniques such as surface infiltration and vadoze zone infiltration are not applicable, and aquifers are often deep or unconfined (Bouwer 2002; Edwards et al. 2016). The use of ASR, which is a relatively new technique, employs a combination of recharge and a pumped well (Pyne 1995; Bouwer 2002).

2.1 Concepts of Aquifer Storage and Recovery (ASR) and Examples of its Use

The term ASR, as defined by Pyne (1995), is *"the storage of water in a suitable aquifer through a well during times when water is available, and recovery of the water from the same well during times when it is needed*." With the ASR technique, water can be stored in an aquifer when the demand for water is low and recovered for use when the demand is high (Bouwer 2002). Figure 1 demonstrates an ASR system where the two main principles involved (water infiltration and abstraction) are shown. Water is infiltrated into an aquifer from storm water or wastewater during the wet season. This increases the groundwater level close to the well. This water is abstracted later in the dry season from the same well. These two principles are essential to ensure efficiency of an ASR system.

Various techniques exist for infiltrating water underground. This study will concentrate on ASR using a borehole to infiltrate and abstract water. As an artificial recharge method, ASR can be viewed as a way of augmenting the natural movement of surface water into underground formations by some method of construction or artificially changing natural conditions (Todd 1980; Asano 1985; Bear 2012; Edwards et al. 2016). ASR is a water conservation technique, and it is useful for boosting groundwater levels in semi-arid areas where rainfall variability leads to insufficient groundwater recharge (Asano 1985). Abstraction, on the other hand, is the ability to get the stored water back. The higher the abstraction rate of the stored water, the more efficient the ASR scheme. Therefore, the design and implementation of an ASR scheme must consider this factor, especially since the infiltration

FIGURE 1. Diagram showing the ASR principle of water infiltration and abstraction.



rates can highly affect the usefulness of the ASR scheme. Pyne (2010) reported an infiltration rate of 8,000-12,000 m^3 day^{-1} per borehole for ASR, while Bouwer (1999) indicated a rate of 0.3-3 m day^{-1} for surface spreading recharge systems with relatively clean and low turbidity river water.

Application of the ASR technique has been documented by Pyne (1995) and these instances have been taken from different other sources. The broad category of use of the ASR technique includes the following:

- Water storage - the technique can be useful for seasonal storage and abstraction, and long-term storage (e.g., sand dams).
- Water quality control - the technique is applied for nitrate removal and control of other contaminants that are dangerous to human health.
- Environmental improvement by way of boosting groundwater levels, enhancing baseflow to streams, and reducing saline intrusion (Asano 1985).
- Wastewater disposal, secondary oil recovery, prevention of land subsidence and crop development (Oaksford 1985).

ASR has been practiced and implemented across the globe, with extensive artificial infiltration in the coastal dunes in the Netherlands, supplying the domestic water of Amsterdam and The Hague (Stuyfzand and Doormen 2004; Murray 2008). Amsterdam alone receives about 60% of its drinking water from artificial recharge, involving injection of treated river water and over 40 recharge ponds which cover 86 ha of land (van Duijvenbode and Olsthoorn 2002; Stuyfzand and Doormen 2004; Murray 2008). In Australia, ASR has been practiced for more than a century using various innovative methods. For example, the Burdekin Delta scheme is a surface infiltration technique involving artificial channel and recharge pits to support irrigation of agricultural land, which is served by over 2,000 production boreholes (Charlesworth et al. 2002; Murray 2008). In Windhoek, Namibia, ASR aims at improving water supply for the entire city by injecting surface water, which is treated using sand filtration into the aquifer via boreholes (Gale and Dillon 2005). Although ASR has been primarily used for the provision of water for domestic purposes, the so-called Bhungroo ASR has been widely used for the infiltration of floodwater into the aquifer to supply water for farming during the dry season (Naireeta Services 2015; Paul 2013).

2.2 Bhungroo Irrigation Technology (BIT)

The ‘Bhungroo’ is a floodwater harvesting and storage system developed and widely used in India (Naireeta Services 2015). The name originates as a reference to the main component, the borehole, termed Bhungroo which means ‘straw’ in Gujarati (Naireeta Services 2015; Paul 2013). The total package of the Bhungroo and the irrigation system comprise the Bhungroo Irrigation Technology (BIT); a technique for collecting excess floodwater for agricultural use during the dry season (Naireeta Services 2015). BIT came to flourish after the serious drought that affected the western Indian state of Gujarat in 2000, and at the same time, flash floods in the region led to waterlogging during the wet season. The Bhungroo harvests water and stores it in underground reservoirs or unsaturated layers. It is estimated that as much as 40,000 m^3 of water can be stored, but the average is closer to 4,000 m^3 (UNFCCC 2014), which is sufficient for supplying irrigation water for almost 7 months. Water is used for farming in the dry season of the same year, thereby improving food security. Such an innovative water storage and irrigation system enhances water efficiency (Steduto et al. 2012; Paul 2013; Levidow et al. 2014), and Bhungroo, in particular, provides economic benefits to farmers and also reduces a serious environmental challenge such as a flood hazard (Paul 2013; UNFCCC 2014).

As an ASR technique, the Bhungroo has generally three key components – ***water harvesting, water storage*** and ***water abstraction*** (Naireeta Services 2015; UNFCCC 2014). Figure 2 shows a schematic diagram of a typical Bhungroo system, demonstrating the main features. The infiltration bed, which is component ‘2’, serves as the water collection point from storm water/runoff source. The Bhungroo is designed and sited with the aim of freeing farmlands from waterlogging; relatively flat terrains or locations of adjoining floodplains are potentially useful in this context (Naireeta Services 2015; Paul 2013). The infiltration component is designed with different materials of unique sizes to remove unwanted matter and odor (when activated, a charcoal layer is added) from the water source before transmitting it underground (Bouwer 2002; Pyne 2005; Edwards et al. 2016). The Bhungroo borehole is connected with a pipe system, which may have screens at various sections, and is labelled ‘1’ in Figure 2. The connecting pipe forms the transportation link for water storage and abstraction. This component is often capped to prevent unfiltered water going through the pipe and polluting groundwater. The third component (‘3’) is the storage part of the system, which is unsaturated layers of the aquifer often prepared from 8-25 m deep depending on the geology of the area (Bunsen and Rathod 2016). It is important to consider the hydrogeological characteristics of the site where the scheme is to be implemented, in order to ensure efficiency of the system, as it becomes unbeneficial if water is stored where it cannot be accessible for use when in demand. This, together with all the essential criteria for successful implementation of Bhungroo, will be further explored in this study.

The other irrigation components making the Bhungroo a full BIT include a pump for ‘lifting’ water from the Bhungroo, overhead tank for on-site water storage and distribution, and a drip or sprinkler irrigation system for applying water to crops. These are just some selected examples of the BIT package, with the choice of the actual BIT package determined by a number of factors such as the cost, experience of use and maintenance of the irrigation systems. Figure 3 shows one of the constructed Bhungroo schemes fitted with on-site overhead storage tank in Jagsi community, West Mamprusi District, northern Ghana.

FIGURE 2. Schematic diagram of a typical Bhungroo system.

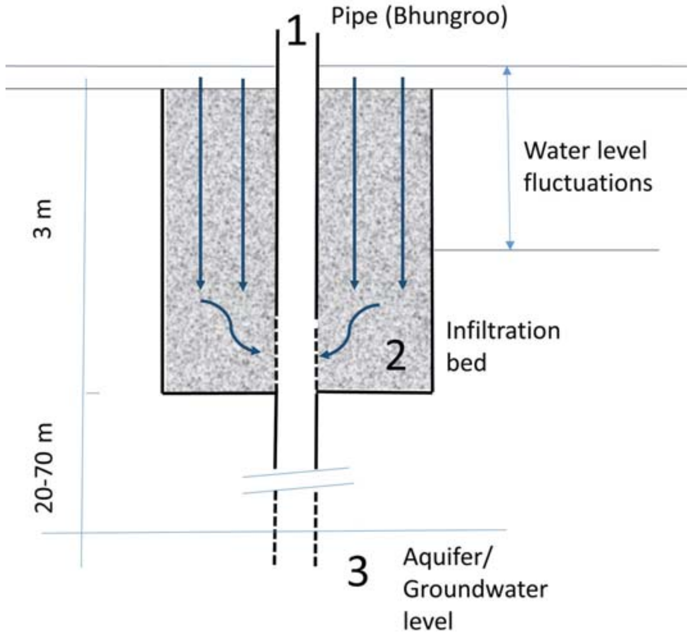


FIGURE 3. (a) Bhungroo with on-site overhead storage tank, and (b) irrigation field supplied by water from the Bhungroo in Jagsi community, West Mamprusi District, northern Ghana.

(a)

(b)

Photos: Fusheini Salifu, IWMI.

The installations for Bhungroo and BIT in India generally have the following characteristics (UNFCCC 2014):

- The Bhungroo well is usually 8 to 25 m deep depending on existing ground conditions, and is usually designed to accommodate a maximum floodwater level of 1 m from ground level (Bunsen and Rathod 2016).
- Bhungroo is constructed using materials that are readily available and accessible at local sites and communities where installed (Naireeta Services 2015; Bunsen and Rathod 2016).

- The use of floodwater as a water source for the Bhungroo means that the system turns what is generally a hazard to a resource into an opportunity for farmers to boost their agricultural productivity (Naireeta Services 2015).
- BIT has improved agricultural activities, especially dry-season farming. Specifically, it improves land fertility for farming families and guarantees cropping for dry and wet seasons with an assumed lifespan of 30 years, depending on maintenance of the system and other factors (Paul 2013).
- BIT has freed women from debt and improved their involvement in local governance, and also their influence in agriculture and water issues (Naireeta Services 2015).
- BIT enhances food security and sustainable livelihoods of more than 18,000 marginal farmers (with over 96,000 dependent family members) in India, with a typical family's annual income increased by over 200% in the first year of use (Naireeta Services 2015; Paul 2013).

A similar technology to the Bhungroo is the PAVE, which has been implemented in 10 smallholder farming communities within the Upper East and Northern regions of Ghana (PAVE Irrigation 2015). Both technologies follow the same operating principles, with the PAVE slightly distinguished in the construction materials for the infiltration layers and adaptability for floodwater levels. Table 1 compiles the major similarities and differences between the Bhungroo and PAVE irrigation systems.

TABLE 1. Similarities and differences between the Bhungroo and PAVE irrigation systems.

Aspect	Bhungroo	PAVE
Design and construction	Requires minimal land to install	Requires minimal land to install
	Materials are locally available	Materials are locally available or near to site
	May require charcoal as part of infiltration layers to improve water odor	Requires charcoal in the infiltration layers
	No additional infiltration component aside main infiltration layers	Attached paver device infiltrates water directly into the pipe component and thus enhances infiltration
	Standard pipe length above ground level, up to 1 m	Elongated pipe above ground level, greater than 1 m
	Total cost can be higher than other on-site water storage systems, and high for individual farmers to invest in	Total cost can be higher than other on-site water storage systems, and high for individual farmers to invest in
Water storage and reuse	Capacity of up to 1 m rising floodwater level	Capacity for higher rising floodwater level, up to 1.5 m deep
	Capacity to infiltrate as much as 40,000 m^3 of water underground[1]	Capacity to infiltrate ranges from 4,000-40,000 m^3 of water underground[2]
	Recovery potential for 8-12 ha irrigable area based on the water stored and crop water requirements	Recovery potential for 8-12 ha irrigable area based on the water stored and crop water requirements

Sources: Naireeta Services 2015; Paul 2013; PAVE Irrigation 2015.

Notes:

[1] http://unfccc.int/secretariat/momentum_for_change/items/8694.php

[2] http://paveirrigation.com/

3. TECHNICAL REQUIREMENT FOR BHUNGROO

The Bhungroo technology, like other ASR techniques, requires some specific field conditions for it to be effective. Some of these factors include the characteristics of the aquifer, source of water supply into the system, and the means by which water is infiltrated into the aquifer and recovered later (Pyne 1995; Bouwer 2002; Gale and Dillon 2005; CGWB 2007; Murray 2008; Bunsen and Rathod 2016). These elements, compiled in Table 2, are extensively described in the following sections.

TABLE 2. Technical requirements for the Bhungroo technology.

Technical requirements	Key elements	Description
1 Water source	Floodwater source Reliability of supply Floodwater and groundwater quality (e.g., physical, chemical, biological)	Flood-prone lands with agricultural activities Use drinking water quality and irrigation water quality guidelines
2 Artificial recharge method	Direct recharge	Bhungroo uses borehole wells for direct recharge
3 Filtration method	Land availability Local materials Local skills	Ability to construct, for example, a 2 x 2 m infiltration bed at 1-3 m deep, with different infiltration layers made of local materials Subsoil should be unsaturated
4 Nature of aquifer	Type of rock Hydraulic conductivity Storage	Unconfined aquifer, with high hydraulic conductivity and high storage aquifer is best Sand is best preferred to hard rock.
5 Water abstraction and use	Agricultural water needs Irrigation system	Suitable where water can be abstracted and used for irrigation, employing the most efficient irrigation technologies
6 Environmental impact	Environment Ecosystems	Minimal impact on surrounding environment and ecosystems
7 Socioeconomic consideration	Acceptability Accessibility (e.g., site, communities, market) Cost	Establish community interest and participation

Sources: Pyne 1995; Bouwer 2002; Gale and Dillon 2005; CGWB 2007; Murray 2008; Bunsen and Rathod 2016

3.1 Water Source

The effectiveness of the ASR technologies is highly dependent on the source of water, both quantity and quality. In accessing the source of water for the technology, two issues are critical and need to be addressed: (i) volume and quality of water that is available for recharge, and (ii) period or duration the water is available (Murray 2008; Department of Water Affairs 2010). The water may be from rivers, dams, treated effluent, urban runoff and rainwater, depending on the objective and location of the setup. Water quantity and reliability vary with the source of water as shown in Table 3. The Bhungroo technology works well in places where the quantity and availability of recharge water is highly variable, such as in localized floodplains and flood-prone areas supplied by rivers or streams, surface runoff and/or rainwater. Both the quantity and quality of water are crucial for the success of a Bhungroo scheme, in terms of sufficient capture and efficiency of water infiltration (Bouwer and Rice 2001; Bouwer 2002; Edwards et al. 2016).

TABLE 3. Characteristics of different water sources for artificial recharge of groundwater.

Source of water	Quantity	Reliability	Quality
Floodplains	Variable	High	Variable
Perennial rivers	Variable	Variable	Variable
Dams	Variable	High	Variable
Treated municipal wastewater	Consistent	High	Variable (dependent on treatment)
Aquifers (i.e., transfers from other subsurface reservoirs)	Consistent	High	Consistent
Urban runoff	Variable	Moderate-High	Variable
Agricultural return flows	Variable	High	Low
Rainwater harvesting	Variable	Moderate-High	High

Source: Modified from Department of Water Affairs 2010.

Infiltrating water from the surface into an aquifer raises issues related to pollution of the receiving aquifer as well as clogging of the infiltration system. Key issues regarding water quality assessment revolve around the physical, chemical and biological quality of recharge water. Suspended particles cause clogging which is a major challenge to the success of the infiltration system and should be minimized through design of the system and subsequent monitoring of water quality (Bouwer and Rice 1984; Bouwer 2002).

Mixing infiltrated water with groundwater may cause a ***geochemical reaction***, altering the chemistry of the water (Gale et al. 2002; Brand 2008). In an ASR scheme, the geochemical processes or interactions involve a range of chemical reactions between (i) infiltration or source water, (ii) native groundwater, and (iii) characteristics of the aquifer (Gale et al. 2002). Thus, the chemical changes that occur are determined by the chemical composition or characteristics of these three elements (Gale et al. 2002; Murray 2008). Therefore, it is also important that the infiltration water is chemically compatible with the aquifer material through which it flows and the naturally occurring groundwater. Thus, monitoring of the Bhungroo well is very important to ensure the stored water reaches the required standard, either for drinking or irrigation purposes (WHO 2004). Table 4 lists some of the essential water quality parameters to be monitored for the Bhungroo technology.

TABLE 4. Water quality parameters and standards for installing a BIT.

Water quality parameters	Unit	WHO[1]	FAO[2]
Electrical conductivity (EC)	dS/m		0-3
Physical component			
Odor	-	Inoffensive	-
Turbidity	NTU	5.0	-
Potential of hydrogen (pH)	pH units	6.50-8.5	6.0-8.5
Total hardness	mg/l	500	-
Total Dissolved Solids (TDS)	mg/l	1,000	0-2,000

(Continued)

TABLE 4. Water quality parameters and standards for installing a BIT (Continued).

Chemical component			
Nitrate (NO_3-N)	mg/l	10	10
Nitrite (NO_2-N)	mg/l	10	< 5.0[3]
Bicarbonate (HCO_{3-})	mg/l	-	610
Carbonate ($CaCO_3$)	mg/l	-	3
Sulfate	mg/l	250	960
Fluoride	mg/l	1.5	1.0
Calcium	mg/l	200	400
Chloride	mg/l	250	350
Magnesium	mg/l	150	60
Potassium	mg/l	30	0-2
Sodium	mg/l	200	920
Metal component			
Manganese	mg/l	0.4	0.2
Total iron	mg/l	0.3	5
Copper	mg/l	5	0.2
Boron	mg/l	-	0-2
Zinc	mg/l	5	2
Cadmium	mg/l	0.003	0.01
Lead	mg/l	0.010	5.0

Notes:

[1] Drinking water quality guidelines (WHO 2004).

[2] Irrigation water quality guidelines (http://www.fao.org/docrep/003/T0234e/T0234E01.htm).

[3] South African Water Quality Guidelines (DWAF 1996)

3.2 Artificial Recharge Method

Groundwater is naturally recharged by rainwater infiltrating into the underground. Natural recharge by direct precipitation and infiltration (from rivers, for example) is typically 30-50% of precipitation in temperate humid climates and this is lower in dry climates (0-20%) (Bouwer 1989, 2002). In Ghana, for example, natural recharge is estimated to be in the range of 1.5 to 19% (of rainfall) (HAP 2009; Obuobie and Barry 2012). Given these low rates, installing artificial recharge systems could be beneficial for enhancing underground water storage in high temperature zones where there is a high loss of surface water through evapotranspiration (Asano 1985). Different types of artificial recharge methods, as listed earlier, can enhance groundwater recharge. The Bhungroo technology uses borehole infiltration wells for artificial recharging of groundwater.

3.3 Filtration Method

To avoid or reduce the impact of infiltrating surface water into the well, surface water needs to be filtered before it enters the well. An infiltration bed is often constructed to remove unwanted constituents (e.g., debris and other suspended matter in the source water) before the water is transmitted into the aquifer (Bouwer 2002; Edwards et al. 2016). This is usually carried out by the technique of separation by straining, where the particles removed are larger than the pore size of the infiltration layers (Bouwer 1978; Hofkes and Visscher 1986). In view of this, the infiltration bed is designed with various layers of particle sizes, consisting of boulders, grades of pebbles, sea sand and fine sand, with a mesh wire cover to keep each layer intact and compact (UNFCCC 2014; PAVE Irrigation 2015). For example, the infiltration bed may have layers of activated charcoal which help to purify and remove odor from the water (PAVE Irrigation 2015). The quantity and quality of the water source are essential for the effectiveness of the infiltration bed, particularly to reduce clogging and subsequent low infiltration rates in the system (Bouwer and Rice 2001; Bouwer 2002; Gonzales-Merchan et al. 2012; Edwards et al. 2016).

The effectiveness of infiltration layers constructed is vital for the sustainability of BIT, as contamination to groundwater can constrain the wider use of such ASR systems (EPA 1999; Jurgens et al. 2008). Many of the challenges or difficulties with the use of ASR have been due to mismanagement of the facilities (Edwards et al. 2016). These can be minimized, if the system is sited at an appropriate location, and there is an effective management strategy and trained staff to undertake the required tasks (EPA 1999; Jurgens et al. 2008; Edwards et al. 2016). When properly designed, most bacteria and other microorganisms can be removed or retained in the top few decimeters of the infiltration zone, which can be easily cleaned (Hofkes and Visscher 1986). Moreover, the designed filtration rate must allow for a degree of clogging, which is usually about 20-30% of the standard test infiltration rate, to help improve the overall efficiency of the system (Hofkes and Visscher 1986). Table 5 presents infiltration rates for various types of soil, with gravel having the highest infiltration rate of 10-20 m^3 m^{-2} day^{-1}. These findings are relevant and will inform the design and selection of materials for constructing the infiltration bed of the Bhungroo.

TABLE 5. Infiltration rates for various types of soil.

Type of soil	Infiltration rate (m^3 m^{-2} day^{-1})
Fine sand	0.2-0.4
Sandstone	0.3-0.5
Medium-sized sand	1-2
Coarse sand	4-6
Gravel	10-20

Source: Hofkes and Visscher 1986.

3.4 Nature of Aquifer

The storage medium of ASR is groundwater. Groundwater is water stored underground in spaces of fractured rocks and gravels of the geological formation of soils, called aquifer (Todd 1980; Bear 2012). Aquifers allow for a significant amount of water to move through it under ordinary field conditions (Bear 2012). Generally, there are two classifications of aquifers: (i) unconfined aquifer usually lies underneath the water table. Water stored in an unconfined aquifer is manifested in a rise of the water table; and (ii) confined aquifer is bounded above and below by impervious formation (i.e., aquitard) with groundwater occurring at deeper depths for such formation. Water storage in a confined aquifer is manifested by increasing water pressure (Bear 2012). In assessing the characteristics of the aquifer, it is vital to establish whether it can receive and hold stored water; that is the aquifer's hydraulic conductivity and storage capacity. Unconfined aquifers are suitable due to their high storage coefficient (Bouwer 2002; Bear 2012). The composition of the aquifer is also important. The high storage coefficient of unconsolidated, inter-granular aquifers, which is related to porosity, is generally one to three orders of magnitude greater than hard rocks (Murray 2008). For this reason, alluvial aquifers, coastal sands and the infrequent thick inland sandy deposits are prime targets for the storage of considerable volumes of water (Murray 2008). Table 6 shows the water storage capacity for sand and hard rock of different dimensions.

The differences in the volume of water stored clearly emphasize the high storage of water by sand rather than hard rock.

The effective porosity of the aquifer is also very crucial and refers to the pore space in a unit volume of rock in which the water can move freely (Hofkes and Visscher 1986). For example, the type of rock, size distribution of formation particles and the density of the particles are factors that determine the effective porosity. The effective porosity is high for gravel at 25-30%, followed by sand at 10-30%, while a combination of sand and gravel is also suitable and ranges from 15-25% (Campbell and Lehr 1973; Hofkes and Visscher 1986).

TABLE 6. Aquifer storage potential.

Aquifer type	Aquifer size (thickness x length x breadth)	Storage coefficient	Volume of water stored (Mm^3)
Sand	20 m x 5 km x 5 km	0.1	50
Hard rock		0.003	1.5
Sand	40 m x 10 km x 10 km	0.1	400
Hard rock		0.003	12

Source: Murray 2008.

Hydraulic conductivity of a soil or rock defines its ability to transmit water and is dependent on a variety of physical factors, including particle size and distribution, shape of particles and their arrangement (Murray 2008; Department of Water Affairs 2010). For successful application of Bhungroo, hydraulic conductivity needs to be sufficient both at the point of recharge and further in the field. Table 7 provides the hydraulic conductivity range for different rock types, with a high range of 100-1,000 m day^{-1} for gravel and insignificant values for consolidated rocks such as shale and limestone.

Aquifers which have high hydraulic conductivity and high storage capacity are more suitable for Bhungroo than those which have low conductivity and capacity (Murray and Tredoux 1998; Murray 2008). However, highly permeable aquifers are not always best if high quality water is stored in a saline aquifer, as this may result in undesirably high blending (of source water and groundwater) ratios (Murray 2008). High hydraulic conductivity combined with high storage capacity is the most suitable for the ASR scheme.

TABLE 7. Hydraulic conductivity for different rocks.

Rock type	Hydraulic conductivity (m day^{-1})
Gravel	100-1,000
Coarse sand	20-100
Sand and gravel	5-100
Fine sand	1-5
Clay	0.001-0.01
Fractured or weathered rock	0-300
Sandstone	0.001-1
Shale	Negligible
Limestone	Negligible

Source: Adapted from Bouwer 1978.

3.5 Water Abstraction and Use

Traditionally, water abstraction has involved the manual lifting of water from mainly shallow wells and dug-outs through the use of water cans, and ropes and buckets, which, although affordable, are very laborious and less efficient methods (Namara et al. 2011, 2014). The Bhungroo well forms the recovery medium for the water stored. Therefore, more enhanced pumping techniques, such as the use of motor, electric, diesel and petrol pumps, or even the use of a solar pump, are required.

It is vital to establish the availability of water in the area being considered for the ASR scheme, by assessing the characteristics of the aquifer of the site to inform effective planning and use of the technology. In the case of Bhungroo, irrigation potential is dependent on the storage potential and recovery rate as indicated previously. Furrow irrigation is the most inefficient way of irrigating (60%), followed by sprinkler irrigation (75%) and drip irrigation (90%) (Brouwer et al. 1989). Irrigation water is either directly pumped from the well to the field (furrow and sprinkler irrigation) or stored in an overhead storage tank (drip irrigation). The choice of water application methods is influenced by factors such as climatic conditions, type of crop, and the cost and benefit of the system (Brouwer et al. 1988). Although sprinkler and drip irrigation systems are very efficient methods, they are relatively complicated and require high capital investment, experience of use, and high operation and maintenance costs (Brouwer et al. 1988, 1989).

3.6 Environmental Impact

Artificially recharging and abstracting groundwater can affect the natural environment, by either altering the water quality of the groundwater or by affecting groundwater levels (Gale et al. 2002; Murray 2008). There are concerns related with water quality, aquifer pollution, lowering and raising of the water table, and the piezometric level above those of existing use (Murray 2008). When properly designed and managed, the ASR technique is a viable water management technology that has minimal environmental impacts. However, when not properly monitored, the following negative consequences could occur due to the fluctuations in the water table:

- Changing vegetation structure and composition as a result of soil saturation, which can also cause dieback of riparian trees (Le Maitre et al. 1999; Murray 2008).
- Potential impact on river flow regimes, and wetland and riverine ecosystems, depending on the relationship between surface water and groundwater (Gale et al. 2002; Gale and Dillon 2005; Murray 2008).
- Possibility of land subsidence in areas where groundwater levels are greatly lowered (Murray 2008).
- Drying up of existing boreholes where technology installed can affect other groundwater users (Murray 2008).

To achieve the generally minimal impact of ASR, the site for the scheme must be correctly selected and then carefully monitored (Gale et al. 2002). For example, Gale et al. (2002) highlighted the need for closely assessing the change in head for some specific distances (e.g., 100 m, 500 m and 1 km) from the ASR well to help determine any major change in the surrounding surface water features, such as wetlands and streams. The observed changes, if any, compared to the natural groundwater fluxes, for instance on an annual basis, would give an indication of the significance of the impact of any ASR scheme on the natural environment.

3.7 Socioeconomic Consideration

3.7.1 Cultural Acceptability

Cultural considerations, stemming from socioeconomic concerns, are essential in the selection of an ASR method and site (UNEP-IETC 1998). Factors such as land availability, land use in adjacent areas, and people's attitudes toward ASR generally play a role in defining the acceptability of such systems in a given setting (UNEP-IETC 1998; Gale and Dillon 2005; Murray 2008). For example, in communities and urban areas where land availability, cost of land and land use in adjacent areas may pose restrictions to large-scale recharge methods such as surface spreading methods, ASR techniques which require highly controlled water supplies and a small land area may be preferable. Surface recharge facilities generally require protected property boundaries, regular maintenance and continuous surveillance if they are to be accepted (UNEP-IETC 1998).

Moreover, ASR schemes require organizational and institutional arrangements for successful implementation (UNEP-IETC 1998; Department of Water Affairs 2010). There is a need for a local committee or other local organization with the ability and willingness to assume responsibility for operation and maintenance of the scheme, and organization and collection of local contributions (Hofkes and Visscher 1986). The complexity in implementing such schemes means that the level of community involvement is a key factor, especially in ensuring there is sufficient interest and support right from the start of construction and operation of the scheme. In view of this, some technical background, skills and experience with the type of work involved (e.g., control of water flow, excavation of the ground and construction of the infiltration system) are needed at the local level (UNEP-IETC 1998).

3.7.2 Accessibility of Site

It is essential that communities have easy access to the ASR site to reduce issues such as unduly long travel times to and from the site. Proximity to road or access route to the ASR site are, therefore, important criteria for assessing the suitability of the systems (Owusu et al. 2017). Alternatively, the use of *market accessibility* data, where available, can be helpful in siting the ASR scheme in relation to economic activities (such as using the water for dry-season irrigation). This analysis usually combines population information and access route to estimate travel times to market centers (HarvestChoice 2011). When an ASR scheme is used for irrigation of agricultural crops, in particular, cash crops, sites need to be in reasonable proximity to markets.

3.7.3 Cost

The costs, both initial and operational, of an ASR scheme could be a challenge for poor communities and farmers to invest in such a project (UNEP-IETC 1998). This barrier has often seen the government and nongovernmental organizations (NGOs) intervening to provide funding and implementing high-cost technologies for farmers. Rushton and Phadtare (1989) reported the costs of various ASR schemes in two different aquifer formations - alluvial and limestone aquifers in India. Table 8 shows the relative initial and running costs for the technologies per unit volume of recharged water. The injection well in an alluvial aquifer, which is the most expensive scheme, is assigned initial and operating costs of USD 100 per unit volume of recharged water (Rushton and Phadtare 1989). The costs of the remaining schemes were determined with reference to the cost of the injection well, which is assumed to be the most expensive. The relatively low costs for limestone areas is a result of hard rock, which means that the injection wells are shallower in those areas. Low initial cost for percolation tanks is a result of already existing tanks. The overall higher running costs than the initial costs suggest the challenge of operating an ASR scheme in general (Hofkes and Visscher 1986).

TABLE 8. Relative costs of various ASR schemes (costs updated to 2016 inflation rates).

ASR method	Rock type	Initial cost (USD/m^3)	Running cost (USD/m^3)
Injection well	Alluvial	146	146
	Limestone	9	31
Spreading channel	Alluvial	13	15
	Limestone	10	9
Percolation tank	Alluvial	3	10

Sources: Rushton and Phadtare 1989; UNEP-IETC 1998.

The high total annual cost of an ASR scheme, over a 20-year cycle, is highlighted by Arshad et al. (2014) and detailed in Table 9. This shows the total capital and maintenance cost as being almost twice (USD 247,700 m^{-3}) that of basin infiltration at USD 122,700 m^{-3} (Arshad et al. 2014). In the same study, the irrigation benefit, which is the value of the crop that can be grown with the useable volume of water in each case, was very high (USD 65 m^{-3}) for both ASR and basin infiltration than for surface storage (USD 41 m^{-3}) (Powell and Scott 2011; Arshad et al. 2013, 2014). Some assumptions were made in estimating these values, including 0.2 m^3 of floodwater storage for the systems, and a 30-year lifespan for surface storage and basin infiltration. A 40% evaporation loss was assumed for surface storage, with a 5% loss for each of the other systems (Arshad et al. 2014). Limited studies have investigated the costs and benefits of BIT. The key study was by Paul (2013), who indicated a total installation cost of USD 10,000 for one BIT, which has a capacity to irrigate 8-12 ha and a net return of USD 5,000-10,000. Compared to the values for other ASR schemes found in the literature reviewed (Table 9), the costs for BIT are lower.

TABLE 9. Levelised costs of various ASR schemes.

ASR method	Annual cost (USD m^{-3})	Annual operation, maintenance and management costs (USD m^{-3})	Total annual cost (USD m^{-3})
Surface storage	0	22,500	22,500
Basin infiltration	32,200	90,500	122,700
ASR with existing well	26,000	221,800	247,700

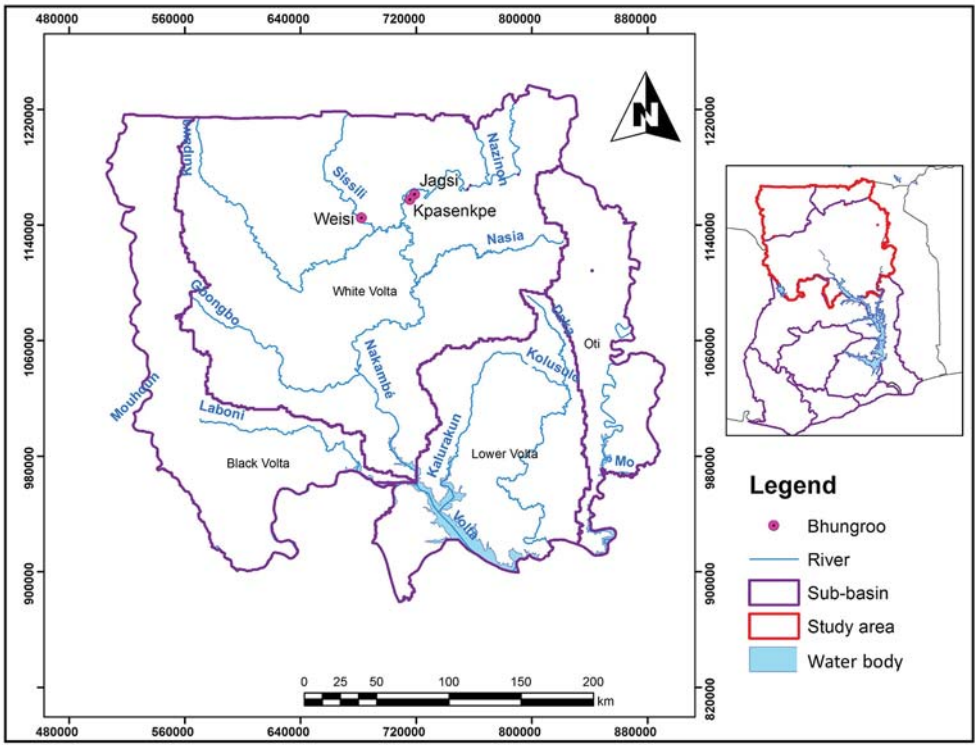
Sources: Dillon and Arshad 2016; Arshad et al. 2014.

4. CHARACTERISTICS OF BHUNGROO SITES IN NORTHERN GHANA

4.1 The Study Area and Bhungroo Sites

Three Bhungroo structures were constructed in northern Ghana - two in the Jagsi and Kpasenkpe communities in West Mamprusi District in the Northern region, and the third in the Weisi community in Builsa South District in Upper East region (Figure 4). They are located in a high temperature zone, where the temperature ranges from 27-29 °C with an extreme range of 17-40 °C (HAP 2009; Carrier et al. 2011). The area has a seasonal rainfall distribution, from May to October, with annual rainfall ranging from 800-1,300 mm yr^{-1} and a higher intensity in the Northern region than the Upper East and Upper West regions (Carrier et al. 2011). With high climate variability in these regions, irrigated agricultural practices are relatively small scale and mostly using surface water, shallow wells and small reservoirs (Namara et al. 2011, 2014).

FIGURE 4. Map of northern Ghana showing Bhungroo sites.



The communities are located in areas with relatively flat terrain, and sufficient rainfall and surface runoff during the wet seasons. The Bhungroo sites in Jagsi (10º 29'58.6'' N, 00º 59' 54.8''W) and Kpasenkpe (10º 28' 0.1''N, 01º 01' 44.0''W) communities fall within the main White Volta Basin, while the site in Weisi (10º 21' 13.5''N, 01º 20' 12.8''W) is within a tributary of the White Volta Basin, the Sissili Basin. The Bhungroo sites are located in so-called lowland areas where intense waterlogging or flooding affects most of the lands during the wet season, which was confirmed through interviews conducted with stakeholders/farmers. Assessment of the sites showed that they were underutilized for agricultural activities, especially due to flooding in the wet season and lack of water during the dry season. Maximizing the potential of such lands for farming activities all year round through the installation of the Bhungroo technology was justified and welcomed by those communities.

Key determinants for siting of the Bhungroo scheme have been identified and grouped into three classes: land surface criteria, subsurface criteria and socioeconomic criteria. Conservation Alliance in Ghana identified these criteria for implementation of the Bhungroo technology, which served as a framework for the geographic information system (GIS) mapping of suitable sites in the study area (Conservation Alliance 2016; Owusu et al. 2017). The following sections describe the characteristics of the sites in relation to these three criteria.

4.2 Land Surface Characteristics

Land surface characteristics, such as land use, slope and soils, were determined from the suitability mapping exercise carried out by Owusu et al. (2017). Field visits were conducted to gather additional information on soil and flood proneness in the area, as described below.

4.2.1 Land Use

Land use data were obtained from a previous study conducted by Mul et al. (2015). Since the main purpose of the Bhungroo technology is to provide irrigation water for agriculture, Bhungroo schemes are to be sited in areas where cultivation is possible. This would exclude settlements, national parks and natural vegetation. Land use in the three sites is rangeland and cropland, which are very suitable for the Bhungroo technology (Table 10; Owusu et al. 2017).

TABLE 10. Land surface characteristics for the Bhungroo sites in northern Ghana.

Bhungroo site	Land use	Slope (degrees)	Soil type	Height above the nearest drainage (m)	Flood	
					Depth (m)	Duration (months)
Jagsi	Rangeland	0.21	Lixisols	12	1-1.5	2-3
Kpasenkpe	Rangeland	0.99	Planosols	1	0.6-1	2-3
Weisi	Cropland	0.67	Planosols	0	1-1.5	2-3

Source: Owusu et al. 2017.

4.2.2 Slope

The Bhungroo is most preferable on relatively flat surfaces, as these are more likely to be flood-prone areas. Generally, the lower the gradient of the landscape, the more suitable the area for the installations; an estimated value of up to 5% (~3 degrees) is recognized as being best for the systems, depending on the landscape of the area (Conservation Alliance 2016; Owusu et al. 2017). Owusu et al. (2017) mapped the slopes using the SRTM 90 m resolution data (LP DAAC 2016). For all three Bhungroo sites, the terrain was very flat - less than 1 degree (Table 10; Owusu et al. 2017).

4.2.3 Soil

The soil types for the site need to be fit for two purposes: retaining water during flooding, and providing good soil conditions for agricultural production. Owusu et al. (2017) mapped the soils for northern Ghana using the Food and Agriculture Organization of the United Nations (FAO) soils map (FAO-IIASA-ISRIC-ISS-CAS-JRC 2012). There are sizeable proportions of Acrisols, Planosols, Leptosols and Fluvisols present largely inside the floodplain in northern Ghana (Balana et al. 2016). Planosols are mostly clayey alluvial and colluvial deposits often found in seasonally waterlogged flat land, while Acrisols and Luvisols are also rich in clay but could be useful for agriculture given good internal drainage (FAO 2016). Soils in both Kpasenkpe and Weisi are Planosols (sandy clay), whereas Jagsi is characterized by Lixisols (sandy loam), which are defined by the presence of surface accumulation of clay and high base saturation.

A study conducted by Mante et al. (2017) analyzed soil samples from the Bhungroo sites. The results, shown in Table 11, provide information on the soil sample locations, depth, percentage of particle sizes, texture, pH and EC of the larger analysis (Mante et al. 2017). The soil texture, which was based on the classification of the United States Department of Agriculture (USDA), has many similarities with what was reported earlier and is the main basis for selecting the sites. The soil type in the Bhungroo site in Weisi community was sandy loam for both sampling depths (0-15 and 15-30 m), while it was sandy clay loam for both sampling depths in the site in Jagsi community. The site in Kpasenkpe community has a variety of soil types. It was sandy clay loam for the 0-15 cm sampling depth, while it was sandy loam for the 15-30 cm sampling depth. Overall, the characteristics of the soils of the Bhungroo sites indicate that a combination of soils has a high capacity for water infiltration, good aeration and percolation. They are good for farming, but may require frequent irrigation and fertilization given the less ability to retain nutrients and water. However, the high portion of clay at the sites in Jagsi and Kpasenkpe communities suggests higher water and nutrient retention capabilities for farming.

TABLE 11. Results of the soil sampling tests conducted in the Bhungroo sites in northern Ghana.

Bhungroo site	Depth (cm)	Particle size distribution (%)			Texture (USDA)	pH	EC (dS/m)
		Sand	Silt	Clay			
Weisi	0-15	63.8	20.0	16.2	Sandy loam	6.02	0.09
	15-30	61.7	20.8	17.5	Sandy loam	6.27	0.14
Jagsi	0-15	49.3	18.2	32.5	Sandy clay loam	5.09	0.04
	15-30	52.5	12.5	35.0	Sandy clay loam	5.15	0.03
Kpasenkpe	0-15	50.6	24.4	25.0	Sandy clay loam	5.11	0.02
	15-30	55.5	25.7	18.8	Sandy loam	5.01	0.02

Source: Mante et al. 2017.

4.2.4 Flood Proneness

With respect to the appropriateness of floodplains for the Bhungroo technology, there is a need for caution especially in instances where floodplains with high flood risks are involved. Flood depths should not exceed 1 m as it can overwhelm such systems, resulting in siltation problems (the PAVE irrigation system can accommodate water up to a depth of 1.5 m). The duration of floods should also exceed at least 1 month to allow the water to slowly infiltrate into the aquifer. Several flood-prone areas exist in northern Ghana. These are created by the several tributaries of the Volta River, as shown in Figure 4. All the Bhungroo sites have a history of flooding, where farmlands have consistently been inundated during rainy seasons of the year, which highlights a clear need for flood mitigation in those areas. Figure 5 shows flooding around the site in Weisi community. This floodwater will be harnessed by the Bhungroo installed at that site. Table 10 also shows the height above the nearest drainage values: a relative vertical flow path distance to the nearest drainage useful for several purposes, as indicators of the flood proneness of the sites (Nobre et al. 2016; Balana et al. 2015). The height to the nearest drainage in the sites at the Weisi and Kpasenkpe communities was very low at 0 and 1 m, respectively, but it was 12 m at the site in Jagsi community. Further details of flood proneness of the area are shown (Table 10) in terms of depth and duration of floods recorded in the study area.

FIGURE 5. Flooded lands around the Bhungroo site in the Weisi community in northern Ghana.

Photos: Yaw Mante, IWMI.

4.3 Subsurface Characteristics

Subsurface characteristics (such as geology) and aquifer characteristics (such as transmissivity, regolith thickness and static water level) were determined from the suitability mapping of Bhungroo sites (Conservation Alliance 2016; Owusu et al. 2017). Additional information on the borehole was gathered in the field by applying a pumping test, as described below.

4.3.1 Geology

The geology of northern Ghana can be categorized into the Precambrian basement (PCB) rocks and the Voltaian Sedimentary Basin (VSB), which underlie the locations where BIT was installed. PCB usually has low primary porosity and permeability, and groundwater flow in this context is influenced by secondary porosity due to chemical weathering, faulting and fracturing (HAP 2009; Carrier et al. 2011). The three Bhungroo sites are located close to the boundary of the two systems. Both sites at Jagsi and Kpasenkpe communities are of the Voltaian Supergroup comprising the Obosum and Oti-Pendjari Group, and their composition is mainly shale, mudstone and sandstone. The site in Weisi community is of the Birimian Supergroup, with its main composition being undifferentiated granitoid (Table 12).

TABLE 12. Rock types for the Bhungroo sites in northern Ghana.

Bhungroo site	Geology	Rock formation	Major composition
Jagsi	Voltaian Sedimentary Basin	Voltaian Supergroup: Obosum and Oti-Pendjari Group	Mainly shale, mudstone and sandstone
Kpasenkpe	Voltaian Sedimentary Basin	Voltaian Supergroup: Obosum and Oti-Pendjari Group	Mainly shale, mudstone and sandstone
Weisi	Precambrian basement	Birimian Supergroup: Dahomeyan	Undifferentiated granitoid

Sources: GGS 2009; Forkuor et al. 2013.

4.3.2 Hydrogeological Factors

Various hydrogeological parameters are required for implementing the Bhungroo technology, and only a holistic assessment of all the key factors can provide a strong basis for deciding where the scheme will best flourish. One of these factors is the rate of recharge of the aquifer. For northern Ghana, the average annual recharge range was 36-146 mm yr^{-1} (8-13% of annual rainfall) (Forkuor et al. 2013). In terms of the spatial distribution of the recharge, the rate is generally higher for the VSB geology (mostly in the Northern region) than the PCB geology, which largely occurs in the Upper East and Upper West regions. The recharge rate for both Jagsi and Weisi communities was 52 mm yr^{-1}, and relatively higher for Kpasenkpe community at 110 mm yr^{-1} (Table 13; Forkuor et al. 2013; Owusu et al. 2017).

Transmissivity represents the groundwater flow (horizontally) through the saturated thickness of an aquifer (Hudak 2004). It is equal to the hydraulic conductivity of the aquifer multiplied by the saturated thickness of the aquifer (Heath 1983; Hudak 2004). The transmissivity value is an indicator of the productiveness of the aquifer and does vary from one location to another given the saturated thickness of the aquifer. The higher the transmissivity, the more productive the borehole and less drawdown values are recorded. For northern Ghana, the transmissivity trend is in the range of 3-26 m^2 day^{-1}, while the average transmissivity for the three Bhungroo sites ranges from 8-12 m^2 day^{-1}, which is within the moderate zone for the study area (Table 13).

TABLE 13. Hydrogeological parameters for the Bhungroo technology in northern Ghana.

Bhungroo site	Transmissivity (m^2/day)	Regolith thickness (m)	Static water level (m)	Recharge rate (mm/yr)	Borehole success (%)
Jagsi	7.60	19.32	14.30	51.77	75-85
Kpasenkpe	6.32	19.83	1.15	110.12	50-65
Weisi	7.36	19.3	1.51	52.18	50-65

Sources: Forkuor et al. 2013; Owusu et al. 2017.

The *regolith* is the entire unconsolidated or secondarily re-cemented cover that overlies more coherent bedrock that has been formed by weathering, erosion, transport and/or deposition of the older material (Eggleton 2001; Obuobie and Barry 2012). Understanding the thickness of the regolith is important for determining the extent and accessibility of groundwater, as well as the storage of water. It is suggested that the thicker the regolith, the higher the storage (Obuobie and Barry 2012; Forkuor et al. 2013). As previously indicated, the regolith of the VSB is thinner and ranges from 4 to 20 m, while the PCB has a thicker regolith and ranges from 10 to 40 m and can even be as high as 140 m in some parts of Ghana (Smedley 1996; Acheampong 1996). The average regolith thickness in the study area ranges from 18 to 25 m for the three Bhungroo sites (Table 13), which was determined through a GIS analysis of hydrogeological data for the area (Forkuor et al. 2013; Owusu et al. 2017). This value could suggest groundwater potential and storage of the area, depending on other aquifer conditions.

Borehole information, such as *static water level*, represents the depth below the ground surface of the ambient groundwater, giving an indication of the groundwater accessibility of a site. It is said that groundwater could be ‘easily accessible’ in terms of technology and cost, for decreasing depths of the water. Given the geology of the area where the Bhungroo technology was piloted, the static water levels would be within the range of 0-35 m (Forkuor et al. 2013; Owusu et al. 2017), and signify a relatively low water level and easy accessibility. However, this does not necessarily indicate a high quantity of water given the depths of Bhungroo wells. Moreover, an estimation of the rate of successful boreholes in an area will provide information on where the Bhungroo will be more productive, depending on other factors. A threshold of 10 liters/minute, used by the Community Water and Sanitation Authority (CWSA), was considered as the minimum standard yield for assessment of successful boreholes (CWSA 2010; Forkuor et al. 2013). A successful borehole is expected to have an estimated rate of at least 50%, with higher success rates (≥ 65%) considered for the Bhungroo technology. The borehole success rate was good (50-65%) for sites at Kpasenkpe and Weisi communities, and much higher for the site at Jagsi community (75-85%) (Forkuor et al. 2013; Owusu et al. 2017).

4.3.3 Borehole Characteristics

Following the installation of the Bhungroo technology, a field-pumping test was conducted at the sites. The main purpose of this investigation was to obtain actual field results to complement the findings from the desk study. The analyses include the borehole yield and the time taken for the Bhungroo to recover after the pumping test. Figure 6 shows the pumping test being conducted, where the investigators were observing the static water level of the Bhungroo at the site in Weisi community.

The results of the pumping test are presented in Table 14. For static water levels of the Bhungroo wells, the site at Jagsi community recorded a level of 7.1 m during the pumping test (Mante et al. 2017). The recovery time for the same borehole was 55 minutes (min) for a yield of 0.075 m^3 min^{-1}, which was a good result, and was within the values known for the study area.

The site at Kpasenkpe community had a similar yield for a deeper borehole depth of 39 m, and a static water level of 10 m away from reach. However, the recovery time was slightly longer at 1 hour, which was reasonable given the design. Considering the sites, with a depth of 18 m, the Bhungroo at the site in Weisi community had the lowest yield of 0.06 m^3 min^{-1} and the longest recovery time of 2 hours after the pumping test. This was the least performing site based on the geology of the study area. Overall, these findings are crucial with the static water levels being consistent with the broad range of 0-14 m recorded by the desk study, while the borehole yield of 0.075 m^3 min^{-1} was significant for installation of the technology in the study area.

FIGURE 6. Test pumping of the Bhungroo at the site in Weisi community in the Northern region of Ghana.

Photo: Fusheini Salifu, IWMI.

TABLE 14. Results of the test pumping of the Bhungroo technology in northern Ghana.

Bhungroo site	Depth (m)	Yield (m^3 min^{-1})	Static water level (m)	Recovery time (minutes)
Jagsi	32.5	0.075	7.1	55
Kpasenkpe	38.92	0.075	10.0	60
Weisi	18	0.060	6.7	120

Source: Mante et al. 2017.

4.4 Bhungroo Design and Subsoil Properties

This section provides details of the design of the Bhungroo scheme at the three sites (in particular, the design of the filtration component of the system) and describes some of the characteristics of the hydrogeological properties, such as the hydraulic conductivity and porosity of the Bhungroo wells.

4.4.1 Bhungroo Design

Figure 7 shows the Bhungroo scheme installed at Weisi community and the design of the scheme at Kpasenkpe community. The rectangular shaped infiltration bed has a dimension of 2.5 x 2 m and a protruding pipe. The length of the protruding pipe ranges from 40-60 cm above ground level with a diameter of 5 inches for all the sites. In the infiltration bed, there are layers of particles of different sizes compactly arranged and covered with a wire mesh to facilitate the movement of floodwater to the Bhungroo well and the unconfined aquifer (Conservation Alliance 2016). Local skills and labor were used in constructing the Bhungroo with the materials that are available locally or accessible nearby. The materials used include coarse rocks, gravel and fine, and charcoal, particularly for the Bhungroo at the site in Weisi community, which had an odor problem with the water. According to the design shown in Figure 7(b), the infiltration bed is 3 m and the borehole depth is 39 m, and screens are located within the system. It also shows the groundwater level in relation to the actual depth of the design, and the observed water depth in the Bhungroo during a field test in April 2016. Table 15 presents a compilation of the design details for all the Bhungroo schemes installed.

FIGURE 7. Bunghroo schemes installed at (a) Weisi community, and (b) design of the scheme at Kpasenkpe community.

(a)

Photo: Marloes Mul, IWMI.

(b)

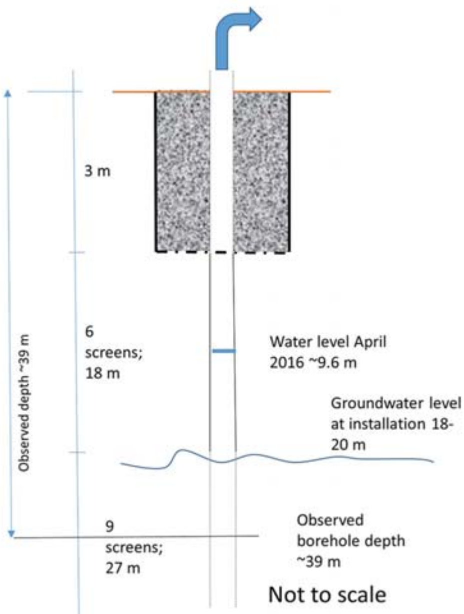


TABLE 15. Design parameters of the Bhungroo scheme.

Bhungroo site	Depth (m)	Size of the Infiltration bed (m)	Depth of the infiltration bed (m)
Jagsi	32.5	2.5 x 2	3
Kpasenkpe	38.92	2.5 x 2	3
Weisi	18	2.5 x 2.5	3

Source: Mante et al. 2017.

4.4.2 Hydraulic Conductivity and Porosity of Subsoils

Further analyses of the drilled Bhungroo boreholes highlight the characteristics of the regolith, hydraulic conductivity and porosity of the sites. Table 16 provides details of the texture, hydraulic conductivity and porosity of the Bhungroo wells at various depth ranges. The texture of the regolith of the boreholes varied from clay, sandy-clay and sandy-clay-loam for all the sites, and exhibited a hydraulic conductivity range of 0-37 mm h^{-1} for Kpasenkpe and 0-43 mm h^{-1} for Jagsi. Weisi recorded a hydraulic conductivity range of 0-35 mm h^{-1} and a porosity range from 19 to 42%. Similarly, the porosity for the site at Kpasenkpe was high (26-51%), while the site at Jagsi had a wider spread of porosity values (2-43%), depending on the clay content and organic matter of the soil. The pattern of the hydraulic conductivity observed was largely due to the different soil textures at various depths of the borehole. The possibility of the drilled boreholes not connecting well with the groundwater may depict patterns different from that expected from the geology of the study area.

TABLE 16. Hydraulic conductivity and porosity of Bhungroo boreholes.

Bhungroo site	Depth (m)	Texture	Hydraulic conductivity (mm h^{-1}) range	Porosity (%) range	Groundwater level
Jagsi	0-5	Clay, sandy-clay-loam, sandy-clay	0-3	37-43	50-65
	5-35	Sand	0-43	2-25	
Kpasenkpe	0-5	Clay, sandy-loam	0-28	32-43	18-20
	5-20	Sandy-clay-loam, sand, Sandy loam, clay	0-31	26-51	
	20-39	Sandy-clay-loam, clay, sandy-loam, loamy-sand	0-37	26-45	
Weisi	0-7	Sandy-loam, loam	8-35	33-42	30-45
	7-18	Sandy-loam	0-8	19-20	

Source: Abdul-Ganiyu and Gbedzi 2015.

4.5 Socioeconomic Characteristics

Socioeconomic characteristics such as accessibility to the Bhungroo site and proximity to beneficiary communities have been reported (Conservation Alliance 2016; Owusu et al. 2017). Additional information on public attitudes towards the Bhungroo was extensively gathered in a field survey by the project partners (Conservation Alliance 2015b).

4.5.1 Accessibility to Bhungroo Sites

Accessible roads are primarily important for agricultural activities within the study area where Bhungroos are installed, as they provide easy access to markets. Close proximity to roads also supports the installation of Bhungroo, as heavy equipment needs to be moved close to the sites. The site should not be located too close to a major road in order to avoid runoff from the road entering the Bhungroo. All the Bhungroo schemes are located in close proximity to roads within 1 km (Conservation Alliance 2016; Owusu et al. 2017).

In terms of *population density*, highly populated towns and cities are often not appropriate for the installation of Bhungroo systems due to the high risk of human interference. Taking this into consideration, a population density assessment of the study area showed that a density less than or equal to 100 km^{-2} is generally good for the Bhungroo. Northern Ghana has highly populated areas, such as Tamale in the Northern region, Bolgatanga in the Upper East region and Wa in the Upper West region, but the communities where the Bhungroo technology was sited have low population density from 24 to 32 km^{-2} (Table 17; Owusu et al. 2017).

TABLE 17. Summary of socioeconomic characteristics of the Bhungroo sites in northern Ghana.

Bhungroo site	Proximity to road (m)	Population density (pop km^{-2})
Jagsi	1,000	24.10
Kpasenkpe	26	24.10
Weisi	67	32.22

Source: Owusu et al. 2017.

4.5.2 Public Attitudes toward Bhungroo

When considering the *attitudes* of farmers and the communities where Bhungroo is being implemented, they should generally be ‘acceptable’ of the innovation and have a ‘willingness’ to fully participate in the project. Prior to piloting the Bhungroo, a survey of 30 households from four communities in northern Ghana was conducted by Conservation Alliance on water needs, flood issues and implementation of the Bhungroo. The findings first emphasized the need for the Bhungroo technology in the selected sites to boost dry-season farming, as people acknowledged their limited access to water in dry seasons as well as excessive flooding of their farmlands during wet seasons (Conservation Alliance 2015b). Respondents showed a ‘willingness’ to work together with the project team, and on the issue of gender and women’s involvement in irrigation, key recommendations were made to provide support and training on the use of such a technology (Conservation Alliance 2015b). Although access to lands can be an impediment to the successful implementation of such community-based projects, the willingness of landowners to participate in the project facilitated this process. Importantly, most individuals owned their farmlands, while chiefs had ownership of the flood-prone lands. The chiefs were consulted and they freely offered appropriate sites for the installation of the Bhungroo (Conservation Alliance 2015b).

5. CONCLUSION

Bhungroo has become an interesting technology addressing a pertinent need, given the fact that rainfed agriculture is threatened by rainfall variability in the region, and limited options exist for dry-season farming. However, the technology has strict biophysical and socioeconomic requirements for its successful implementation. Initial findings from the piloted scheme in three locations in northern Ghana show the technique suits the conditions in the study area with potential for up-scaling.

First, the land surface characteristics of the Bhungroo sites underscore a reliable source of water for the technology. The need for flood-proneness of the site is key. The study area is characterized by seasonal rainfall and rich tributaries of the Volta River, as well as evidence of a repeated history of flooding in northern Ghana. The surface soil types, including the significant presence of clay, silt and loam, and the relatively flat terrain were factors that facilitated flooding and good indicators for the Bhungroo technology. Subsurface features, which include the geology and aquifer nature, determine groundwater storage potential and accessibility. The Bhungroo sites were found in an unconfined aquifer with elements such as transmissivity, regolith thickness of the aquifer and recharge potential being moderate or high compared to the broad range for northern Ghana. This means that the Bhungroo boreholes exhibit good yield and accessible water level, with Jagsi and Kpasenkpe recording very high water recovery rates after a test pumping. Moreover, the socioeconomic features of the sites established that the Bhungroo schemes are accessible to the farming communities, with the stakeholders, including women in the farming communities, showing a positive attitude toward the initiative and a willingness to ensure sustainability of the scheme. These encouraging signs are particularly vital for successful delivery of innovations and community-based projects, where such stakeholders have a greater role in maintenance of the systems.

Overall, the study has shown that there is evidence that the Bhungroo technology has potential for piloting in northern Ghana, by exhibiting important biophysical and socioeconomic features essential for a successful scheme. The design and construction of the three Bhungroo technologies, which largely depended on existing conditions of the sites, emphasize the fit of the technology to the local communities. In addition, results of the field observations, including the soil and pump tests, following the installation of the Bhungroo, comply with the requirements for the technology. Further studies are ongoing to test the technology on its performance with regard to recharging and recovering water from the aquifer, as well as to assess the irrigation potential, and costs and benefits associated with the technology.

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Postal Address
P O Box 2075
Colombo
Sri Lanka

Location
127 Sunil Mawatha
Pelawatta
Battaramulla
Sri Lanka

Telephone
+94-11-2880000

Fax
+94-11-2786854

E-mail
iwmi@cgiar.org

Website
www.iwmi.org

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