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Feasibility and Efficiency of an Integrated Large-Scale Bhungroo Irrigation Technology in West Mamprusi Sub-Catchment, Ghana

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Abstract:
Many smallholder farmers are intensifying their production in ecologically harmful ways, necessitating an urgent shift towards sustainable agricultural practices using appropriate local technologies. This study focuses on the feasibility and efficiency of integrated agro-ecological technologies and their impact on socio-economic livelihoods in arid and semi-arid lands, specifically in the West Mamprusi sub-catchment in Ghana. The study evaluates Integrated Bhungroo and Grundfos Lifelink technologies, examining the interoperability and techno-economic aspects of large-scale Bhungroo Irrigation Technology (BIT) deployment. Nine Bhungroos were tested successfully in the West Mamprusi sub-catchment, which served as the field observation site. Using a quasi-experimental design, the study compared responses from Upstream Farming Communities (experimental group) and Downstream Farming Communities (control group) regarding agricultural water adaptation to climatic trends and surface water flow patterns under Bhungroo Irrigation schemes. Field observations revealed that over 95% of the area is underlain by rocks of the Voltaian SuperGroup, with 85% of upstream farmlands consisting of about 80% clay. These materials have low vertical hydraulic conductivities, ranging from 2.56 m/day to 18.27 m/day, leading to waterlogged conditions, especially upstream. Bhungroo technology can be implemented where subsoil strata allow water storage. The highest percentages of waterlogging occur in JAS, with 67% upstream and 48% downstream. Data from BIT pilots indicate that recharge distribution follows the geology, with the highest recharge in areas underlain by Birimian rocks. This suggests a high probability of retention in underground reservoirs for harvesting floodwaters, particularly in the lower catchment area of the West Mamprusi District.

Keywords: *Agro-ecological technologies, Grundfos Lifelink*'s, *Holiyas, MPesa, steady state infiltration, water harvesting, groundwater recharge*

1. Introduction

Ghana, like many African nations, grapples with a water crisis characterized by poor availability, accessibility, and affordability (Eludoyin & Olanrewaju, 2022; Luwesi et al., 2017). These challenges are exacerbated by shifts in global macroclimate patterns, population growth, urbanization, and human environmental impacts (Dinar, Tieu & Huynh, 2019; AGRA, 2009). Farmers facing increasing water needs encounter temporal and spatial variability in water availability (Luwesi et al., 2017; Gleick, 2001). Addressing these water supply deficiencies requires the development of dynamic strategies to meet both current and future agricultural water demands.

Innovative water projects in Arid and Semi-Arid Lands (ASALs) prioritize enhancing the sustainability of small-scale farmers (Yu et al., 2019). These projects advocate for principles such as cost-sharing, user-pays, and polluter-tax in ASALs, yielding significant benefits (Haas & Nagarajan, 2011). Various institutions have funded projects aimed at promoting new groundwater abstraction technologies. This study focuses on three groundwater projects implemented in East and West Africa, specifically Grundfos Lifelink's groundwater pumping technology, the MPesa mobile money transfer technology, and the Holiya groundwater storage technology, also known as "Bhungroo" (Luwesi et al., 2017).

Bhungroo irrigation technology (BIT) has proven to be effective in providing water to more than 3,000 farmers in Gujarat State (Shah et al., 2016; Bunsen & Rathod, 2016; Biplab, 2012). In Northern Ghana, the Holiyas were tested by the Conservation Alliance International (CAI) at Jagsi, Kpesenkpe and Weisi communities of the Walewale area (Luwesi et al., 2017). These communities are confronted by acute water shortages in the dry season and excessive rainfalls and floods in the rainy season. The aim of the Holiyas is to solve the waterlogging of farms in the ASALs and improve water supplies during the dry season by supporting small-scale irrigation programs (WLE, (2015). However, the success of the Bhungroo technology is site-specific, and its performance is dependent on local climate, topography, land types, soils and groundwater table. In this regard, the deployment of BIT requires a multivariate assessment of these factors to ensure that it is both feasible and efficient. Consider domains of agro-ecological innovations, rainfall distribution patterns and regimes, farm-water management, and access to affordable and user-friendly technologies.

In this work, the objective was to evaluate the feasibility and efficiency of integrating large-scale BIT among small-scale farmers in the West Mamprusi Sub-Catchment. The specific objectives are to:

- Describe available agro-ecological technologies with the potential to enhance the application and efficiency of BIT and
- Test and project the integration of these technologies with BIT with regard to compatibility, scalability and affordability (efficiency).

Grundfos Lifelink's groundwater pumping technology (from Denmark) and MPesa mobile money transfer technology (used in Kenya) are given priority in this study. It then links these to the Holiya groundwater storage technology (also known as "Bhungroo") developed along the edges of the Gujarat State desert of India and which is currently being tested in Ghana, West Africa (Luwesi et al., 2017). This study projects an integration of these technologies into a Climate Smart Agriculture (CSA) water design to provide a basis for groundwater development and services financing in Ghana.

2. Materials and Methods

2.1. Description of Study Area

Based on the quasi-experimental design, the study area (West Mamprusi District) was subdivided into an experimental group (Upstream Farming Communities) and a control group (Downstream Farming Communities), all in the West Mamprusi District. Geographically, the West Mamprusi District lies within latitudes 9°55'N and 10°35'N and longitudes 0°35' and 1°45'W. It shares boundaries with East Mamprusi, Gushegu District to the East, West Gonja, Tolon/Kumbungu Savelugu/Nanton, and Karaga District to the south, Builsa, Kassena-Nankana and Talensi/Nabdam Districts (Upper East Region) to the north and Sissala and Wa East District (Upper West Region) to the West, DPU, West Mamprusi District Assembly, (2016).

The study sampled responses of Upstream Farming Communities' stakeholders (experimental group) in comparison with those in downstream farming communities (control group) in terms of agricultural water adaptation to climatic trends and surface water flow patterns under Bhungroo Irrigation schemes. The selection of the West Mamprusi sub-catchment is mainly explained by the need to build scenarios of vulnerability to water disasters, mainly for droughts and floods. The following Cochran (1977) equation for categorical data was used to determine farmers' sample size in each catchment area under study (Bartlett et al., 2001):

$$n = \frac{t^2 * p * (1-p)}{\alpha^2}$$

Where:
n = required sample size
t = t of Students' value (set at 1.65 for a 10% confidence level)
α = the acceptable margin of error the researcher is willing to except for the proportion being estimated (set at 5% confidence level)
p = the maximum proportion of the sample size in the population (for a variance of p(1-p) equals to 0.25).*

In this study, a total of 155 farm plots were selected, with the UFC and DFC contributing 80 and 75, respectively. The demarcation was carried out based on the Krumme (2006) approach with a 95% confidence level and a 7.5% acceptable margin of error for the DFC. The UFC demarcation had a 90% confidence level and a 10% acceptable margin of error. In addition, Zeiller's (2000) random walk was used as a rational basis to provide an equal chance of selection to all respondents located at the market center and further away from main roads. In areas where no farmer was available with a farm unit, the farming unit with the immediate random number was selected.

2.2. Techniques of Data Collection

The study relied on project site observations, information from pilot project reports, on-farm survey questionnaires, interviews with local administration officers and Focus Group Discussions (FGDs). Data was gathered under the following domains: feasibility (hydro-climatic conditions, climate preparedness, climate predictability, transferability of innovations) and efficiency (scalability of innovations, affordability/willingness and ability to pay for agro-ecological technologies). Primary physical data was collected *in situ* using a soil moisture meter and a current meter. Physical data included monthly rainfall and temperature data from available rain gauge stations (ranging from 1980 to 2018) and soil moisture (25 field points and 25 soil cans). Missing data was estimated using the Multiple Linear Regression (MLR) Approach (Eischeid *et al.* (1995).

2.3. Data Analysis and Results Interpretation

The data collected above was first pre-processed and analyzed using SPSS 17.0, MS Excel 2007, and OpenOffice 2002 spreadsheets, as well as the WEAP hydrological system. Thereafter, the data was successfully subjected to the analytical procedures. This included transcribing, translating and anonymizing transcripts. This allowed for an inductive, thematic data analysis, with a comparison between upstream and downstream observations.

In estimating the internal consistency reliability of the determinants feasibility and efficiency on agro-ecological technologies, the study made use of the Kuder Richardson formula 21 (KR 21). The KR 21 provides an estimate of internal consistency reliability by determining how all the items on a test relate to the total test (Kuder & Richardson, 1937). This is based on the assumption that all the items of the test are of equal or nearly equal difficulty and inter-correlations. The KR21 formula is given by:

$KR_{21} = [n/(n-1) * [1-(M*(n-M)/(n*Var))]$

Where:

n= sample size,

Var= variance for the test,

M = mean score for the test.

Results were interpreted and discussed to shed light on the design domains of agro-ecological innovations, farm-water management (including availability, accessibility and affordability to/of innovations), hydro-climatic conditions and transferability of innovations in West Mamprusi sub-catchment. The following subsections provide a detailed description of the type of data collected and its subsequent analytical frameworks. In relation to assessing the potential for IBIT, the study estimated the efficiency of agro-ecological innovations (scalability of innovations, affordability of Bhungroo technology with other agro-ecological technologies including Solar Photovoltaic (PV) systems (Zyl et al., 2000) as a power source for the irrigation system. It also estimated the ability and willingness of farmers to pay for solar energy under the different modes of financing. The potential increase in solar energy demand was estimated under the different financing modes and overall system effectiveness of IBIT. Tools for this data collection included questionnaires and Institutional interview guides.

3. Results

3.1. Describing Available Agro-Ecological Technologies with the Potential to Enhance the Application and Efficiency of BIT

This objective is addressed by the results presented in table 1 and figures 1 to 3. Key results from the study indicate a lower BIT compliant rating index 7.5 with a mean clay content of 27.7%, (SD=0.157), mean sand content of 62.3%, (SD=0.071), mean stoniness of 8.9%, (SD=0.011), mean soil depth of 15m at (SD=0.172), mean bulk density of 1.79 g·cm^{-3}, (SD=0.203), mean slope of 22% at (SD=0.091), mean groundwater table of 43.5m, (SD=0.003), mean annual rainfall of 1200mm at (SD=0.166), mean rainfall intensity of 0.92 mm/hour at (SD=0.117), mean steady-state infiltration 18.2cm h^{-1}, (SD=0.201), mean waterlogged days /year of 73 days, (SD=0.148), and mean groundwater recharge rate of 53.22 m/yr (SD=0.077).

Plot Properties	Downstream		Upstream	
	Mean	SD	Mean	SD
Clay content (%)	27.7	0.157	27.5	0.320
Sand content	62.3	0.071	61.7	0.333
Stoniness (%)	8.9	0.011	8.8	0.251
Soil depth (m)	15	0.172	15	0.044
Bulk density (g·cm^{-3})	1.79	0.203	1.66	0.124
Slope (%)	22	0.091	31	0.030
Groundwater table (m)	43.5	0.003	43.8	0.012
Annual rainfall (mm)	1200	0.166	1120	0.170
Rainfall intensity (mm/hour)	0.92	0.117	0.89	0.211
Steady-state infiltration (cm h^{-1})	18.2	0.201	17.6	0.344
Waterlogged days /year	73	0.148	69	0.232
Groundwater recharge rate (m/yr)	53.22	0.077	52.28	0.051
BIT compliant rating index (1 to 10)	7.5	0.114	8.3	0.130

Table 1: BIT Pre-Requisite Conditions and Processes Downstream Vs Upstream Catchments Delineation
SD = Standard Deviation

The upper catchment area, on the other hand, depicts a BIT-compliant rating index 8.3 with a mean clay content of 27.5%, (SD=0.320), mean sand content of 61.7%, (SD=0.333), mean stoniness of 8.8%, (SD=0.251), mean soil depth of 15m, (SD=0.044), mean bulk density of 1.66 g·cm^{-3}, (SD=0.124), mean slope of 31%, (SD=0.030), mean groundwater table of 43.8m, (SD=0.012), mean annual rainfall of 1120mm, (SD=0.170), mean rainfall intensity of 0.89 mm/hour, (SD=0.211), steady state infiltration of 17.6 cm h^{-1}, (SD=0.344), mean waterlogged days /year 69days, (SD=0.232), mean groundwater recharge rate of 52.28 m/yr, (SD=0.051). Field observations indicate that within the study basin, BIT and other similar technological systems have been tested in a total of 9 Bhungroos sites, which generate roughly 1,000 m3 during the dry season to serve up to 800 farmlands.

The following are the key components for the Experimental Design Framework of Bhungroo Irrigation Technology.

Step 1	*Siting & Drilling as depicted in*	This stage includes several technical assessments of potential sites to ascertain the feasibility of a Bhungroo installation. It deals with a large set

	A; figure 3	of data collection for initial assessments. Drilling involves creating a vertical hole underground using a borehole drilling machine. The depth of the drilling varies due to differences in altitudes, the water table depths and the characteristics of unsaturated soil layers. Observed drilling depth varied from 45m to 74m.
Step 2	*Bhungroo design and erection, as depicted in **C;*** figure 5.1	This stage involves arranging the Bhungroo pipes according to the soil strata identified during the drilling process. In the design process, layers of soils that had no potential capacity to hold water was assigned unperforated pipes, while unsaturated water storage zones were assigned perforated pipes, with fix strainers or screens. This enabled the flow of injected water from the unsaturated layer to the aquifer.
Step 3	*Filtration chamber construction as depicted in **D;*** figure 3	*A filtration* chamber 1.5 to 1.55m in length, breadth, and depth was created around the Bhungroo to clean flood waters. This chamber was to provide housing for the Bhungroo's filtration materials, which included stones of different sizes, as well as sand and wire mesh. Once the chamber was completely dug out, a wall made of cement blocks was set on all four sides of the chamber.

Table 2

This process is further illustrated in figure 1 with a description of available technologies to enhance BIT application and efficiency.

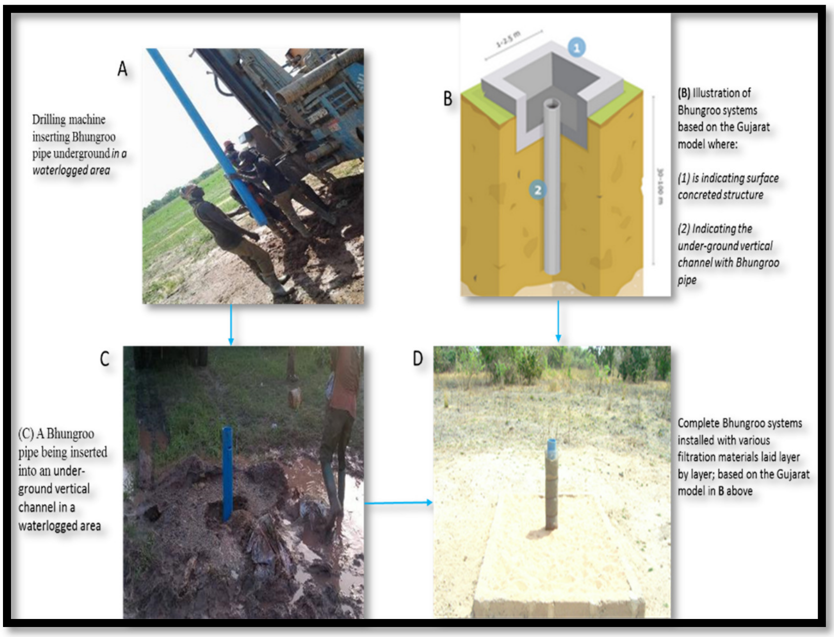

Figure 1: The Experimental Design Framework of Integrated Bhungroo Technology in Northern Ghana

Available technologies to enhance BIT application and efficiency include:

- Grundfos Lifelink: This technology has been piloted by a Danish pump-making company (Grundfos Ghana) and Ghana Water Company Limited (GWCL). As an independent component, Grundfos Lifelink's pumping has proven to improve the efficiency of groundwater withdrawal using a solar pump activated by a mobile phone. The Grundfos AQtap consists of 3 units (Figure 2).

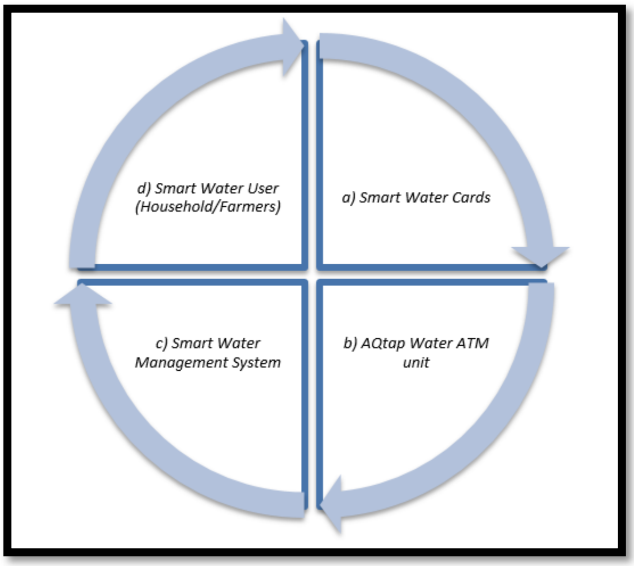

Figure 2: The Grundfos AQtap

- *Smart Water Cards:* This is the unit where electronic water credits are stored
- *AQtap Water ATM unit*: This is an electronic unit where water is tapped and water credits are managed.
- *Smart Water Management System*: This is the digital portal where data from transactions and operations are processed and published.
- *Smart Water User (Household/Farmers): Water Users/communities connected to* The Grundfos AQtap

The three units (a, b, c) are combined as a single intelligent system that connects users to 24/7 non-stop access to water through a personalized payment card (called WaterCard) with an in-built automatic fee payment system that enables the service provider, Ghana Water Company Limited to provide a reliable water supply in which all transactions are logged.

- MTN Mobile Money Transfer: MTN Mobile Money is the MPESA service model in Ghana. This service is provided by MTN Ghana. MTN Mobile Money provides users with a secure electronic (mobile phone-based) payment system that enables users to pay for goods and services electronically, save money, receive payments and remittances and access micro-credit facilities. This service is provided on a pay-as-you-go basis. This suggests a high interactional feasibility of BIT systems under development in Northern Ghana with the Grundfos-MTN Mobile Money framework and with the support of drip/micro irrigation equipment to make a full Bhungoo-Grundfos-MTN Mobile Money system (Integrated Bhungroo Irrigation Technologies-IBIT) (Figure 3).

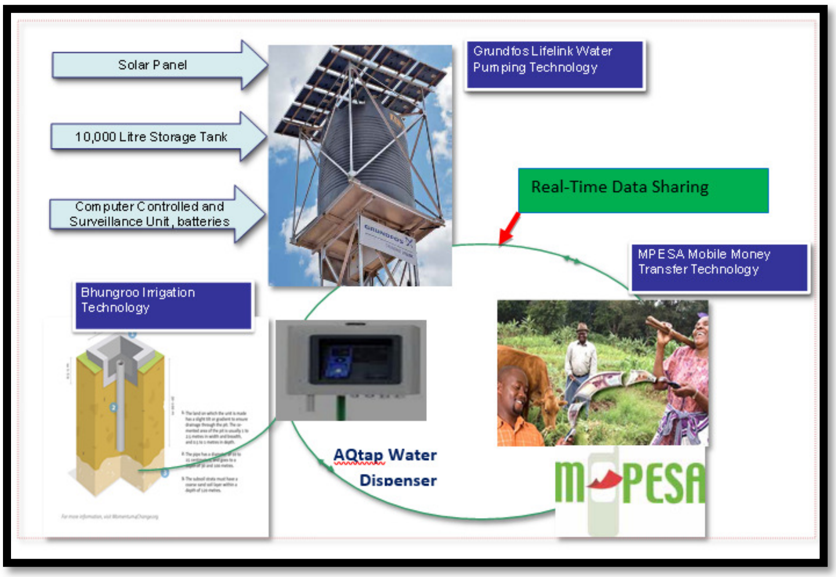

Figure 3: Display of Integrated Bhungroo Grundfos Lifeline's Technology Scheme with MTN Mobile Money (MPESA Money Transfer Model in Ghana) as a Payment Mechanism

3.2. Testing and Projecting Integration of These Technologies with BIT with Regard to Compatibility, Scalability and Affordability (Efficiency)

This objective is addressed by the results presented in table 3 to 5 and figures 4 and 5. Of the 800 farmers, 74% had access to MTN Mobile Money service. This indicates that the concept of using MTN Mobile Money service as a payment mechanism for BIT is feasible in the study basin, with an average of 74% of farmers having access to MTN Mobile Money service at an average cost of US$0.0625/m3 of water supply under drought scenarios. The integration of these technologies builds a digital framework where water users (farmers) electronically pay for the right quantities of water needed at the right time (during dry season/periods).

IBIT Component	Cost of Component (in USD) UPSTREAM	Cost of Component (in USD) DOWNSTREAM	McNemar Test (Chi-square) (95% C.I)
Bhungroo (site development and erection)	8250	8250	-
Grundfos Lifelink Pumping system (CM–PS– 1X240V 50Hz) (including installation)	7300	7300	-
Amiran Drip Irrigation system	300	300	-
PV Solar (including installation)	4000	4000	-
MTN Mobile Payment Merchant	1400	1400	-
Cost of System Maintenance (projected for 10 years)	570	500	0.036
Total cost of IBIT System	21820	21750	1.251
Ability to pay/ month/community	360	250	0.672
Projected Payback Period (In Years)	**5.05**	**7.25**	**0.866**

Table 3: Simplified Calculation of Cost and Payback for IBIT

The results of the predictions of water demand alongside water supply in the district between 2019 and 2030 (comparing water balance under conventional BIT and an integrated BIT), using the water evaluation and planning (WEAP) system. Key results illustrate the projected developmental change and the associated water demand and water supply under current and altered conditions in the district. It further shows that significant water gains can be achieved. It is observed that ET0 (mm/month) decreases from 87.31 to 81.88 by 2030, and crop water requirement (mm/month) decreases from 71.20 to 70.11 by 2030. The data shows that the percentage of irrigation efficiency will increase from 52.80 to 85.00 by 2030. The percentage of irrigated areas will increase from 51.61 to 74.00 by 2030. Finally, results show that the irrigation water requirement (mm/month) will increase from 43.21 to 51.27 by 2030. The results depicted with error bars indicate the 95% confidence intervals of the mean irrigation water requirement under conventional BIT.

Variable	2019	2030
ET0 (mm/month)	87.31	81.88
Mean ET0 (mm/day)	2.87	2.98
Mean monthly Precipitation (mm/month)	51.26	50.32
Effective rainfall (ER/mm)	35.61	34.12
Crop coefficient	0.80	0.80
Crop water requirement (mm/month)	71.20	70.11
Percentage rain deficit	51.21	51.26
Percentage irrigation efficiency	52.80	85.00
Percentage irrigated area	51.61	74.00
Irrigation water requirement (mm/month)	43.21	51.27
Net water requirement (mm/month)	66.33	72.32
Irrigation water volume (m^3/month)	267,742.22	377,343.55

Table 4: Irrigation Water Requirement under Conventional BIT

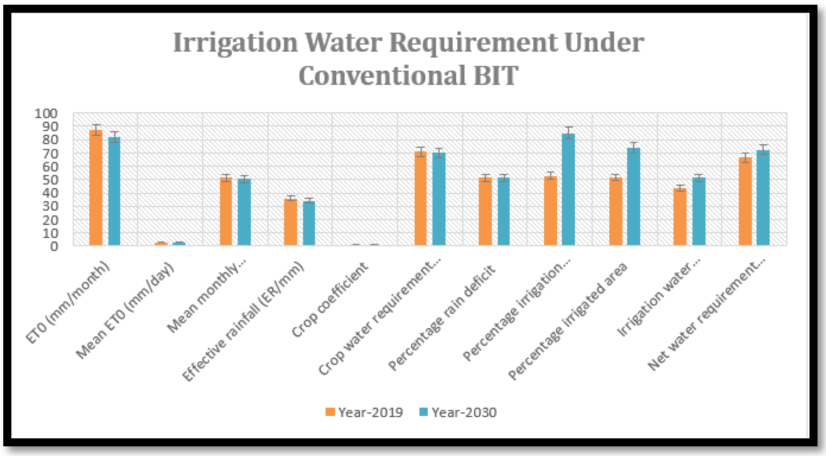

Figure 4: Irrigation Water Requirement under Conventional BIT (95% Confidence Interval)

Results on irrigation water requirement under IBIT show increased water gains compared to conventional BIT. It is observed that ET0 (mm/month) decreases from 87.31 to 81.32 by 2030, and crop water requirement (mm/month) decreases from 71.20 to 61.22 by 2030. The data shows that irrigation efficiency increases from 52.80 to 92.10 percent by 2030. The percentage of irrigated areas will increase from 51.61 to 94.00 by 2030. Finally, results show that the irrigation water requirement (mm/month) will decrease from 43.21 to 31.22 by 2030. The results depicted with error bars indicate the 95% confidence intervals of the mean irrigation water requirement under conventional BIT. This prediction signalled both the need for and feasibility of BIT deployment on a large scale to complement existing water management systems.

Variable	2019	2030
ET0 (mm/month)	87.31	81.32
Mean ET0 (mm/day)	2.87	1.45
Mean monthly Precipitation (mm/month)	51.26	50.32
Effective rainfall (ER/mm)	35.61	34.12
Crop coefficient	0.80	0.80
Crop water requirement (mm/month)	71.20	61.22
Percentage rain deficit	51.21	53.35
Percentage irrigation efficiency	52.80	92.10
Percentage irrigated area	51.61	94.00
Irrigation water requirement (mm/month)	43.21	31.22
Net water requirement (mm/month)	66.33	65.32
Irrigation water volume (m^3/month)	267,742.22	361,621.43

Table 5: Irrigation Water Requirement under IBIT

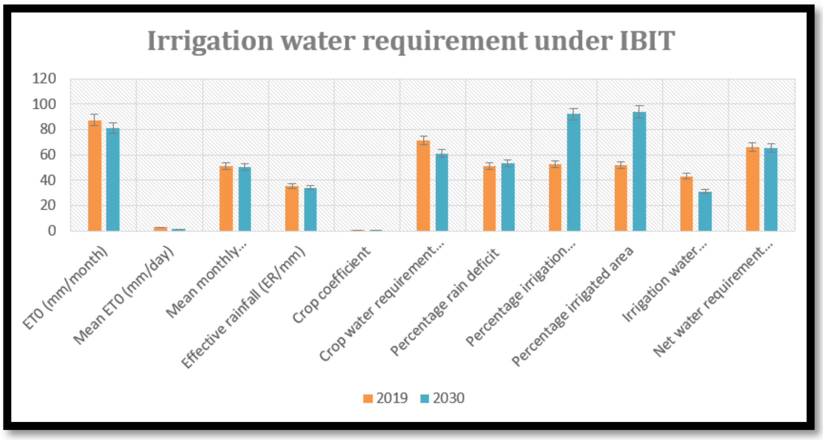

Figure 5: Irrigation Water Requirement under IBIT (95% Confidence Interval)

4. Discussion

This section discusses the results presented in the previous section. It highlights the results of the study as well as other previous studies in relation to the objectives.

4.1. Describing Available Agro-Ecological Technologies with the Potential to Enhance the Application and Efficiency of BIT Interactional Feasibility for Deployment of BIT

This study observed the interactional feasibility of BIT systems under development in Northern Ghana, using the Grundfos-MTN Mobile Money framework with the support of Amiran or KB micro irrigation equipment to make a full Bhungoo-Grundfos-MTN Mobile Money system (illustration in Figure 3).

As an independent component, Grundfos Lifelink's pumping has proven to improve the efficiency of groundwater withdrawal using a solar pump activated by a mobile phone. The system enables water managers to effectively account for every drop that flows from the tap to farmers or the consumption site using mobile money technology. Stakeholder engagements pointed to a positive conclusion that such an exemplary application of modern technologies for water provision and efficient use can be made viable in irrigation through an effective partnership between the Danish pump-making company (Grundfos Lifelink) and mobile operator (MTN-Ghana). The combination of these sets of technologies, which is referred to as Integrated Bhungroo Irrigation Technologies (IBIT), effectively addresses the cycle of flood and drought disasters in the district. This design is meant to effectively ensure that groundwater can be lifted and availed to farmers in their plots and also enable farmers to achieve efficiency and accelerate local capacity to manage climate risks. However, the efficiency of this design will be accelerated exponentially with the use of a real-time data-sharing mobile application. According to Owusu et al. and Owusu et al. (2015), Trend analysis of irrigation development in parts of the White Volta Basin since the 1950s (Ofosu et al., 2014) suggests impressive growth relative to the growth in Sub-Saharan Africa, which fluctuates around 2.3% per annum.

4.2. Economic Feasibility for Deployment of BIT

Based on a simplified cost-benefit assessment, an IBIT system will cost USD21750 to establish. Given a community of an average of 45 farmers willing to adopt the IBIT system, the average local ability to pay per farmer is given to be USD 5.56 per month. Based on this, the Ability to pay/month/community is estimated at USD250 per community. Given the Ability to pay/ month/community of USD250, it is estimated that the payback period per IBIT system shall be 7.25 years. This shift away from these widely accepted methods will require a deep-rooted understanding of the agro-ecological, socio-economic and cultural anecdotes of various communities.

Using data from satellite imagery and historical data from the Ministry of Food and Agriculture, the Ghana Irrigation Development Authority, GIDA, farmer interviews, field observations and surveys, Ofosu et al. (2014) suggest privately led irrigation in the White Volta Basin is about 74% of all irrigation in the basin. Based on these analyses, private-led irrigation schemes in the basin grew at an annual rate of 6.4%, whilst the regular government-led schemes grew at a rate of 5.9% between 2005 and 2010. It is, therefore, essential for this study to assess the technical efficiency of new pathways to water provision for farming in terms of availability, adequacy, accessibility and affordability and how these are changing with time within ultra-critical sub-catchment areas. This is in line with Mcgray *et al.* (2007) using an adaptation framework to assess stakeholders' response to water hazards and their adaptation capacity in the context of innovative water management schemes, in this case, BIT.

Guided by Mcgray *et al.* (2007), the capacity gap analysis of the Integrated Bhungroo, Grundfos Lifelink technologies showed the need to facilitate sustainable agricultural intensification in the West Mamprusi sub-catchment, Ghana. It involves a model suitability assessment of Bhungroos and Grundfos Lifelink's technologies using stock-taking of water demand, baseline and alternate scenario analysis, farm-plot productivity analysis, Institutional Capacity-Gap Analysis (CGA), Water Land and Ecosystem Planning Models involving women farmers, farmer groups, agriculture extension service providers and water managers.

To test the effectiveness of farmers' adaptive strategies vis-à-vis water disaster intensity, the analysis uses the vulnerability-capacity assessment (VCA) technique, future adaptation simulations and other qualitative techniques (Koutsovili et al., (2023) and Mechler et al., (2014). The data presented in this study suggests that an underground reservoir for harvesting flood waters will have a high probability of retention, especially in the lower catchment area of the West Mamprusi District. Establishing a BIT system will have to be sufficiently deep and lower than the hydraulic head so that stored water can be sustained by net inward groundwater flow. This observation underpins Owusu et al. (2015), which further suggest that it is important that efficient water conservation and storage facilities are developed to enhance the resilience of the communities to the impacts of climate change/variability and the concomitant water resources availability for all year round irrigation activities in the area.

Guided by Owusu et al. (2015), the study inferred that since the geometry and flow system are determined by net groundwater recharge, which also depends on rainfall pattern, scenarios of possible reduction in rainfall, increasing temperatures leading to increasing evapotranspiration rates and a consequent reduction in net groundwater recharge will likely lead to a reduction in the groundwater levels throughout the area, even in the areas previously noted to have high groundwater levels. This is a clear indication that the BIT system is susceptible to climate variables such as rainfall patterns and temperature variations. Given that predictions indicate a likelihood occurrence of both events, this suggests that BIT design needs to take into account implications of climate change and variations and incorporate future modifications in design to accommodate any slight changes in climate variables.

Again, data from the BIT pilots in the district indicates that the general design of BIT is based on the hydrogeological structure of candidate sites for BIT. The selection of appropriate sites for the project, therefore, influences the other design elements. Bhungroo can be erected in those places where subsoil strata allow water storage. These observations confirm the findings of previous studies (observed in Luwesi et al., (2017), indicating that BIT context is dependent since water storage can be possible within subsoil sand layer, subsoil partially sand and partially coarse granule zones (in this case design is changed partially), subsoil saline water table (in this case the design is changed), subsoil water table, stony areas provided fracture is possible (recovery, in this case, might be lesser), riverbed provided it is not saturated (here recovery is possible quite high but injection level is very slow).

4.3. Testing and Projecting Integration of These Technologies with BIT with Regard to Compatibility, Scalability and Affordability (Efficiency)

The pilot data indicates that given the observation that BIT is already a context-dependent innovation, it is extremely important to account for the environmental as well as these socio-economic capacities. Even more so, the introduction of supplementary technologies, including Grundfos Lifelink pumping mechanism, photovoltaic solar systems and mobile money payment systems, make the socio-economic context more critical. The study further notes that currently, a small proportion of farmers use irrigation as their complementary source of water for agriculture since rain-fed agriculture is still widespread in the district. This study also indicates a conditional depiction of the affordability of various forms of irrigation systems based on field observations. It is noted that the highest accessible irrigation systems in the catchment included traditional shallow groundwater irrigation, private smallholder systems, group or communal smallholder systems, seasonal shallow groundwater irrigation systems, informal riverine shallow-well systems, permanent good irrigation, shallow-tube well irrigation systems, borehole irrigation systems, domestic wastewater and stormwater, water capture, recession agriculture or residual moisture irrigation and lowland/inland valley rice water capture systems. This observation is in line with the observations of Balana *et al.* (2020).

This section presents and discusses the results of the assessment of the observed uses of water (water demand) alongside the availability of surface and underground water resources (water supply) in the district. The water balance was assessed by first computing the potential water demand for the present year (2019). Afterwards, the water evaluation and planning (WEAP) system was used to generate water balance predictions from 2019 to 2030 (under current conditions). Table 4 illustrates the projected developmental change and the associated water demand and water supply under current and altered conditions in the district. This prediction signalled both the need for and feasibility of BIT deployment on a large scale to complement existing water management systems. This is in accordance with the procedure proposed by Förch *et al.* (2008).

The computation of water demand and water resources was based on projected growth and development expected by the year 2030 in the district. These projections took into consideration some demographics such as population per capita, population growth rate, number of households, size of household, expected development or level of urbanization. These population data enabled the prediction of economic variables, including annual population growth rate, income growth rate, cost of water supply (US$/$m^3$), cost of water supply under drought scenario (US$/m3), and cost of water supply under flood scenario (US$/m3). Besides water demand for domestic uses, the agricultural water uses in the district encompassed important use of water. Monthly irrigation water requirements are displayed in table 4. The study estimated that mean ET0 (mm/day) will increase by 0.11 mm/day while mean monthly precipitation (mm/month) decrease by 0.94, leading to an increase in irrigation water volume of 377,343.55m^3/month) in 2030. These observations take note of the fact that crop water requirements differ from time and space, owing to effective rainfall, crop transpiration and evaporation at different stages of crop growth (emergence, flowering, yield formation and vegetative growth), as also noted by Mavimbela & Van Rensburg (2015); Mavimbela & Van Rensburg (2012).

The study further noted that almost all the irrigation systems that were regarded as accessible were also noted to be affordable to local farmers. However, not all the irrigation systems regarded as being affordable are currently accessible to farmers to local farmers. For instance, it was observed that based on the pricing of group or communal smallholder systems, large-scale or commercial systems, large-scale or commercial systems and commercial public-private partnership-based commercial irrigation systems established in other parts of Ghana, farmers regarded them as being highly affordable. Based on this observation, if BIT is to be deployed based on these models, it will be highly affordable to small-scale farmers.

5. Conclusion

Key results from the study suggest a high BIT-compliant rating index for both the upstream (8.3 BIT-compliant rating index) and downstream (7.5 BIT-compliant rating index) catchment areas. The highest percentage of waterlogging on farmlands is experienced in JAS both upstream and downstream. However, it is also noted that the percentage of waterlogged farmlands is consistently higher upstream and consistently low downstream. These observations noted that vertical groundwater recharge from direct infiltration of rainwater is low in upstream farmlands but moderate in downstream farmlands. As an independent component, Grundfos AQTaps has proven to improve the efficiency of groundwater withdrawal using a solar pump activated by a mobile phone using a personalized payment card (called WaterCard) with an in-built automatic fee payment system that enables the service provider. On the other hand, MTN Mobile Money provides users with a secure electronic (mobile phone-based) payment system that enables users to pay for goods and services electronically, save money, receive payments and remittances and access micro-credit facilities. The combination of Grundfos AQTaps and WaterCard enables Ghana Water Company Limited to provide a reliable water supply in which all transactions are logged. This suggests a high interactional feasibility of BIT systems under development in Northern Ghana with the Grundfos-MTN Mobile Money framework and with the support of drip/micro irrigation equipment to make a full Bhungoo-Grundfos-MTN Mobile Money system (Integrated Bhungroo Irrigation Technologies-IBIT).

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