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Role of Soil Properties and Precipitation Concentration in Enhancing Floods in Northern Ghana

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Abstract
Rainfall and soil inherent properties are natural factors that influence flood occurrence. The study assessed water infiltration rates and storage capacities of soils in the Northern and Upper East Regions of Ghana and their contribution floods. The objective was to assess the ability of the soil to absorb hydrological shock from floods and explore ecological tools that could be used to manipulate the soils of the regions to play flood reduction and mitigation roles. A field infiltration test was carried out and precipitation concentration index (PCI) was estimated for over a 30 year period. Soil bulk density was determined and porosity inferred. The PCI indicated that 100% of rainfall in Northern Region for 1977 - 2012 has been uniform in distribution and should not pose flood threat assuming rainfall is the only determinant. For the same period in the Upper East Region, 46% – 54 % of the rainfall distribution is indicative that could be succeptible to flash flood. Soil infiltration rates ranged between very slow and extremely infiltration classes (0.5 – 7 mm hr^{-1}) and slow class (7.75 – 8.18 mm hr^{-1}) for the Northern and Upper East regions respectively.. Soil bulk density ranged from 1.54 – 3.13 g cm^{-3} with porosity from 19 – 41% for Northern Region and 1.81 – 2.17 g cm- and 18 – 31 % for the Upper East Region. These accounts for the inability of the soil to carry the hydrological load during floods. Introduction of trees in combination of vetiver grass as an ecological tool could break and open-up the soil profile to allow more water intake and mitigate flood damage.

Keywords: Ghana, soil hydrological load, ecological tool, flood mitigation, soil water intake.

1. Introduction

Flood is an overland flow and accumulation of water that submerges land which is naturally dry (Arochman, 2008). Rainfall intensity and frequency within a catchment area and soil characteristics are natural factors that have strong influence on the severity of flood and are functional in prevention and mitigation. Flood events are a recurring feature in the landscape of the three regions in northern Ghana. Flood occurs when the soil cannot hold any more water or the rate of rainfall is higher than the rate at which water is infiltrated by the soil. The excess water accumulates on the surface and generates force and causes damage to human and extends to properties. With flood these regions have experienced death of many as well as loss of properties, farmlands, produce and field crops worth millions of Ghana Cedis, as shown in Plates 1, 2 and 3. Flood is believed to affect these regions and its people than in all other West African countries combined (Humanitarian News Analysis, 2007; Francis, 2010; Ghana Business News, 2012; Abdulai, 2013). In 2007, a town in the North of Ghana experienced 20% of the annual rainfall for that year in just a single day (Government of Ghana, 2010). A gathering of invited professionals and government technocrats in Ghana identified urbanization, human activities and poor urban land planning as a factor that contributes to flooding in Ghana (GNA, 2011). The stakeholders called for increased channelization and the creation of water retention and detention bonds.

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Plate 1. Homes, schools, crops and livestock washed away in Northern Ghana
Source: Ghana web (2007).

Plate 2. Canoe ferring people on flooded streets in Northern Ghana
Source: Savannah News (2010)

Plate 3.Community submerged by flood in Upper East Region of Ghana in 2012
Source: Modern Ghana (2012)

Poor drainage systems and spilling of the Bogre dam in Burkina Faso and Akosombo dam in Ghana has also been linked to floods in the northern regions and other parts of the country. Natural causes of flood such as high rainfall intensity cause water bodies to overflow their banks in cities and communities and in effect these floods have been attributed to climate change in recent times. Vegetation in Northern Ghana is fast disappearing as a result of increasing demand for wood fuel, charcoal production, and other wood products as well as land for agrarian activities and settlement,.. Such practice accelerates land degradation and aggravates climate change effects and to an extent possible reduce resilience to climate change. Sparse or lack of vegetation also contributes to the severity of floods, as runoff easily gains momentum to run over the land into the rivers, and once the rivers get full the excess amount returns to the community as a flash flood. In these regions, climate change intensified drought occurs at certain periods of the year and it's usually followed by storms with associated severe flood and damaging consequences. The intensification of climate change is likely to further exacerbate the uncertainty about the occurrence of storms, intensity and the frequency of floods with unprecedented damages in the future. This will result in the continuous exodus of people from their ancestral villages and homes, inevitably becoming environmental and climate refugees.

Soil serves as a natural sponge that can absorb flood water and store within its profile. Through its inherent property, soil could play the role of enhancing or mitigating flood. Soil has the potential of mitigating the impact of floods by accepting large quantity of water into it (infiltration). Where the soil water intake capacity is limited due to Plinthic ("concrete") layer which is an inherent property as that of the study region, infiltration is impaired. These soils also usually have limited capacity in holding water and could be naturally prone to erosion and flooding. It has been reported that Scottish soils can store more water than that which is held in all of Scotland's freshwater lochs (SEPA, 2013). According to SEPA, the storage of water by soil and its slow releases regulates water flow hence reducing the risk of flooding. This is true for most soils under natural condition or good management. In spite of the relevance of soils as a key factor in flood development processes and actual occurrence, it is least featured in scientific and policy discussions on floods. This could be attributed to lack of knowledge of the function of the soil beyond its capability for plant growth, crop yield and food security by policy makers. Infiltration- the entry of water into the soil is an important property of the soil that determines whether a soil is easily flooded or flood water is easily absorbed when flood occurs. The ease or difficulty in the movement of water into the soil determines to a large extent whether land flow will occur. When the rate at which water is supplied to the soil has exceeded the rate of absorption by the soil (infilteration), there would be enough water accumulation on the surface to cause floods on flat and valley areas and runoffs will occur following the slope gradient in the landscape. . Infiltration is an important property of the soil that can be explored to reduce flooding or overland flow and enhance ground water reserves. Knowledge of soil water intake (infiltration) is required as an indicator in determining the vulnerability of an area to flood. Infiltration in soils is governed by other primary soil properties such as bulk density, porosity, soil permeability, hydrologic conductivity, etc.

Soils of Northern Ghana are predominantly Plinthosol and Ferric Acrisol (Asiamah and Dedzoe, 1999). Plinthosols have ironstone at shallow depth, low water storage capacity and the soil is a valuable material for Civil Engineers in construction works - at airport runways among others. From the report, Plinthosol occupies 96,920 km^2 of land of Ghana. From flood proneness point of view, about 40.6% of the country are vulnerable.. Acrisol under a vegetative cover has porous surfaced, but it slakes and form hard surface, impeding the penetration of water once the forest cover is cleared (ISRIC, nd). The objective of the study was, 1) to determine the Precipitation Concentration Index (PCI) of the regions using rainfall information from 1977 – 2012; 2) assess the water intake ability of soils of the Upper East and Northern Regions of Ghana by evaluating their infiltrability; and 3) assess the ability of the soil to absorb hydrological shocks or to carry load such as floods

2. Materials and methods

2.1 Study locations

The study was conducted in communities in Navrongo (Upper East) and Tamale (Northern

Region) both in the Northern Ghana. The vegetation in both regions is typical of savanna and reflects an interaction between the climate, soil type and human activities. Most of the vegetation is being cut down for firewood and charcoal production. The major soils of Navrongo is Eutric Plintosol and Endoeutric-stagnic Plintosol with bulk density ranging from 1.7 – 1.88 g cm^{-3} · In Tamale, the majority of soil are classified as Ferric Acrisol, Dystric Plintosol - with bulk density ranging from 1.15 – 1.80 g cm^{-3} (although a few patches of Eutric Gleysol), Luvisols and Leptosols exist (Fosu *et al*., 2007).

3. Measurements and calculations

3.1 Precipitation Concentration Index (PCI)

Thirty five years (1977-2012) rainfall data for Northern Ghana (Upper East and Northern Region) were used for the PCI calculation. The PCI was calculated using Oliver (1980) equation 1, as adopted by Luis *et al*., (2011) and Valli *et al*., (2013)

$$PCI_{annual} = 100 \text{ X } \frac{\sum p^2}{P^2} = \frac{\sum p^2}{\sum P^2} \qquad (1)$$

Where p = monthly rainfall

P = annual rainfall

100 = twelve months of the year, signifying 100%.

Oliver (1980) gave a classification scale for PCI to be: PCI < 10 indicating uniform rainfall distribution (low rainfall contration); PCI value of 11 – 15 indicating moderate rainfall concentration; PCI of 16 - 20 indicating an irregular distribution and PCI > 20 indicating a strong irregularity (i.e high rainfall concentration).

3.2 Infiltrometer measurements

Infiltrometer measurements were carried out in Navrongo, the Upper East and Tamale, the Northern Region. A double ring infiltrometer using the falling head method described by Mbagwu (1997) was used. The dimensions of the inner ring used were 50 cm high and 30 cm inner diameter, whereas the outer ring was 50 cm high with a diameter of 60 cm. The cylinders were driven into the soil to a depth of 25 cm with a sledgehammer, being careful not to disturb the soil surface during this process. Ponded water was kept in both rings while measurements of water intake were made only in the inner cylinder. As described by Mbagwu (1997), one side of the inner cylinder was marked at two points (5 cm and 15 cm) from the ring with a meter ruler permanently glued to the inside of the inner ring. These two points served as the reference levels. Water was quickly poured into the inner and outer rings. When the water level dropped to the 5 cm reference point, enough water was quickly added to bring the water level to its initial level. The level and time before filling and the level after filling were recorded with a stopwatch. The process continued until a steady-state rate was attained. As advised by Mbagwu (1997), the interval between the refilling of the ring was kept short to avoid errors caused by water intake during the refilling period, since the analysis of data from this type of measurement assumes that the refilling is instantaneous

4. Results and discussion

Table 1, shows the degree of monthly or annual heterogeneity of rainfall within the 35 years (1977-2012) calculated and expressed as PCI as proposed by Oliver (1980). The hydrological behaviour of the soils of the Northern (Tamale) and Upper East (Navrong) is presented in Table 2. The initial one minute infiltration measured in the field ranged from 0.4 – 2.24 min^{-1}. Whereas, the measured, steady flow that represents the hydraulic conductivity of the soil ranged from

0.016-0.36 cm hr^{-1}. Field cumulative saturated hydraulic conductivity (SHC) of the soil ranged from 0.5 – 8.18 mm hr^{-1} (Table 2). The soil bulk density, indicating level of soil compaction ranged from 1.5 – 2.13 g cm^{-3} for Tamale soil and 1.81 – 2.17 g cm^{-3} for Navrongo soil (Table 3). Porosity in this study area ranged from 18-35 % for Navrongo and 19 – 41 % in Tamale (Table 4).

Table 1. Precipitation Concentration Index grouping for Northern and Upper East Regions of Ghana over a 35 years period (1977 – 2012)

PCI	PCI classification	Distribution of rainfall concentration(years)	
		Northern Region	Upper East Region
<10	uniform	35	0
11-15	moderately seasonal	0	0
16-20	seasonal	0	19
20-50	high seasonal	0	15
>50	irregular	0	1

Table 2: Hydrological characteristics of some parts of Northern Ghana

Location	Initial one minute infiltration	Steady flow (L cm min^{-1})	Cumulative infiltration (99 mins)
Tamale			
site 1	0.5	0.016	5.2
site2	1	0.16	22.4
site 3	0.4	0.025	10.2
site 4	1.2	0.16	23.3
Navrongo			
site 1	1.5	0.17	25.9
site 2	2	0.1	27.7
site 3	2.4	0.36	47.7

Table 3: Water transmission ability of soils of Northern Ghana

Location	Saturated hydraulic conductivity (mm hr^{-1})	*Rating	*Interpretation
Tamale	< 0.5	Extremely slow	Liable to water log
	0.7 - 7	Very slow	Poor infiltration, may cause overland flow, flood under rainfall
Navrongo	7.75 - 8.18	Slow	Poor infiltration

*Source (field data, 2012) *Hazelton and Murphy (2007)*

Annual hererogeneity of rainfall in Northern Region showed uniformity in rainfall, as concentration PCI values were below 10 from 1977 – 2012. The uniformity of rainfall over a 35 year period in this zone shows that if rainfall was the only input needed for flood to occur, this zone would not have witnessed any flood within that period. However, the soil of the area and its inherent property is also an input factor. The PCI for Upper East Region was either irregularly distributed/concentrated with PCI ranging from 16-20 for 19 years out the 35 years monitored. For 16 years within 1977 - 2012 rainfall in the Upper East was strongly irregular with high rainfall concentration (PCI was > 16). This evidence correlates with the Government of Ghana's (2010) claim that in 2007 the Upper East Region experienced 20% of its annual rainfall in a single day. The interaction between rainfall concentration and soil property in this region is evident in Plates 1, 2 and 3.

The equilibrium rate or steady flow rate was attained at approximately two hours at each location. The ability of Tamale and Navrongo soils to allow the passage of water through it, was either extremely slow or very slow. This implies the infiltrability of the soil is poor and soils with such characteristics are liable to be water log and floods under rainfall with overland flow (Hezelton and Murphy, 2007). The low infiltrability of the soils is connected to the compactness of the soils inferred from bulk density. Higher bulk density values indicate the soils have tight profiles that does not allow water to pass through easily. Similarly, Hunt and Gilkes (1992) described this kind of soil as very compact to excessively compact. Compaction is a serious restriction of water entry into and movement through the soil. When the soil is compacted, it facilitates rainwater accumulation on the soil surface and attains the requisite force to runoff and flood areas under the influence of the topography. Thus the greater the soil compaction and rainfall intensity, the greater the volume of runoff or flood generated. The sparse vegetation and frequent bush fire in the Northern regions enhance flooding in this region as the little or no vegetation increases the volume and speed of runoff. Low porosity value on a scale of 100 indicates pore spaces in the soil are tightly fused together and the consequence is reduced permeability or infiltration. The water storage capacity of the dry soil or porosity ranged from 19 - 41 % for Tamale while Navrongo ranged from 18 – 31 %. Soil is expected to act as a sponge that soaks excess water from high intensity rainfall. This limited storage capacity of the soil reduced its ability to act as sponge. This explains the inability of the soil to absorb much water into it during rainfall and flood events, hence the perennial floods and damage witnessed in the two Northern Regions of Ghana.

Table 4: Bulk density and water storage capacity of soils of Northern Ghana

Location	Bulk density (g cm-3)	Porosity (%
Tamale	1.54 - 2.13	19 - 41
Navrongo	1.81 - 2.17	18 - 31

5. Ecological tool for amelioration

The capacity of soil to function as a sponge or "tank" to hold water and reduce flooding is limited in the soils of Northern regions of Ghana. As a reduction or mitigating measure, conventional engineering structures are recommended and sometimes employed. This is effective, though but has major disadvantages of being expensive represents huge drain on state budgets and expensive to maintain. Frequent structural failures and damages occur depending on the magnitude of the next flood event. Where the ground is soft it becomes difficult to install and the structure rather than absorb flood water to reduce the impact, divert the energy or flow, leading to more damage and disaster in unprotected area or downstream.

Trees in Northern regions of Ghana are scanty whereas these trees could play a beneficial role in reducing and mitigating the impact of flood in the communities. Soil under forest tend to be relatively porous with high water intake (Humann et al., 2011) Afforestation in combination with retention basins reduced flood peak by 12.8% and delayed it by three hours, providing a time lag for possible settlement evacuation when warned. Further studies in Central Europe indicate afforestation of flood plains reduced peak flows by up to 4% when applied to unwooded flood plains. From UK Forestry Commission (1958) report, trees use more water than other vegetation due to interception of rain drops by their aerodynamically rougher canopies. From the same report, the intercept can reduce the amount of rainfall reaching the ground by as much as 45%. A reduction of even half of this amount could make a major contribution to flood reduction and control. The roots of the trees will penetrate the compacted soils of Northern Ghana allowing more water to infiltrate. Trees will be effective, when planted close enough to form a thick canopy to intercept rainfall and cause delay in the time of raindrop reaching the ground. The delay allows time infiltration of water into the soil to occur. It takes many years for tree roots penetrate the soil, grow down, open up the soil for acceptance of more water and to hold the slope from failing or sliding.

Vetiver grass is a fast growing, with root strength of 1/6 the strength of mild stell, reaching a length of 3-5 m in 12 - 24 months (Troung et al., 2008). This root is able to penenrates the highly compacted soils as the Plinthosols of Northern Ghana allowing the soil to take in and store more water. Vetiver in combination with trees or stand alone is well suited for mitigating flood damage and also, binding the soil on the slope against sliding during flooding or heavy down pours.

Plate 4. Vetiver grown along river bank mitigates flood damage by dissipating the energy of the water flow to the community.
Source: www.vetiver.org (2010)

References

Abdulai, A. A., (2013). Periodic flood in Ghana. The Chronicle. http://thechronicle.com.gh/periodic-flooding-in-ghana/ (Retrieved September 11, 2013)

Arochman, T., (2008), How does flood occur, http://classge.wordpress.com/2008/12/22/how-does-flood-occur/ (Retrieved March 23, 2013)

Asiamah, R. D., and Dedzoe, C. D., (1999). Plinthization—A threat to agricultural production. *Ghana Journal of Agricultural Science 32 : 223–227*

Francis N.B. 2010. Floods wrecked Northern Ghana. http://npong2franco.wordpress.com/2010/11/01/floods-wrecked-northern-ghana/ (Retrieved September 11, 2013)

Humanitarian News and Analysis, (2007), Ghana: nearly 275,000 affected by floods in little-known disaster" http://www.irinnews.org/report/74278/ghana-nearly-275-000-affected-by-floods-in-little-known-disaster. Retrieved March 23, 2013.

Ghana Buisiness News (2012) Ghana takes measures to control floods in northern Ghana. http://www.ghanabusinessnews.com/2012/07/03/govt-takes-measures-to-control-floods-in-northern-ghana/ . (Retrieved September 11, 2013)

Ghana web (2007), Floods in Northern Ghana. http://www.ghanaweb.com/GhanaHomePage/NewsArchive/photo.day.php?ID=130749 (2012) (Retrieved March 2, 2013).

GNA (Ghana News) (2011). Stakeholder identify causes of flooding. http://www.ghanaweb.com/GhanaHomePage/NewsArchive/artikel.php?ID=223289. (Retreived March 23, 2012).

Governement of Ghana, (2010). Ghana goes for green growth (Ghana's national climate policy framework).

Government of Ghana, (2013) Upper East. http://www.ghana.gov.gh/index.php/about-ghana/regions/upper-east. (Retrieved September 11, 2013).

Fosu,M., Buah, S.S., Kanton, R.A.L., Bediako, J., Abatania, L., Agyare, W and Salifu, A.B., (2007). Challenge Program on Water and Food (CPWF) *Ghana progress report 2004 -2006. Savanna Agricultural Research Institute, Ghana.* 42p.

Hazelton, P. and Murph, B., (2007), *Interpreting soil test results.* CSIRO Publishing.

Hunt, N. and Gilke, B., (1992). *Farm monitoring handbook.* The University of Western Australia, Crawley, Western Australia.

Modern Ghana., (2012). Floods kills three, affect 22,008 eople in Northern Upper East Region. http://www.modernghana.com/news/419147/1/floods-kill-three-affect-22008-people-in-northern-.html. (Retrieved March 3, 2013).

ISRIC (nd) ISRIC world soil information. *http://www.isric.org/isric/webdocs/docs//major_soils_of_the_world/set6/ac/acrisol.pdf* (Retrieved March 12, 2013)

Luis M. de., Gonzalez, J.C., Brunetti, M and Longares, L.A., (2011). Precipitation concentration changes in Spain 1946 – 2005. *Natural Hazards and Earth System Sciences, 11, 1259-1265.*

Mbagwu, J.S.C., (1997), Quasi-steady infiltration rates of highly permeable tropical moist savannah soils in relation to land use and pore size distribution. *Soil Technology 11: 185–195*

Ministry of Food and Agriculture (MOFA), (2012). Food security in Ghana. Northern region agricultural development unit. Ministry of Food and Agriculture.

Oliver, J. E., (1980). Monthly precipitation distribution: a comparative index. Prof. *Geography. 32, 300-309.*

Savannah News. (2010). Another flood disaster hit East Gonja. *http://savannahnewsblogspotcom.blogspot.com/2010/11/another-flood-disaster-hits-east-gonja.html* (Retrieved March 2,2013).

Science and Enviroenment Policy, (2012). Decentralized flood protection: key to natural flood management. *European Commission DG Environment News Alert Service. Special Issue 32.*

SEPA (Scottish Environment Protection Agency), (2013). Protecting Scotland environment. *www.sepa.org.uk/land/why_soil_is_important.aspr*. (Reteieved March 2, 2013).

UK Forestry Commission, (1958). The case for forestry reducing flood. *http://www.ccjcin.org/trees.htm* (Retrieved March 2, 2013)

Valli, M., Shanti, S.K. and Krishna, I.V.M. 2013. Analysis of precipitation concentration index and rainfall prediction in various agro-climatic zones of Andhra Pradesh, *India International Research Journal of Environment Sciences. Vol 2 (5) 53-61.*