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State and Performance of Water Retention Structures of Earthen Irrigation Dams in Northern Ghana

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ABSTRACT

The study assessed performance and state of water retention infrastructure of eight (8) irrigation schemes in three (3) northern regions of Ghana. Data was collected using field observation and key informants' interviews. The results indicated that the Tono and Bontanga earthen irrigation dams' embankments had no structural defects whereas the embankments of Libga, Golinga, Karni, Vea, Doba and Sankana had some structural defects. Except Libga, all the spillways had no structural deficiencies and signs of risk of failure. All the reservoirs contained some amounts of sediments and weeds. The night storage reservoirs at Tono and Vea were weedy and silted up. The developed irrigable areas of Vea, Tono, Doba, Sankana and Karni schemes had average irrigation rates ranging from 12 - 76 % for the years 2010 - 2017. The water retention infrastructure of the irrigation schemes are recommended for maintenance and periodic repairs to ensure sustainable water retention and availability for crop irrigation.

INTRODUCTION

The agricultural sector is considered as one of the critical national assets in Ghana. Agriculture employs the majority of the active labour force as well as contributes substantially to the Gross Domestic Product of the country (Amoah *et al.,* 2014). However, limited access to water due to erratic and seasonality of rainfall in some parts of the country militates against agricultural productivity. In northern Ghana, the climatic conditions do not allow for an all-year-around crop production thus making irrigated agriculture an alternative area which offers opportunities for greater livelihoods security and poverty reduction (Swamikannu and Berger, 2009). Kyei-Baffour and Ofori (2006) pointed out that, the development and maintenance of irrigation schemes have been identified as promising remedies to boost levels of agricultural productivity in the northern parts of the Ghana due to the unimodal rainfall regime. Over the years, the Government of Ghana has collaborated with donor agencies such as Non-Governmental Organisations, World Bank and Catholic Missions in the construction of many small, medium and large earth dams and their associated reservoirs all over the country since 1960s to facilitate irrigated agriculture and other purposes (Namara *et al.,* 2011). As of 2011, a total of about 850 earthen embankment dams and reservoirs have been constructed in the country, of which about 150, 85 and 130 respectively are situated in the Upper East, Upper West and Northern Regions (Namara *et al.,* 2011). A dam is a hydraulic structure of impervious material, usually constructed across a river(s) or stream(s) to obstruct flow and to create a reservoir on its upstream side for impounding water for various purposes including irrigation. The water stored in a given reservoir during rainy season can be easily used almost throughout the year, till the time of arrival of the next rainy season, to refill the emptying reservoir again (Garg, 2002).

To ensure longevity and sustainability of earthen embankment dams and their reservoirs, the siting, design and construction must be properly executed (FAO, 2010). However, the third world countries in recent times are faced with numerous challenges with regard to designing, construction and maintenance of water retention infrastructure. The challenges include silting of reservoirs and failure of spillways and dam walls with emphasis on those made of earthen embankments. Emphasis is placed on this type of dams due to the fact that they are the most common types of dams in the world and reports have shown that the frequency of failure of such dams is about four times greater than that observed for masonry and concrete dams. Reports have also revealed that, the dams and spillways which have been constructed for over 15 years without periodic maintenance and repairs recorded the highest frequency in terms of failure, attempted failure or risk of failure (Kolala *et al.,* 2015). A spillway is a structure that is either incorporated in a dam or constructed just beside the dam, over or through which flood water is discharged safely in a controlled manner when the reservoir is full to its maximum storage capacity. It is a safety structure and the spill level is set below the maximum height of the embankment to overtopping (ICOLD, 2007).

A dam failure is commonly defined as an incident of structural failure that involve unintended releases or surges of impounded water or incidents that lead to the loss of the dam (Kolala *et al.,* 2015). Mufute (2007) described dam failure as the loss of the ability of a particular dam facility to hold water in its reservoir that might be induced by reservoir sedimentation. Guadalupe -Blanco River Authority (2003) stated that dam failure can take several forms including a collapse of, or breach in the structure and can result from any one, or a combination of causes such as improper design or use of improper construction materials; improper maintenance, including repair of internal seepage problems; internal erosion caused by embankment or foundation leakage; inadequate spillway capacity, resulting in excess overtopping of the embankment; and prolonged periods of rainfall and flooding, which cause most dam failures. The spillway is a safety structure (ICOLD, 2007), but can fail due to factors such as foundation failures – leakage and piping; improper construction; lack of periodic maintenance; concrete/mortar deterioration as a result of aging; and flow erosion (Environmental Fact Sheet, 2011). Literature revealed that that chutes spillways are less vulnerable to failure than the other spillway types namely; side channel, overfall, shaft, drop inlet, saddle, emergency and siphon spillways (Kolala *et al.,* 2015). According to Ezugwu (2013), siltation is an inevitable end for reservoirs since deposition of sediments starts immediately after construction. Many cases have been recorded where reservoir siltation rendered reservoirs of dams useless in less than 25 years and needs to be periodically monitored for levels (Chanson and James, 2005; Mama and Okafor, 2011). Earthen embankment dams and their components such spillways, valves and reservoirs require ongoing maintenance, monitoring, safety inspections, and sometimes even rehabilitation to ensure safe services and sustainability (FAO, 2010).

Irrigation schemes in the northern part of Ghana play a crucial role in improving and sustaining the livelihoods of the populace as they are provided with dams and reservoirs for irrigated farming to ensure continuous crop production during the long dry season of 7 – 8 months. Namara *et al.* (2011) stated in general terms that, majority of the irrigation schemes in the country especially those over 25 years are battling with several infrastructural challenges due to lack of maintenance among many other factors and therefore cannot perform to their fullest potentials. This study was conducted to assess the state and performance of water retention infrastructure namely; earthen embankments, reservoirs, spillways and night storage reservoirs of eight (8) irrigation schemes in northern Ghana.

MATERIALS AND METHODS

Description of Study Areas

Irrigation schemes of the study include; Libga, Golinga and Bontanga in Northern Region; Tono, Vea and Doba in Upper East Region; and Sankana and Karni in the Upper West Region. Data was collected in 2017. Crops grown in the schemes include; tomatoes (*Lyocopersicon esculentus)*, okra (*Hibiscus esculentus),* onion (*Allium cepa*), rice (*Oryza sativa*), roselle (*Hibiscus sabdariffa),* cowpea (*Vigna unguiculata*), maize (*Zea mays*). The characteristics of the irrigation schemes are presented in Table 1.

Table 1: Characteristics of the Irrigation Schemes

Characteristics	Name of Irrigation Scheme							
	Sankana	Karni	Golinga	Libga	Bontanga	Doba	Tono	Vea
Year Construction Started	1969	1989	1971	1969	1980	1956	1975	1965
Year Construction Completed	1971	1993	1976	1980	1986	1956	1985	1980
Year of Rehabilitation	1998	1998	2011/2012	1984, 2000, 2008, 2016	2011/2012	2015	2008	2017
Height of Embankment (m)	7	5	4.5	6.5	12	4.5	18.6	13.5
Length of Embankment (m)	510	631	700	650	1900	510	3500	1600
Maximum Storage Capacity (10^6 m^3)	1.7	0.37	1.23	0.71	25	0.118	83	17
PIA (ha)	130	30	100	40	800	15	3860	1197
DIA (ha)	60	15	40	16	495	7	2490	859
UDIA (ha)	70	15	60	24	305	8	1370	347
No. of Canals	2	1	2	1	2	1	2	2
No. of Laterals	26	7	12	8	28	10	82	60
MWD	Gravity	Gravity	Gravity	Gravity	Gravity	Gravity	Gravity	Gravity
Management	GIDA/ WUA	GIDA/ WUA	GIDA/WUA	GIDA/ WUA	GIDA/ WUA	WUA	ICOUR	ICOUR

PIA – Potential irrigable area, DIA – Developed irrigable area, UDIA – Undeveloped irrigable area, No. – Number, MWD – Mode of water delivery, GIDA – Ghana Irrigation Development Authority, ICOUR – Irrigation Company of Upper Regions

Data Collection and Analysis

The methods used for the data collection and analysis comprised of the following:

i. Primary data was collected using key informants and relevant authorities/stakeholders involved in construction, repairs, maintenance and management of the irrigation schemes on conditions of physical structures which include embankments, spillways and, reservoirs as well as farmers' operations and irrigation practices.

ii. Secondary data in the form of characteristics of irrigation schemes was obtained from Ghana Irrigation Development Authority in Tamale, Bolga and Wa and,

iii. Empirical formulas were used to compute the performance indicators such as irrigable land utilisation efficiency.

RESULTS AND DISCUSSIONS

State of the Dams' Embankments of the Irrigation Schemes

The state of the various earthen dams' embankments of the irrigation schemes across the three (3) northern regions is presented in Table 2.

Table 2: State of Earthen Dams' Embankments

Scheme	Dam Embankment	State as of 2017

Sankana		i. The 510 m long embankment was overgrown with shrubs and trees on both upstream and downstream slopes. ii. All the ripraps on the upstream slope had fallen off under the strength of reservoir water waves. iii. Presence of crocodile burrows on the upstream slope. iv. Evidence of gully erosion on the downstream slope.
Karni		i. The 631 m long dam had about 60 % of the ripraps on the upstream slope fallen off under the strength of reservoir water waves. ii. No vertiver grass to protect the downstream slope from erosion. iii. The crest was in good shape.
Tono		i. The embankment is 3500 m long and 18.6 m high. ii. The upstream slope fully and properly riprapped with igneous rocks and the crest also in good shape. iii. The embankment had no signs of risk of failure. iv. The wave wall was in good shape, no cracks. v. The embankment had no structural defects.
Vea		i. The embankment is 1600 m long with a maximum height of 13.4 m. ii. It was under rehabilitation at the time of assessment. iii. Poor riprapping has resulted to caving-in at some sections of the upstream slope.
Doba		i. The embankment is 510 m long with a maximum height of 4.6 m. ii. The upstream slope had disperse ripraps. iii. The embankment was overgrown with weeds, shrub and trees. iv. The crest contained potholes.
Libga		i. The embankment has a length of 650 m and a maximum height of 6.5 m. ii. It was rehabilitated in 2016 but still has defects. iii. The entire upstream slope had not been riprapped. iv. The embankment had several structural defect with signs of breaching.
Bontanga		i. The embankment has a length of 1900 m and maximum height of 12.0 m. ii. The upstream slope was fully and properly riprapped. iii. Generally, the embankment had no structural defects and there were no signs of risks of failure.
Golinga		i. The embankment is 700 m long with a maximum height of 5.0 m. ii. The upstream and downstream slopes are eroded as no riprapping and vegetative cover respectively on the upstream slope and downstream slope. iii.There are potholes at some sections of the crest and erosion has reduced the height of the dam wall. iv. The embankment had some structural defects although it was rehabilitated in the year 2012.

Spillway Structures of the Irrigation Schemes

The state of the spillway structures of the irrigation schemes understudy are presented in Table 3. It was observed that the spillway structures varied in their characteristics in terms of constructional design and ability to discharge excess water safely from the reservoir when the maximum storage levels of the dams are attained.

Table 3: State of Spillway Structures of Earthen Irrigation Dams

Scheme	Spillway Structure	State as of 2017
Sankana		i. The spillway is a side channel type made of concrete. ii. It has no structural defects. iii. It has no signs of risks of failure. iv. It spills water at fully supply level, no premature spillage.
Karni		i. Spillway is side channel type made of concrete. ii. The concrete wall has no structural defects. iii. No signs of risks of failure.
Tono		i. Spillway is side channel made of concrete. ii. The top width of the spillway is 60 m and its discharge capacity is 496 m^3/s. iii. There had been a risk of failure but was immediately repaired. iv. It had no structural defects and functioning properly.
Vea		i. Spillway is side channel type made of concrete. ii. The top width is 56 m with a flood discharge capacity of 105.56 m^3/s. iii. No risk of failure had ever been experienced iv. Functioning properly with no structural defects.
Doba		i. Spillway is side channel type made of concrete with top width of 13.80 m. ii. No structural defects after rehabilitation in 2015. iii. Functioning properly, no premature spillage. iv. No signs of risks of failure.
Libga		i. Spillway is side a channel type made of concrete. ii. The 50 m wide spillway had several structural defects such as cracks and breaches. iii. It was breached in 2010 and has not rehabilitated yet, causing premature spillway annually.
Bontanga		i. The spillway type is drop inlet made from concrete. ii. It is a side channel type made of concrete. iii. It has a maximum discharge capacity of 85 m^3/s. iv. It had not experienced failure or attempted failure since construction was completed in 1986. v. There were no signs of risks of failure.

Golinga		i. The 80 m wide spillway is a side channel type made of concrete. ii. The spillway breached in 2009 but was rehabilitated in 2012. iii. Generally, the spillway is functioning properly with no signs of anomalies of risk of failure.

State of the Reservoirs of the Irrigation Schemes

The reservoirs of the dams of the irrigation schemes understudy presented different conditions at the time of assessment. The conditions varied from silted to weedy state and reservoirs in moderately good or poor conditions. Details of the reservoirs of the various irrigation schemes are presented in Table 4.

Table 4: State of the Reservoirs of the Irrigation Schemes

Scheme	Dam Reservoir	State as of 2017
Sankana		i. Presence of sediment dunes. ii. No desiltation since construction in 1971. iii. Upstream activities such as farming and sand winning causing siltation of the reservoir.
Karni		i. Presence of huge amounts of sediment dunes. iii. No desilting had been done after construction in 1993. iv. Sedimentation of reservoir caused by crop farming, lack of v. riparian area protection and loss of vegetative cover.
Tono		i. The reservoir has a maximum storage capacity of 83 x 10^6 m^3. ii. Presence of sediments. No desilting has been done after construction was completed in 1985. iii. Sedimentation of the reservoir is caused by farming in the catchment close to the reservoir, lack of riparian area protection and increase loss of vegetative cover in the catchment due to annual bush fires.
Vea		i. The reservoir has a maximum storage capacity of 17 x 10^6 m^3. ii. Presence of sediments in the reservoir. No desilting works since its construction (37 years ago). iii. The siltation has been caused by upstream farming activities and no catchment protection strategies.
Doba		i. The reservoir contained less sediment ii. Reservoir was desilted in 2015.
Libga		i. The reservoir has lost a considerable storage capacity to siltation and weeds. ii. It had not been desilted after 50 years of construction.
Bontang a		i. The maximum storage capacity of reservoir is 25 x 10^6 m^3. ii. The reservoir contained some amount of sediments especially at the left bank and the upstream portions. iii. Farming very close to the reservoir was the main cause of the reservoir sedimentation.

Golinga		i. A considerable storage capacity of the reservoir is lost to sediments and weeds. No desilting carried out since construction was completed in 1976. ii. Farming very close to the reservoir and poor catchment protection causing siltation No catchment protection strategies to check siltation.

State of Night Storage Reservoirs in the Irrigation Schemes

Out of the eight (8) irrigation schemes, Tono and Vea schemes were the only irrigation schemes with night storage reservoirs. These structures were constructed at strategic locations downstream of the schemes. The Tono irrigation scheme has seven (7) night storage reservoirs and all were rehabilitated in 2008. However, as of 2017, all the reservoirs were in very poor condition. They were silted and weedy as illustrated in Plates 1 to 5 . The Vea irrigation scheme has one (1) night storage reservoir (Plate 6) and this had not been in use since 1997 due to broken inlet and outlet canals, valves and siltation.

Plate 1: Silted and Weedy Night Storage Reservoir 1 in Tono

Plate 2: Silted and Weedy Night Storage Reservoir 2 in Tono

Plate 3: Silted Night Storage Reservoir 3 in Tono

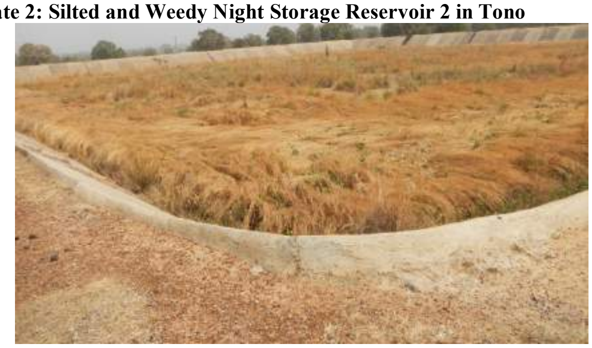

Plate 4: Weedy Night Storage Reservoir 4 in Tono

Plate 5: Silted Night Storage Reservoir 5 in Tono

Plate 6: Silted Night Storage Reservoir in Vea Scheme

Classification of the Dams and Reservoirs Based on Height and Storage Capacity

Classifying the dams based on height as given by Atallah (2002), ICOLD (2007) and Kolala (2015) as presented in Table 5 indicates that, five (5) of the assessed dams belonged to the class for "small dams" - as the maximum height of their dam walls are less than 8 m. These dams include; Sankana, Karni, Doba, Libga and Golinga dams. Also, the Vea and Bontanga dams were noted to belong to the "medium dams" category while the Tono dam is categorized as "large dam". However, classifying the dams based on the maximum storage capacity of their reservoirs using the classification given by Atallah (2002), ICOLD (2007) and Kolala (2015) also as presented in Table 5 indicates three (3) of the dams as being "large dams" (> 3 x 10^6 m^3) and these are Tono, Vea and Bontanga dams. Also, four (4) of the dams are categorized as "medium dams" (1 – 3 x 10^6 m^3) and they are Sankana, Karni, Libga and Golinga dams while the Doba dam was categorized as "small dam" (< 1 x 10^6 m^3).

Table 5: Classification of Dams and Reservoirs Based on Height and Storage Capacities

S/No.	Classification	Maximum Height of Dam (m)	Gross Storage Capacity of Reservoir (million cubic metres)
1	Small	< 8	< 1
2	Medium	8 - 15	1 – 3
3	Large	> 15	> 3

Source: Atallah (2002), ICOLD (2007) and Kolala (2015)

According to Chanson and James (2005), small and medium size reservoirs are predominantly vulnerable to rapid siltation if strict reservoir protection measures are not put in place and enforced. Similarly, studies carried out on 19 reservoirs in Central Europe with storage capacity ranging of 1.48 x 10^5 m^3 (small dams) and 2.26 x 10^6 m^3 (medium dams) showed that they were depleted by siltation at an average rate of 0.51 % per annum (Mama and Okafor, 2011). The findings in this study on the state of the reservoirs regarding siltation align reasonably with the results of the above authors, as the Sankana, Karni, Libga and Golinga reservoirs being small and medium reservoirs were observed to contain considerable amounts of sediments.

Irrigable Land Utilisation Efficiency of the Irrigation Schemes

Irrigable land utilisation efficiency is the relationship of the actual irrigated area and the total developed irrigable area. It is also referred to as irrigation rate (Bekisoglu, 1994). This criterion gives an indication of whether the irrigable areas are used at full capacity or not. The results of the irrigable land utilisation efficiency from the year 2010 – 2017 for the various schemes are presented in Table 6.

Table 6: Irrigable Land Utilisation Efficiency of the Irrigation Schemes (2010 – 2017)

Indicator	Irrigated Area (ha)*								DIA (ha)*	Irrigable Land Utilisation Efficiency (%) **							
Year	2010	2011	2012	2013	2014	2015	2016	2017		2010	2011	2012	2013	2014	2015	2016	2017
Tono	1325	1189	1341	1302	637	0	1409	1400	2490	53	48	54	52	26	0	57	56
Vea	124	71	86	100	155	64	60	130	850	15	8	10	12	18	7.5	7	15
Doba	2.5	1.5	2	1.5	0	0	2	2	7	36	21	29	21	0	0	29	29
Libga	15	15	15	15	15	15	15	15	16	94	94	94	94	94	94	94	94
Bontanga	412	420	424	431	449	453	474	485	495	83	85	86	87	91	92	96	98
Golinga	20	27	32	40	40	40	40	40	40	50	58	63	100	100	100	100	100
Sankana	27	29	26	24	24	35	40	37	60	45	48	43	40	40	53	67	62
Karni	13	13	11	10	10	10	12	12	15	87	87	73	67	67	67	80	80

*(Source: * - Project Records, 2017 and ** - Desk Computation, 2017)*

The irrigation rates of the Tono Irrigation scheme were found to be in a range of 0 – 57 % with an average rate of 41 % during the years of 2010 – 2017. The rates recorded in the years 2010, 2012, 2013, 2016 and 2017 suggest that barely half of the scheme's developed irrigable area was irrigated each year, whereas the rates recorded in 2011 and 2014 indicate that considerably less than half of the developed area was irrigated in those years. These lower rates of irrigation were attributed to low reservoir water levels, silted night storage reservoirs and poor working conditions of laterals. There was no irrigation in 2015 mainly due to very low water level, the reservoir was at dead storage. These rates are similar to the results obtained by Cakmak *et al.* (2009) which ranged from 44 – 55 % in the Asartepe Irrigation Scheme for the period of 2001 - 2004. In the Vea irrigation scheme, irrigation rates for the scheme for the period of 2010 - 2017 were found to be very low in a range of 7 – 18 % with an average of 12 % as in Table 6. These low irrigation rates were also attributed to factors including silted night storage reservoir and broken irrigation water conveyance structures. The irrigation rates for the Doba and Sankana irrigation schemes over the past seven years (2010 -2017) were also significantly lower. Doba recorded a range of 0 – 36 % with an average rate of 21 % whilst Sankana recorded a range of 40 – 48 % with an average value of 44 %. At Doba, there was no irrigated farming in 2014 and 2015 due to low reservoir water level. Sener *et al.* (2007) recorded irrigation rates which ranged from 15.77 - 54.47 % in the Hayrabolu Irrigation Scheme for a period of 13 years (1989 - 2001). From 2010 – 2017, Libga, Bontanga, Golinga and Karni irrigation schemes recorded average irrigation rates of 94 %, 89 %, 84 % and 87 % respectively. The rates indicate that the schemes are performing better than the others earlier mentioned when compared to the notional nominal value for irrigation rate (90 – 100 %) as given by Ijir (1994) and Sener *et al.* (2007).

CONCLUSION

The findings of the research revealed that all the assessed irrigation schemes had one problem or the other regarding their water retention infrastructure. The Tono and Bontanga dams' embankments were in good shape with no structural defects due to proper rip-rapping, periodic maintenance and repairs. The embankments had no signs of risks of failure. The Sankana, Karni, Vea, Doba, Libga and Golinga dams' embankments were in a moderate to poor state with problems such as caved-in upstream slopes, displaced rip-raps, overgrown with weeds, shrubs and trees, eroded downstream slopes with rills and gullies features, and degraded crest. The Libga dam embankment was at a high risk of breaching. All the spillways of the dams except Libga had no structural deficiencies. No signs of risk of failure were seen on them except Libga which breached in 2010 and has not been rehabilitated. All the reservoirs of the dams contained considerable amounts of sediments and weeds with Karni, Libga and Golinga reservoirs being the worst affected. Farming at the upstream very close to the reservoirs was the main cause of siltation of the reservoirs. Farmers refused to obey the operation rules restricting farming activities in the watersheds of the dams and were engaged in both rainfed and irrigated farming at the upstream very close to the reservoirs. The night storage reservoirs at Tono and Vea were weedy and silted up and therefore had not been in use for the past ten (10) years. The developed irrigable areas of Libga, Bontanga, Golinga schemes were almost put to full utilization with average rates of 94 %, 89 % and 84 % respectively. Based on the findings of the assessment, it is recommended that the water retention and delivery structures of the irrigation schemes be rehabilitated and maintained periodically to ensure efficient water retention and delivery for sustainable irrigated agriculture. Public-Private Partnership (PPP) management of the irrigation schemes is also recommended to ensure effective and efficient management and good performance.

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