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SILTATION AND IMPACTS ON THE DENSU RIVER AT ANO AS WATER FLOWS FROM THE DAM TO WEIJA IN THE GREATER ACCRA REGION OF GHANA.

ISAAC ODOI DANQUAH

diok1982@yahoo.com

Water Resources Engineer, Goldrain Mountain Company Limited, Koforidua, Eastern Region – Ghana.

Abstract

Siltation by soil erosion and runoffs carrying varied amounts of residues has both positive and negative impacts on the Densu Ano River. The sediment has reduced the total capacity of the River both at the upstream and downstream face and therefore posing threats to the future and survival of the River. Different kinds of technologies such as bioengineering has been employed to work on the banks of the River in order to avoid this eventuality. This research work looks at siltation impact on the Densu River at Ano Community as it flows through the natural channel from the Ano community to Weija. The work establishes that, sedimentation has reduced the total capacity of the River and having effect on total volume of water in the river and on abstraction rate for water treatment and distribution. Farmers and people within the communities are adhering to the 20m buffer zone policy administered by the Water Resource Commission to protect the resource for the future.

Key Words: Siltation, Sedimentation, impacts, buffer zone, catchment, Densu Ano, runoff.

1 Introduction

1.1 Background of the Research

Siltation of rivers in Ghana has been a major problem when dealing with the flow of water from one community to the other. The Densu River in the Eastern Region of Ghana has experienced a lot of siltation at various points in the river especially at Ano community and as a result, a lot of standing waters developed resulting in odors and algae growth. Sediments play an important role in elemental cycling in the aquatic environment. The study of river suspended sediments is becoming more important, nationally and internationally, as the need to assess fluxes of nutrients and contaminants to lakes and oceans, or across international boundaries, increases. One of the most serious environmental problems is erosion and the consequent loss of top soil. Erosion of river banks is what usually results in siltation of rivers and hence the decrease in

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river depth. Although erosion is a natural phenomenon, the rate of soil loss is greatly increased by poor agricultural practices which result, in turn, in increased suspended sediment loads in fresh waters (Bartram et. al., 1996). River banks enforcement and dredging has been one of the major ways by which rivers are kept free of sediment for easy flow downstream. The White Volta is one of the main rivers in Ghana where siltation is greatly experienced. As a result, indigenous usually dredge the river and make use of the soil for construction, manufacturing of blocks and serving other purposes. The transport of fine material in suspension is the major transferring mechanism of particulate material in streams worldwide (Hillier, 2000). The occurrence and intensity of sediment transport also has been reported (López-Tarazón et. al., 2010) to be dependent on the hydroclimatic and geomorphologic characteristics of the basin, together with the availability of sediment within the catchment. For this reason, total sediment yields are often based purely on suspended load data (Wood, 1977). Sediment control is very important as it helps to keep the aesthetic and the quality of water de-voiding it of all odors and pathogens. Good environmental practice in agriculture, which may include contour ploughing and terracing, helps to protect against soil loss and against contamination of Densu River. Water users downstream of areas of heavy soil run-off may have to remove suspended sediment from their water supplies or may suffer a reduction in the quantity of water available because of River Densu siltation (Bartram et. al., 1996). River Densu in Ano community of the Eastern Region is serving as the main source of raw water abstracted and treated for distribution to Koforidua and its environs. This is a river which is serving varied purposes: fishing, swimming, drinking within the community and meeting all kinds of demands.

River banks protection is the main means by which the rate of siltation in most rivers is controlled. In such cases, trees and plants such as Alcassia, Albizia are planted at about 2m distance apart along the river banks to stabilize it. In the forest zones and along the River Densu banks, plants such as Albizia, Cassia, Mahogany, shrubs, other species of trees, long palm trees has been used to serve this purpose. The rate of siltation is high at areas where the soil is sandy and very low at clay and loamy zones. This has resulted in huge sand impoundment in the middle of the Densu River at Ano community leading to slow water flow from the community to Weija. [1]Runoff generation from the catchment especially during heavy precipitation carries all kinds of impurities and soil resulting in siltation to a greater extent. Igneous rocks and small stones or gravels forms the compacted background on which all water moves from upstream to downstream. Siltation around hydraulic structures such as around dams have long term effect on dams. The most immediate long term effect of this problem is the dying of the river or stream. Siltation and filth accumulation always reduces the depth of water in the Densu Ano River. Basically, all sediment (gravel, sand and mud) transported to a river is derived from erosion of the land surface. When the river flow

[1] *Most Rivers in Ghana are located at the downstream of catchment areas. It's due to this that all runoff generations finds its way into the Densu River carrying impurities and particles resulting in siltation to varied depth.*

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enters a reservoir, its velocity and hence transport capacity are reduced and the sediment load is deposited in the reservoir. This is what result in the accumulation of huge quantities of sediment at the upstream face of a dam. The problem of siltation will continue to be a compounded issue as there is always downstream movement of river flow with erosion and runoff carrying all kinds of sediments. Sediment production in mountainous regions has been discussed to be additionally dependent on factors including tectonics and seismic activity, recurring earthquakes, mean elevation of the basin, glaciated area, proportion of solid precipitation, and basin lithology (Glazyrin et. al., 1995).

2 Review of Literature

2.1 Sediment generation in Rivers

Sediment from upland runoffs and erosion is the main process by which the Densu Ano River is siltered to greater extent. However, at a global scale, suspended solid (SS) concentrations in many rivers have dramatically changed in recent years (Walling, 2006). Existing evidence suggests that natural sediment loadings have been substantially exceeded in many catchments in the UK, particularly since World War II (Evans, 2006).

The main anthropogenic activities increasing sediment supply to watercourses include:

- Changes in agricultural practices; for example, increased areas of arable cultivation, leading to greater areas of bare exposed soil susceptible to erosion by winter rainfall (Greig, et al., 2005), and mechanized farm practices which compact the soil and increase runoff and soil erosion (McMellin et al., 2002; Bilotta et. al., 2007). For instance, sediment fingerprinting research indicated 61% of the sediment load of the River Tweed in Scotland was derived from arable and pasture top soils (Owen et. al., 2000).
- Intensification of agricultural practices; for example, increasing stock density (Heaney et al., 2001) and multiple cropping on arable land.
- Increased bank erosion due to loss of natural hydrology.

Sediment in the water column can be measured in three main ways 1) turbidity; the optical (light scattering) property of the water, 2) total suspended solid (SS); direct measurement of particulate weight present in a volume of water and 3) water clarity; also an optical property of water. Deposited sediment can also be measured using sediment traps. Filth generation by the Ghanaian populace is rampant and to a higher degree while the way of disposal is very poor. Most of the disposal points for the refuse produced are within the catchment areas of dams, reservoirs and rivers. This refuse or waste finds themselves in the Densu Ano River after serious torrential rainfalls. This further increases the sediment content of the River as the runoff comes with sand and other waste materials.

To reduce sediment in our Rivers and streams, hydrologic Engineers need to do good drainage analysis and catchment area analysis. In such situations, all areas within the catchment area likely to produce all kinds of sediment will

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be well determined and the quantity of sediment produced determined. This can be channeled into another system or drainage structure to reduce the sediment production in the Densu Ano River and hence increase the size of the River for large quantity of water and good flow downstream towards Weija. Large upstream area coverage has a greater impact on sediment movement downstream. This is because, once the upstream face has a larger coverage area, flow current is very slow.

2.2 Interrupting the Water/ Sediment Continuum

Rivers adjust their morphology (width, depth, slope and channel pattern) and composition in response to the water and sediment supplied from the drainage basin. In a typical dendritic River basin, water and sediment are supplied more or less evenly along the length of the truck stream, causing the channel to become systematically wider and deeper downstream. At the same time, the sediment composing the bed of the river (substrate) becomes smaller and the channel gradient decreases, the physical characteristics of streams vary consistently from headwaters to mouth (Pitlick et. al., 2001). Dams clearly disrupt the orderly downstream transfer of water and sediment. The effect of this interrupting can vary widely depending on the size of the reservoir, the nature of the dam operations, and the position of the dam within the watershed and on the hydrology and geology of the watershed (Williams and Wolman, 1984; Collier et. al., 1996). Sediment control for effective downstream flow requires good management of the water resource. In the southern part of Ghana, the growth of plants and shrubs along river banks is very good and as a result the rate of sediment wash into rivers is very low. This is contrary to the Northern part of Ghana especially along the White Volta in the Bawku West District of the Upper East Region where it’s all sand along the banks of the River.

2.3 Sediment Transport in the Densu Ano River

Average annual rates of erosion and sedimentation have been commonly used to evaluate long-term movement and storage of sediment in watersheds. This is due to the fact that erosion and runoffs from the catchment area is the main process for sedimentation development in the Densu Ano River. Average rates often poorly represent actual rates because changing environmental factors may dramatically alter surface runoff, flooding, and channel stability (Pierre et. al., 2005). Dating of historical, Holocene (postglacial), and late-Wisconsin (late glacial) hill slope and flood plain sediments in southwestern Wisconsin and northwestern Illinois has indicated that rates of sediment erosion, storage, and transportation fluctuated episodically due to changing watershed environmental conditions (Pierre et. al., 2005). In the humid climate of the upper Mississippi Valley, periods of sediment storage tend to be relatively slow and progressive, whereas removal of sediment from storage tends to be episodic with short periods of dramatically high rates separating longer periods of relatively low rates. The replacement of prairie and forest

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by agricultural land use in the upper Mississippi Valley has resulted in accelerated flood plain sedimentation that averages 30-50 cm deep on tributary flood plains and as much as 3-4 m deep on flood plains in lower reaches of main valleys near the Mississippi River (Pierre et. al., 2005). Sediment transport within and along the Densu Ano River to the Weija in Accra is a slow process. Even though this is the case, sedimentation thus develops to greater extent at some points in the River. This is a clear case of miss management and a case of bad operation and maintenance. Siltation in the Densu Ano River is very slow as compared to the White Volta in the Upper East Region of Ghana as in the White Volta, the banks is usually sandy, which is less compacted. The banks of the Densu Ano River is made of rocks at some points and compacted soil due to good River banks protection. Farmers have also made use of the 5m buffer zone rule set by Water Resources Commission and having all kinds of plants, trees and shrubs helping in the compartment of the River banks. The buffer zone protection policy is of very important as it does not allow farmers to farm along the River at a distance of 5m. Trees planted within this distance ranges from Alcassia to long palm trees. Mangrove development has also helped in obtaining well groomed forest areas as the Eastern Part of Ghana is a forest zone. The two seasonal precipitation periods within the year also helps in obtaining a rich soil which is good for plant growth along the banks. This is contrary to what is happening along the White Volta River as it experiences one precipitation season within the year. Buffer zoning helps to improve the fertility of the soil along the Densu River as the soil is not altered by farming activities.

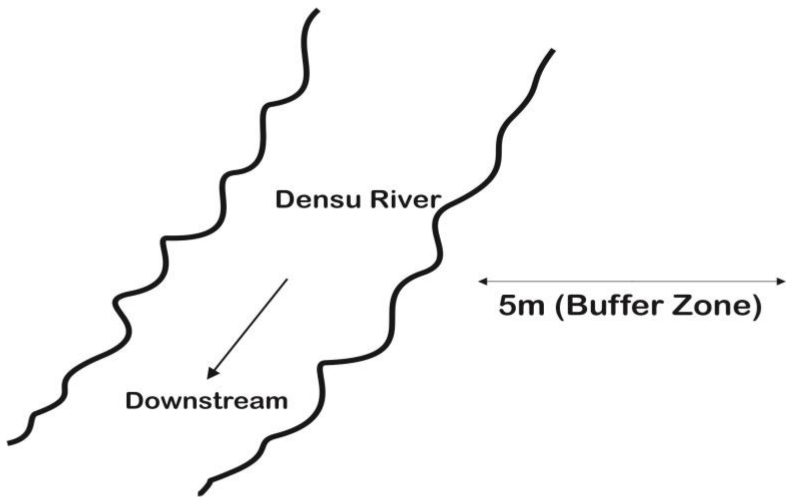

Fig 1: Buffer Zone Protection along the Densu River

2.4 Impacts of Sedimentation on a Reservoir

The basic sources of sediment supply into a river system are:

- Sheet and gully erosion of land surface during heavy rainfall (surface runoff during floods): gullies are formed by concentrated surface runoff in soil;
- Streambed erosion: erosion of the river bed and banks during flood events;
- Mass movement: landslides, slumps, avalanches, creep, mud and debris flows along slopes;
- Erosion around structures;
- Dumping of sediment into river (related to mining activities).

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The sediment load into a reservoir should be determined from sampling stations in the river just upstream of the reservoir and from the direct sediment input into the reservoir by mass movement due to mud slides and slumps (steep valley slopes).

Measures to reduce the sediment input into a reservoir are:

- Replanting and reafforestation of eroded areas (soil conservation);
- Crop rotation and regulation of grazing;
- Terracing of relatively steep valley slopes;
- Building of (removable) check dams, debris-retention basins and sand traps;
- Bypassing of sediments (bypass channels);
- Fire control.

2.4.1 The Trap Efficiency Computation

Based on the mass balance for sediments, the sedimentation along a reservoir can be determined from the following equation:

$$ {}^{\mathrm{dA_z}}/_{\mathrm{dt}} + (\rho_b(1-p))^{-1}\frac{\mathrm{dQ_x}}{\mathrm{dx}} = 0 \qquad (1) $$

Where: A_s =b a_s = sedimentation area of cross-section, b= width of cross-section, a_s= sedimentation thickness, t= time, p= porosity factor, ρ_b = dry bulk density of deposited sediment (kg/m^3), Q_s= sediment transport (in kg/s) at cross-section x, x= longitudinal coordinate.

The sediment transport at section x can be related to the upstream sediment transport by:

$$ \mathrm{Q_s} = (1-\mathrm{E})\mathrm{Q_{s,o}} \qquad (2) $$

With: E= trapping efficiency at section x, $Q_{s,o}$ = incoming sediment transport at x=0.

Based on Equations (1) and (2), the mass balance equation can be formulated as:

$$ {}^{\mathrm{dA_z}}/_{\mathrm{dt}} + \mathrm{Q_{s,o}}(\rho_b(1-p))^{-1}\frac{\mathrm{dE}}{\mathrm{dx}} = 0 \qquad (3) $$

Churchill (1948) presented a trapping efficiency curve based on data from reservoirs in the USA. The trapping efficiency (Eres) is defined as:

$$ E_{res} = \frac{(Q_{s,o} - Q_{s,L})}{Q_{s,o}} \qquad (4) $$

Where $Q_{s,o}$= incoming sediment transport (m^3/s or kg/s), $Q_{s,L}$= outgoing sediment transport leaving the reservoir or reservoir section (m^3/s or kg/s).

$$ \Delta S = E_{res} Q_{s,o} \Delta t \qquad (5a) $$

With E_{res}= trapping efficiency of reservoir (percentage of sediment trapped in reservoir or reservoir section), $Q_{s,o}$= incoming sediment transport (m^3/s or kg/s) and Δt= period considered (s). This may result in zero transport in a certain section of the reservoir if the trap efficiency is maximum (E_{res}=1), which may not be realistic for the transport of very fine sediments. As long as there is flow and turbulence, there will be a minimum transport of sediment. This latter transport can be defined as the equilibrium transport.

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Taking the equilibrium transport into account, the sedimentation volume in the reservoir can be defined as:

$$\Delta S = E_{res}\left(Q_{s,o} - Q_{s,eq}\right)\Delta t \qquad (5b)$$

With E_{res}= trapping efficiency of reservoir (percentage of sediment trapped in reservoir or reservoir section), $Q_{s,o}$= incoming sediment transport (m^3/s or kg/s), $Q_{s,eq}$=equilibrium sediment transport at end of reservoir or reservoir section and Δt= period considered (s). The equilibrium transport can be estimated as: $Q_{s,eq}=(u/u_o)^3 Q_{s,o}$, with u_o= mean flow velocity at upstream reservoir boundary (x=0 m), u =mean flow velocity at end of reservoir or reservoir section.

The trap efficiency according to the formula of **Eysink** and **Vermaas (1981)** is:

$$E_{res} = 1 - \exp\left[\frac{-A_{ev}L}{h}\right] \qquad (6)$$

With: L= length of reservoir, h= mean flow depth of reservoir (or section of reservoir), $A_{ev}=\alpha_s(w_s/u_*)(1+2w_s/u_*)$= deposition parameter, α_s= 0.06= coefficient (in range of 0.04 to 0.08; assuming k_s/h= 0.003, C= 65 m0.5/s), w_s= settling velocity of sediment, u_*= mean bed-shear velocity in reservoir.

The trap efficiency of **Van Rijn** is:

$$E_{res} = 1 - exp[\frac{-A_{vr}L(h-h_o)}{h^2} \qquad (7)$$

Where: L= length of reservoir, h_o= flow depth at upstream reservoir boundary (x=0 m), h= mean flow depth of reservoir (or section of reservoir), $A_{vr}= \alpha_s(w_s/u_*)(1+2w_s/u_*)$= deposition parameter, α_s= 0.25= coefficient (in range of 0.2 to 0.3), w_s= settling velocity of sediment, u_*=mean bed-shear velocity in reservoir.

The trap efficiency of large-scale reservoirs (L/h>500) will be about 90% to 100%; thus nearly all sediments entering the reservoir will be trapped. The coarse fractions will be deposited in the upper part of the reservoir (backwater region), while the finer sediments will be deposited in the lower part (region with horizontal water surface). The proportion of sediment passing through the reservoir will depend primarily on the average flow velocity in the reservoir and the settling velocity of the sediment. In small-scale reservoirs the fine sediments may remain in suspension long enough to pass through the reservoir.

3 Research Method

Survey and investigation was done throughout the whole Densu watershed. Investigations indicated that, sediment and siltation assessment has not been done on the Denso Ano River. The main work done on the Densu River is sampling of water for water quality which is done at four stations: Nsawam, Mangoase, Potroase and Weija. A field visit was done to look and investigate the various kinds of sediment resulting in siltation within the Densu Ano River. Further investigation by analyzing the various plant species along the Densu Ano River that is helping with stabilization of the River was done.

4 Discussion of Research Findings

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4.1 Sedimentation effect on River flow

Siltation and sedimentation of rivers has rendered most Rivers dead as the years go by. Siltation has been as a result of erosion and runoff from heavy storms or precipitation within a catchment area. Sedimentation of rivers usually comes in layers as a result of different kinds of particulates as heavy ones like gravels and stones settle down while sand and fine particles settles on top. These have all kinds of effect on the rate of the Densu River flow to downstream. The effect of siltation and particulates is seen as the water flows downstream during heavy storms. Field investigation and observation at the Densu River at Ano Community within the Koforidua Municipal concluded on the heap of sand within the River as a result of sedimentation. The Densu Ano River serves as an abstraction point for the intake of water for treatment and supply to parts of Koforidua and its environs. The banks has a lot of shrubs, different species of trees, palm trees and other plants making it a mangrove, protecting the banks from eroding and collapse into the River. The river therefore does not need further banks protection but rather buffer zoning so that farmers do not cultivate all kind of crops within the 20m range set by the Water Resources Commission of Ghana. Again, there is the need for dredging to remove accumulated sediments at the upstream face to store more water for abstraction and treatment. The downstream natural channel need to be dredged too. Sedimentation always reduces the volume of the River channel and hence resultant natural channel flow. This is what usually results in flooding of farmlands during torrential precipitations. The Water Resources Commission should take it upon itself to monitor all areas along the River during sampling and monitoring periods to determine all possible areas likely to result in overland flows. Most of the banks of the Densu Ano River is covered by heavy rocks and this reduces the rate of soil movement into the River reducing rate of siltation and increasing River volume. Sedimentation of the Densu River by impurities such as soil, rubbers, leaves, gravels and roots of tress renders a slow movement of water from upstream to downstream. Widening of Rivers due to banks collapse and siltation results in the production of large quantities of sediments within the Densu Ano River as in **Plate 1**. The upstream face of the Densu Ano Dam has impounded a lot of water with little rate of siltation and big coverage area. As a result of this, the depth of water is very deep so that abstraction equipment's can even take water with the use of pumps to the treatment plants during mean periods. Sedimentation in the middle of the Densu Ano River has yielded the growth of plants on the sand pilled within the River (**Plate 1**). Most communities within which such siltation and sedimentation occurs usually dredge and use them for all kinds of activities such as construction, filling of rooms during house building, and molding of blocks. Siltation is inversely proportional to the rate of River flow within the Densu Ano; as the River is filled with all kinds of particulates such as [2]roots, gravels and leaves, the movement of water within the River

[2] *Fig 1: Gives a clear indication of siltation in the middle of River Densu at Ano community. This most at times divide river channels into two or three segments. Most Rivers dry and assumes dead state due to this reason.*

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channel is very slow. The rate only increases during torrential precipitation where runoff from the catchment is very high.

Plate 1: Siltation in the middle of Densu Ano River

4.2 Effect of Siltation on Water Abstraction

Siltation has arduous effect on water abstraction from the Densu Ano River as high rate of sedimentation reduces water volume. Water abstraction from this river is usually to take it treatment plants in Koforidua where the water is purified and transported through distribution lines to consumers. Water abstraction is done with the use of three pumps where currently only one pumps is in operation. Operation and maintenance by the Ghana Water Company Limited who are the main users of the resource is a problems as the facility is seen to be in a very poor state. The rate of dredging the river was established not to be a concern as various areas of upstream and downstream indicated varied amount of siltation. This makes water abstraction very difficult especially during the dry season with sand and other residues added to the abstracted water. This does increases the cost of production as process of water purification and treatment increases. Natural sediment pressures within river systems vary dramatically depending on catchment topography, geology, vegetation, local climate and land use (Hicks and Griffiths, 1992). It is now accepted that excess sediment is a very important cause of deterioration in water quality and aquatic biodiversity (Collins et al., 2008). This is what results in most rivers producing all kinds of odors and the growth of algae and spirogyra making the water unfit for instant drinking. The Water Resource Commission therefore samples for water quality at four main stations: Nsawam, Mangoase, Potroase and Weija. This is to ensure that the quality of flowing water from the Densu Ano community to Weija is maintained and if treatment needed, of a minimal process. Water abstracted for treatment is obtained at the dam constructed on the Densu Ano River within the Densu Ano community. The dam has 5 gates and these are opened for downstream flow when water impounded is of greater amount. The downstream flow comes with huge amount of sediments as seen **Fig. 1** decreasing volume of river channel.

4.3 River Banks Protection

Flooding is a hydrological phenomenon characterized by both precipitation and soil water contribution. The future trend in the climate system leading to extreme hydrological events within the White Volta basin gives no cause for comfort. As a result of greenhouse effect which is being heightened by anthropogenic factors, it’s expected that in future the meteorological conditions that favor extreme hydrological

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events (floods) will occur (Bismuth et al, 2004). African shrub (*Dichro spp.)* is resulting in significant hydraulic resistance especially along the Burkina Faso side of the White Volta River. Erosion resistant materials which can slide down to protect the banks are less seen as sand predominates as the White Volta River bank material hence the continuous widening of the River. River bank erosion is a natural process in stable rivers. However it can become accelerated and exacerbated by direct and indirect human impacts. Destabilization of the banks of the White Volta River bank is by both direct and indirect causes. Livestock trampling and removal of riparian vegetation are the direct causes and factors such as channel incision and widening from hydrologic alteration in watershed are the indirect causes. Bank failures from mass wasting or due to positive pore pressure in River bank (Fischenich, 1989) include the factors destabilizing the Densu Ano River. The Densu Ano River is the main river flowing through all this locations (Nsawam, Mangoase, Potroase, Weija) and serving in diverse ways. Ranging from dry season farming, drinking source for livestock and domestic purposes includes some of the diverse ways in which the river is being used and therefore the need for the integrated management of the resource. Understanding of the rate and cause of erosion resulting in how much bank is lost each year is critical in determining its significance and whether protection of the bank is necessary. Even though the current stabilization of the Densu River is of good condition, further studies on bioengineering and river banks protection need to be done as plant species are prone to failures. Most plants are able to withstand climate conditions for some time and wither as the years progresses. This is usually seen along the White Volta Basin as most plant species used for river banks stabilization are unable to stand harsh climate conditions. River banks protection has been a serious issue worldwide as plant species used for a specific river banks protection (RBP) is not applicable on a River in a particular area or region. River banks protection is easier in the southern part of Ghana because of the two rainfall regimes within a year. The sun effect is not too high reducing the rate of transpiration and evaporation within the region. The rocky nature of catchments within the Densu River regions has yielded greater impacts on the stabilization of the river banks hence reducing siltation as the water moves through natural channels.

5 Conclusion

Sedimentation from all kinds of residues within the Densu River at Ano community has led to reduced river volume and slow rate of flow of water from Densu Ano to Weija. This makes abstraction of water for treatment and distribution very difficult and increasing cost of production. Application of bioengineering and river banks protection has been applied to a greater extent (97%) and by that the river protected. This has reduced the rate of soil wash and sediments from runoff into the river during heavy storms. Buffer zone protection policy is been seriously adhered to as farmers are not allowed to farm within the 20m buffer zone directed by Water Resource Commission of Ghana. Rivers will continue to be siltered with all kinds of particulates due to runoff from the catchment areas during heavy storms but good river banks protection and bioengineering will reduce siltation and such effects, hence protecting the Densu Ano River for future use.

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