RELATIONSHIP BETWEEN WATER DEPTH AND PRESSURE IN MICRO-DAMS IN NORTHERN GHANA

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ABSTRACT

The availability and access to fresh water in sufficient quantities for domestic and productive purposes is an important aspect of improving livelihoods especially in the rural area. It is for this reason that small dam development in the savannah areas of Ghana has become very important as they have a direct link in reducing high incidence of poverty in these areas. Variation of water levels in these water holding structures and the relationship of this variation on the water pressure exerted on these dams cannot be over emphasized. The study therefore examined the relationship between water depth and pressure on dam wall in five dams located at the Gbullung-West Inland Valley Watershed of the Tolon-Kumbungu District, Ghana. A water level sensor HOBO© U20 logger was installed in all five dams for the study period. Water levels were logged at 15 minutes interval on continuous basis for 12 months. Average annual drawdown for the various dams ranged from 0.97 m to 1.42 m. Average dam drawdown's were 1.16 m, 0.97 m, 1.42 m, 1.32 m and 1.01 m for dam 1, 2, 3, 4 and 5 respectively. The variation in water levels was mainly due to evaporation, domestic usage and animal watering. Dam pressure levels were 110.73 kPa, 108.87 kPa, 113.25 kPa, 112.33 kPa and 109.32 kPa for dam 1, 2, 3, 4 and 5 respectively. The correlation coefficients of water depth and water pressure showed a strong relationship between the two. Correlation coefficients were 0.998, 0.969, 0.985, 0.992 and 0.969 for dam 1, 2, 3, 4 and 5 respectively. It was therefore realised that higher water depth resulted in higher water pressure exerted on dam wall. Proper constructional and dam wall management or maintenance practices should therefore be employed in order to avoid dam breaching.

INTRODUCTION

Fresh water is a renewable resource, yet many people still lack reliable access to adequate amount of fresh water of sufficient quantity for domestic and productive purposes. This means the world's supply of clean water is steadily decreasing and in many places of the world, water availability is highly variable over time (UN, 2005).

One of the main sources of surface water supply is rainfall (Ahenkorah, 1994) and this water is usually channeled through streams and rivers and ending up in the sea. Hagan (2007) indicated that most of the rivers in the world have been dammed to serve as water storage facilities for hydropower generation, drinking water supply and irrigation purposes.

Small reservoirs (400 ha) are important tools in bridging the gaps in surface water availability in semi-arid rural areas around the world and several of these reservoirs can be found in West Africa and Northern Ghana is no exception. Reservoirs therefore present indispensable storage facilities of water in arid and semi-arid regions of the world where there is irregular rainfall and scarcity of water especially in the dry season.

Small dam development in the Northern Regions of Ghana have been considered as one of the solutions for curtailing the high incidence of poverty by improving the standard of living of the people through improved small holder irrigation techniques and livestock production.

Small multi-purpose reservoirs are used widely for the provision of drinking and irrigation water in most part of Northern Ghana especially the rural areas where surface water is scarce in the dry season.

The importance of small reservoirs during droughts for the local population in most semi-arid areas cannot be over estimated. Water stored in these reservoirs allows for all year round irrigated agriculture for farmers and ensures there are little or no domestic and drinking water shortages for the local population during the dry periods.

The study established the relationship between water depth and pressure on small dam wall. It specifically monitored the level of water variation in small dams on seasonal basis and also established the effect of water pressure on the dam walls.

MATERIALS AND METHODS

The Study Area

The study was carried-out in the Gbullung-West Inland Valley Watershed in the Tolon-Kumbungu District of Northern Ghana. It is located within latitude $09^{0}26'08''$N to $09^{0}29'00''$N and on longitude 001°00'41''W to 001°03'45''W with the elevation ranging from 129.3 m to 182.9 m (Unami *et al,* 2009).

Figure 1 is a map showing the study dams and the communities these dams serve.

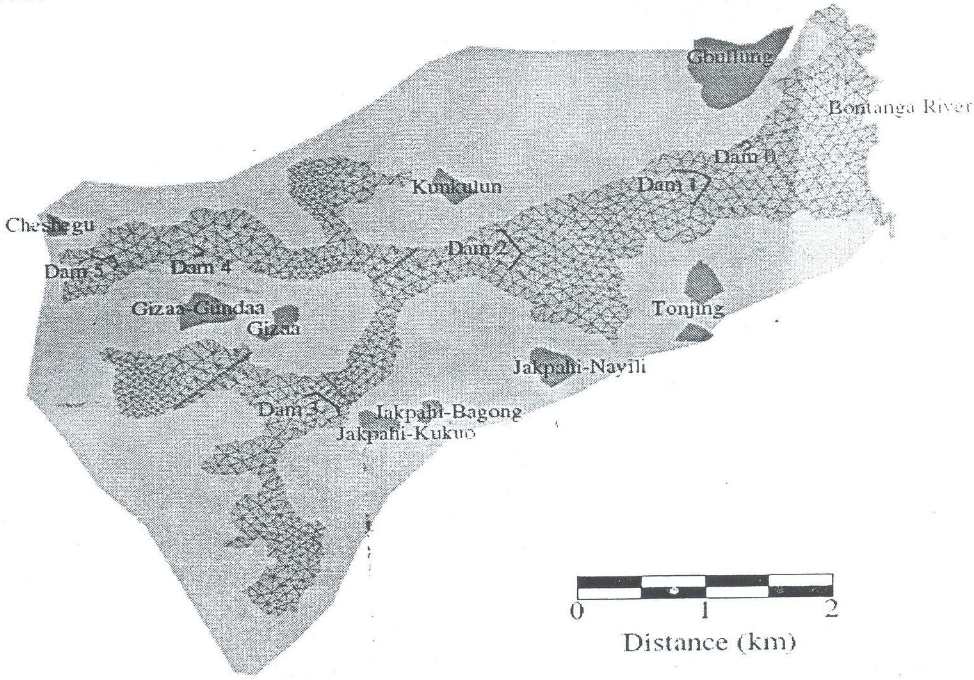

Figure 1: Gbullung-West Inland Valley Watershed

Methods

Water levels in the dams were monitored using the water level sensor- HOBO© U20 logger. The sensors were installed in five dams and labeled dam 1, 2, 3, 4 and 5. The logger recorded water pressure and temperature at 15 minutes interval and automatically converting temperature readings into water level readings. Monthly averages of this data were therefore determined using simple statistics.

RESULTS AND DISCUSSIONS

Water Level Variations

The study monitored the water level of the dams for a year and average water levels of these dams indicated a very wide variation. Average annual recorded water levels for the various dams ranged from 0.97 m in dam 2 to 1.42 m in dam 3. Dam 5 recorded an average water level of 1.01 m, dam 1, 1.16 m and dam 4, 1.32 m as the average water level for the period of study. Figure 2 shows the average water level variation of the study dams.

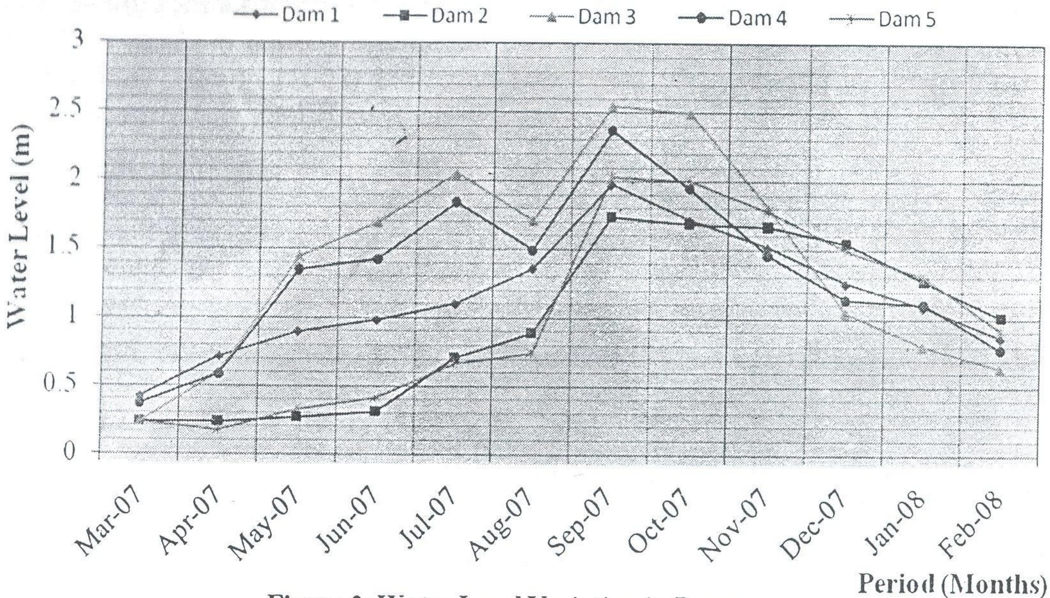

Figure 2: Water Level Variation in Dams

The level of water in the reservoirs increased in relation to the intensification of the rainfall whilst low water levels were associated with the dry season when there was no rainfall coupled with high level evaporation. The rainy season is normally coupled with high groundwater recharge as well as low evaporation rate thus reducing the amount of water that is lost from the reservoirs.

Water level variations trend in the study dams is summarised as follows;

- An initial increase in water depth from March 2007 to the month of July 2007,
- A decline in water level in August 2007 was recorded for dam 3 and 4, whilst dam 1, 2 and 5 recorded a substantial increase in water level for the month of August,
- Subsequently, a rapid rise in water level of all dams was realised from August 2007 to September 2007 resulting in the attainment of maximum water level and,
- A subsequent gradual decline in dam water level from the month of October 2007 to February 2008 was noticed for all the dams.

From Figure 2, there was a gradual increase in the water level of dams 1, 2 and 5 with dams 3 and 4 recording decline in water level for the month of August 2007. This signifies the effect of the two weeks of drought that was recorded during the period of study in the area.

Dam 3 which recorded the highest average water depth of 1.42 m showed the lowest water depth (0.45 m) at the end of the study period in February 2008. A critical examination of the area where dam 3 was built showed that a high amount of the water is loss through seepage which could be attributed to an improper core material lining of the dam. The rapid decline in water depth results in the dam having three (3) different pools of water in small quantities. Even though the effect of evaporation, human use and animal watering cannot be neglected from affecting the amount of water loss, the rate of decline in the quantity of water is so high to be attributed to such factors as they equally affect the other dams. According to Nelson (1985), the purpose of a reservoir influences its design and of which has a high level of influence on the reservoir capacity.

The rapid decline in water level of dam 3 results in members of the catchment communities (Gizaa, Jakpahi-Bagong and Jakpahi-Kukuo) travelling long distances to obtain water for domestic use. Animal watering also becomes a problem in the communities as farmers travel with livestock over long distance to other communities for water. Economic activities requiring the use of large quantities of water such as sheabutter extraction, dawadawa and rice processing also become seriously affected. Rural construction activities during the dry season which require the use of water like moulding of bricks for building activities and other renovations, which are mostly carried out in the dry season, become a problem due to scarcity of water. The loss of productive time to the search for water becomes so enormous and this may affect income levels of inhabitants in the catchment.

Dam Water Pressure Variation

The exertion of pressure by water contained in a dam on the dam wall can be said to vary greatly with time and season and of which is influenced by the amount of water contained in it.

The water pressure on dam walls recorded for the study period was realized to increase directly in relation to the time of the season (Figure 3) as influenced by rainfall. Figure 3 indicates that dam 1, 2 and 5 recorded a gradual increase in water pressure from March to September 2007. Increased in pressure level gradually from March to July 2007 and a change in pressure level in August 2007 for dam 3 and 4 was observed. A drastic drop in pressure as shown in Figure 3 from 119.67 kPa to 115.81 kPa was observed for dam 3 whilst dam 4 recorded a drop of 3.94 kPa i.e. from 117.65 to 113.69 kPa from July to August 2007. A sharp increase in pressure level was observed for all dams from August to September 2007 and of which the month of September 2007 was said to be the month with the maximum water pressure level which ranged from 116.65 kPa in dam 2 to 124.52 kPa in dam 3. The high pressure recorded for this month could be attributed to the high rainfall recorded in the month of August and September 2007. Also during this period soil moisture saturation as well as low evaporation levels of water from the surface of the water body characterized the high water levels and capacity of the dams.

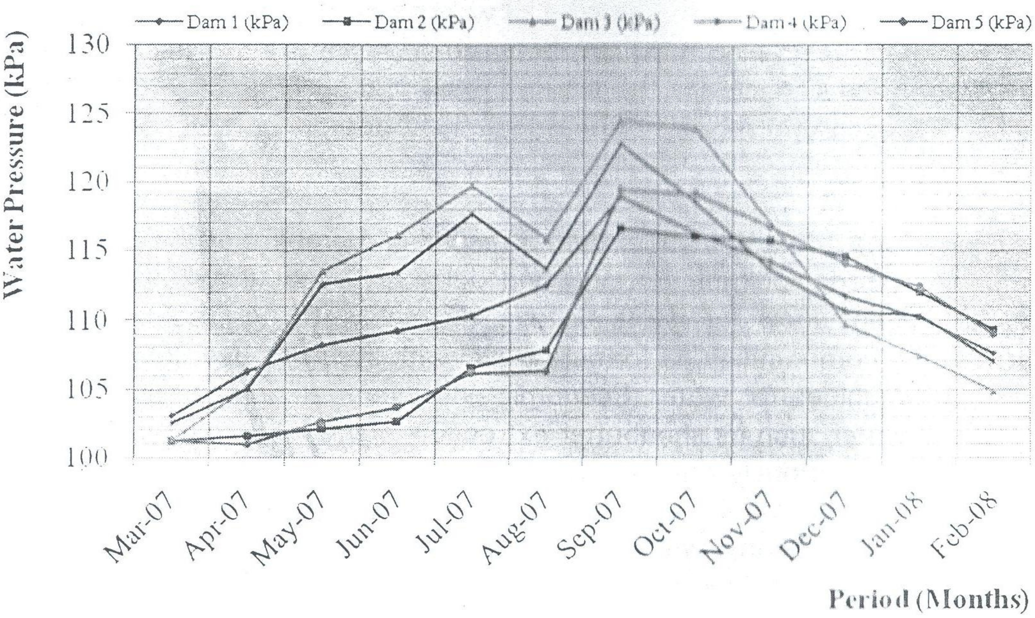

Figure 3: Variation of Dam Water Pressure

During the same period of the year 2007, floods were recorded in the Gbullung West Inland Valley and most parts of Northern Ghana indicating the excess water resulting from the rainfall. The effects of high water pressure levels resulting from high water depths of the dams indicate the force exerted on the earth built dam walls seasonally. In the case of an improper dam wall construction and inadequate flood water discharge by the spillways, overtopping of the dam wall may result thus leading to breaching of the dam wall and loss of water stored.

A rapid decline in dam water pressure was recorded for all the study dams from October 2007, at which period the rain has reduced drastically as it tails-off. Figure 3 shows that dam 3 recorded the highest dam water pressure (124.52 kPa), but this pressure reduced at a very fast rate to a pressure level of 104.90 kPa in February 2008. This fast rate of drop in water pressure has a direct correlation with the dam water level as in Figure 2 and this could be attrib-

uted to a problem of high level of water seepage from the dam and evaporation of water from the reservoir surface.
Dam 2 recorded the least maximum water pressure for the period of study of 109.37 kPa slightly above dam 5 of 109.00 kPa.

Relationship between Water Level and Dam Water Pressure

According to Microsoft Encarta (2008), the pressure exerted on a dam by water stored in a reservoir is directly proportional to the depth of water pushing against the dam. Water pressure is not affected by the total size of the reservoir; it depends only on the reservoir depth.

During the rainy season, water harvesting structures like dugouts and dams reach full capacity and sometimes cause downstream flooding in the study area. The depth and amount of water in a reservoir however depends greatly on the amount of rainfall for a particular season. The pressure therefore exerted on the various dam walls has an effect on the ability of the dam walls to resist this pressure. According to Dupriez and Leenar (2002), the higher the water level, the more the pressure at the point of anchorage of the dam wall.

Regressing the water depth in the various dams and the water pressure results in a strong relationship between the two parameters. Correlation coefficients (r) of 0.998, 0.969, 0.985, 0.992 and 0.969 for dam 1, 2, 3, 4 and 5 respectively shows how the two parameters vary with space. An increase in the depth of water for a particular dam according to the rating equations therefore suggest a corresponding increase in the pressure level produced by the water on the dam wall. It could be realized that as the reservoir behind a dam is filled with water, the pressure that the water exerts on the dam increases. Eventually, the force on the dam wall becomes substantial to the extent that it could cause the dam wall to collapse. The plots as shown in Figure 4 through to Figure 8 shows the direct relationship between the two parameters thus an increase in dam water level results in proportionate increase in water pressure on the dam wall. The variation in the dam pressure levels therefore has a relationship with the amount of water contained in the dam and the depth of water at the deepest side of the dam near the dam wall.

The hydrostatic pressure exerted in a reservoir is said to increase linearly with the depth of water (http://www.dur.ac.uk/~des0www4/cal/**dams**/foun/press.htm, *2008).* This hydrostatic pressure has also been noted to be directed normal to the floor and the sides of the dam wall and also especially on the upstream side of the dam wall.

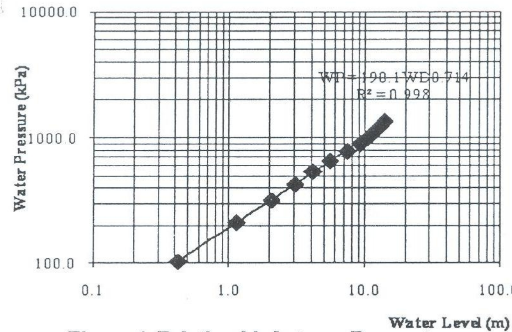

Figure 4: Relationship between Dam water pressure and Water Level - Dam 1

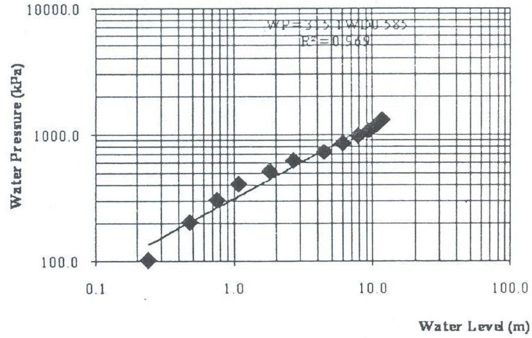

Figure 5: Realtionship between dam water pressure and Water Level - Dam 2

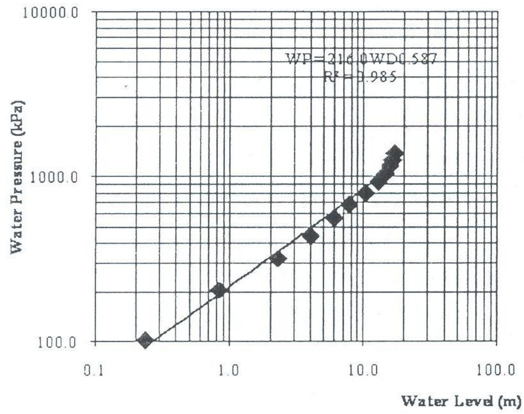

Figure 6: Relationship between Dam Water Pressure and Water Level - Dam 3

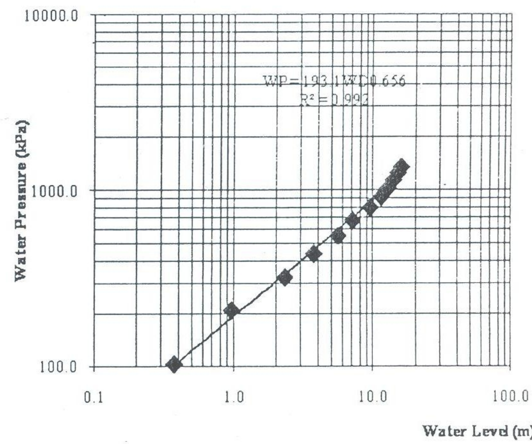

Figure 7: Relationship between Dam Water Pressure and Water Level - Dam 4

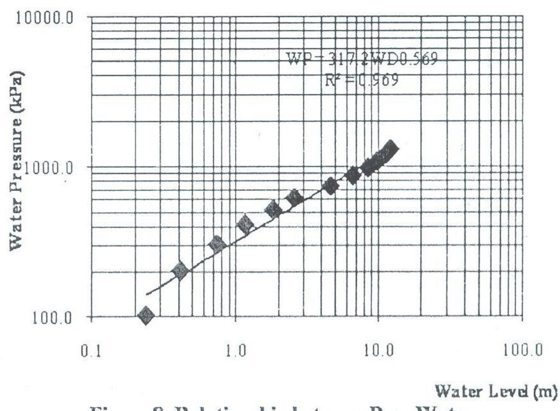

Figure 8: Relationship between Dam Water Pressure and Water Level - Dam 5

The dam wall when built with earth material as in the case of all study dams is presumed to behave like a rigid body. When the reservoir is empty however the weight of the dam is directed vertically downward. It has been reported that when the reservoir is full, a combination of hydrostatic pressure on the up-stream face of the dam wall and the weight of the dam produces a force vector inclined downstream away from the vertical force vector, and there is a tendency for the dam not only to be displaced downstream but also to rotate about the downstream toe of the dam because of a torque (http://www.dur.ac.uk/~des0www4/cal/dams/foun/founf6.htm, 2008).

CONCLUSION

High water levels in dams do not necessarily mean high water capacity in reservoirs as capacity depend not only on the water level of the reservoir but on many other factors such as rainfall, height of dam wall, etc. Generally, high level variation in water levels of all the dams was realized during the study period.

Water pressure recorded for the study period was realized to increase directly in relation to the depth of water in dams at any point in time. The effects of these high pressure levels resulting from high water depths of the dams indicate the exertion of very high pressure on the earth built dam walls. An increase in the depth of water for a particular dam had a direct correlation with the amount of pressure exerted on the dam wall..

Adherence to design criteria and specifications during construction, avoidance of upstream activities that would affect the water level in dams as well as proper care and maintenance by community members would play a very important role in prolonging the lifespan of these reservoirs.

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