ESTIMATION OF WATER BALANCE IN THE NORTHERN REGION OF GHANA

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Abstract
A study was carried out to understand the reasons why there is low groundwater potential in the Northern Region of Ghana. This was done by determining the mean annual recharge using three independent methods. These are the: (i) use of hydrological parameters like precipitation and evapotranspiration (ii) use of the recession curve where baseflow was separated as recharge and (iii) use of Cl concentration in rainfall and groundwater for only the Tamale area. Among the three methods, (i) produced the least recharge values of 1.4% (Pwalugu-Nawuni catchment) and 4.1% (Lawra-Bui catchment) of the annual rainfall. This was considered to be the minimum recharge and was similar to that obtained by the Cl (4.5%) and may not be enough to replenish the groundwater. The amount of storage was also calculated for some parts of the Black and White Volta and the Kulpawn rivers. The change in storage ranged from 4 in the Kulpawn to about 13 mm in the Black Volta rivers. The high storage in the Black Volta partly explains the high groundwater availability in the south of the region. The low storage coupled with low mean annual recharge also partly explains the low groundwater potential in the Voltaian sediments. Another critical factor to explain the low recharge was high runoff. This was attributed to availability of impermeable strata within the Voltaian sediments that prevent sufficient infiltration to take place.

Key words: Water, balance, recharge, precipitation, evapotranspiration, groundwater, chloride

1.0 Introduction
Availability of groundwater in an area depends on its physical, climatic and geological factors. These factors vary in intensity from one place to another. In some areas groundwater is easily available throughout the year while in others it is intermittent especially during the dry season. Most groundwater is replenished by rainfall. Climatic and geo-physical factors determine the amount of rainfall and the amount available for infiltration into the groundwater table.

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Where the ground surface has an impermeable stratum coupled with high slopes, more surface runoff is obtained and very little water is available for infiltration. Evapotranspiration reduces the amount of water above the water table and with high extraction, without equal replenishment, the groundwater reserves become unsustainable. This calls for interventions for efficient management of the resource. It is therefore important to first understand how much groundwater is replenished annually. Even though management may be adequate, sufficient annual recharge determines sustainability. This study is therefore an attempt to answer part of the question by trying to quantify the annual recharge and then understand the problems associated with low groundwater resources with a specific focus on the Northern Region of Ghana.

2.0 *Review on groundwater recharge*

Groundwater recharge has received less attention in the Developing World than in the more Developed probably because of the lack of the requisite logistics and trained personnel. Recharge to groundwater depends on several factors including the geology, the nature of the soil, topography, vegetation and climate.

Sukhija and Rao (1983) obtained a recharge of 13-21% in the granite terrain of Vedavali river basin. In Western Australia where the geology consists of metamorphic, granitic and volcanic fractured rocks, Allen and Davidson (1982) obtained a recharge of 0.05 - 0.5%, but the potential evapotranspiration exceeded the precipitation by about 3 to 10 times. Recharge in crystalline rocks can be influenced by two factors: (i) mode of chemical weathering and surface run-off and (ii) the intensity of fracturing (Lerner *et. al,* 1990). Clay soils resulting from chemical weathering may lead to recharge being limited to areas where the rock is exposed. Lateritic weathering may also wash down the clay materials to form a perching layer between the upper soils and the subsurface. Furthermore, the influence of fracture permeability of crystalline rocks depends on their topography and mineralogy as well as jointing (Lerner *et al.* 1990). The more quartziferous the rocks, the more brittle they are and deep fractures may develop over large areas. In acid crystalline rocks, recharge can reach up to 15% of annual precipitation (Lerner *et al.* 1990). In some fractured granite rocks in Ouagadougou, Thiery (1988) obtained a recharge of 3.3 to 6.5% of the annual precipitation of 690 mm with a storage coefficient of 1%. In the Northern Region, Van Ess (1982) estimated the annual recharge to groundwater to range from 2 to 4% (15 to 30 mm) and that recharge was highest in the Lower Voltaian sandstones.

Several workers have found chemical methods more convenient and easier to use than geo-physical methods for determining recharge. Allison and Hughes (1978) used Cl and tritium to estimate recharge to an unconfined aquifer in Western Australia. In using Cl for estimating the mean annual recharge, it was assumed that the only Cl on the soil surface was from either precipitation or dry fallout and that there was no contribution from weathering or pollution sources. Fertilizers are an important source of Cl but could be eliminated in areas where they have not been applied. Plants remove water down to only two metres and therefore water at depths greater than this could represent recharge water.

Using Cl to estimate recharge had also been studied by others including Gaye and Edmunds (1990), Edmunds and Gaye (1994), Bazuhair and Wood (1996) and Ting et al.(1998) in many part of the world including North and West Africa. An annual recharge rate obtained by Edmunds et. al. (1992) at Abu Delaig in the Sudan ranged from 0.2 to 0.3 mm. The Cl estimation of recharge uses the basic equation:

$\mathbf{R = P \times C_p / C_{gw} 1}$ where R is recharge flux, P average annual precipitation, C_p the weighted-average Cl concentration in precipitation; and C_{gw} is the average Cl concentration in groundwater.

Bazuhair and Wood (1996) used the area-weighted average chloride concentration in rain instead of the point average and obtained a recharge of about 3% of annual precipitation. High recharge was attributed to: (i) Comparatively high relief with lower evaporation; (ii) very coarse angular gravel and boulders in the wadi bed; and (iii) fairly continuous rainfall throughout the year. All of these provide an opportunity for increased recharge for a given precipitation event.

Sharma and Hughes (1985) estimated direct recharge in Perth in Western Australia. In their work, two types of water movement were observed, one associated with the soil matrix and the other through preferred pathways. Recharge associated with the preferred pathways is instantaneous and is not taken up by plants while recharge through the matrix travels slowly and can be taken up by plants and therefore solute concentration increases in proportion to evapotranspiration. Below the root zone the Cl concentration is high in comparison with its concentration in groundwater. In combining the use of Cl and stable isotopes (^{2}H and ^{18}O), Sharma and Hughes (1985) observed that both evaporation and transpiration will result in an increase in Cl concentration of soil water but direct evaporation of groundwater will result in a shift from the meteoric line. The effect of soil cover on groundwater recharge studied by Peck and Williamson (1987) and Sharma et. al. (1987) in Australia observed that recharge is higher in cleared areas than forested places. Interception losses are higher in the forest areas and this accounts for low recharge.

3.0 Location, climate, vegetation, soil and geology of study area

3.1 Location of study area

This study was carried out in the Northern Region of Ghana. The Northern Region is bordered to the south by the Brong Ahafo and Volta Regions, to the east by the Republic of Togo, to the north by Upper East and Upper West Regions, and to the west by the Republic of Côte d'Ivoire (Pelig-Ba 2000). It is located between latitudes 8° and 10° 30' N and longitudes 0° 30'E and 2° 45'W (Figure 1).

3.2 Climate and vegetation

The study area is in the tropical continental climate and savannah zone of West Africa at the fringes of the Sahel region. The movement of the Inter Tropical Convergence Zone (ITCZ) influences the climate. The mean annual rainfall ranges from 900 to 1200 mm of which 70 to 80% falls in the period May to September. Day temperatures are relatively high, especially during the dry season. The mean annual day temperature ranges between 26 and 37°C. The mean annual evapotranspiration exceeds rainfall and was estimated to be about 1750 mm (Pelig-Ba 2000). The soil-moisture deficit during the dry season is prevalent. The relative humidity ranges from 17 in the dry season to 96% in the wet season.

The study area is located in the interior wooded savannah. It is characterized by short trees and low grass cover, especially in the northern part of the zone. Typical trees that grow in this zone are the baobab, dawadawa, acacias and the shea. These are long-rooted and are able to adapt to the harsh environmental conditions of the area. During the dry season, green vegetation may exist only along the fringes of the main riverbanks and usually very close to them. However, the vegetation becomes richer southwards and especially areas bordering the deciduous forest zone.

3.3 Soils

The major soil groups occurring in the area include savannah ochrosols and groundwater laterites (petrosols). The savannah ochrosols consist of red and brown, well drained, friable, porous loamy soils developed over the Voltaian sandstone, Lower and Upper Birrimian and the granites. The groundwater laterites cover extensive areas in the Voltaian Shales (V2) and granites in the Interior Savannah zone. The depth of groundwater laterites ranges from about 5 to 60 cm of pale-coloured, sandy or silty loam overlying vesicular, orange and black iron pan. At depths of 90 to 120 cm, the concretionary layer may overlie grey and ochre mottled clay, which may grade into shale or mudstone, manganese-stained along the patterns. Generally, the soils have very low organic matter contents and low nutrient status. In addition, they have low moisture content because of the less reliable rainfall pattern.

3.4 Geology and hydrogeology

There are three main different geological zones found in the study area. These are the Birrimian, which has been intruded with granites, the Buem and the Voltaian Formation in the order of age. The Birrimian and the granites are located to the west of the region and form part of the West African Shield. The Voltaian is found from the central to the eastern part of the region. The Voltaian forms contact with Birrimian Formation and cover the central basin to the north east of the country (Figure 1). The Buem is along the eastern border, with the Republic of Togo and the Volta Region of Ghana.

Stratigraphically, the Birrimian is subdivided into the Lower and the Upper Series although earlier workers had suggested three subdivisions in the northern part of the country. The subdivisions are based on lithology (Pelig-Ba et. al. 2003). The Lower Birrimian is regarded as a metasedimentary rock formation while the Upper Series are predominantly volcanic.

The rocks of the Lower Birrimian are metamorphosed and effusive sedimentary rocks that are developed in the river basins within the study area such as the Kandea, the Saphe and the Kitapo. The most common rock types observed are clay-mica phyllites and their associated varieties (Samokhin and Lashmonov 1964). There are also tuffites, tuffs and tuff sandstones occasionally present.

The sediments of the Voltaian Formation are dated from Infra-Cambrian to Paleozoic (Kesse 1985; Leube et. al. 1996). Within Ghana, the Voltaian is bounded to the south by the Birrimian, and to the south east by the Akwapim-Atacora ranges. Out of the 45% area of Ghana covered by the Voltaian Formation, about one third is covered by horizontal sandstone, shales, mudstones and conglomerates considered to be of late Precambrian to Paleozoic age (Kesse 1985). The Voltaian has an approximate thickness of 3000-4000 m and rests on the Lower Protereozoic Birrimian system and related granitoids.

(a) The Lower Voltaian Series (V1) is a lower member of basal sandstones overlain by shales and an upper member (V1A) of quartzitic to feldspathic sandstones. These form the Konkori and the Gambaga Highlands. The V1 Formation is found along the western and northern margins of the region.

(b) The Middle Voltaian Series (V2) has a lower member consisting of interstratified shales, siltstones, mudstones, and sandstones with intercalations of limestones and evaporites at the base and an upper member of fine- to coarse-textured sandstones. The V2 formation is found in the eastern part of the Basin and in between the V1 and V3 Formations.

(c) The Upper Voltaian Series (V3) consists of basal shaly sandstones, an intermediate member of interstratified shales, siltstones, mudstones and sandstones, and an upper member of pure sandstones (V3A). The V3 formation is found in the central part of the Basin. The mean yield obtained others put to about 28%. This is because the decomposition of the profile of the formation is very shallow. The sandstone stones are harder and poorly decomposed. The formation is therefore not conducive to infective infiltration of surface water due to shallow weathering, clayey soils and lack of significant fracture patterns.

Each series seems to represent a depositional cycle, commencing with a shallow marine environment with basal sandstones and/or limestones and evaporites. It is followed by a major phase with deeper marine environment with alternating marine to deltaic shales and coarser clastics. The thickness of all the Voltaian sediments increases eastwards because of down warping along the eastern margin (Bouman 1988).

4.0 Data acquisition and Sampling

Rainfall (P), evapotranspiration (ET) and surface runoff (Q) were obtained for Tamale, Damongo, Bole, Yendi and Walewale. Precipitation data were obtained from rainfall records obtained from the Meteorological Services Department of Ghana in Accra. All meteorological data were of a minimum of thirty years duration. Several gaps were observed, which eventually reduced the length of period of the data sets. Rain is the only type of precipitation in the area and was sampled at Tamale. Chloride and other parameters were analysed (Pelig-Ba 2000; Pelig-Ba et al. 2001). Rainwater and groundwater samples collected were filtered at site and sent to the Postgraduate Research Institute of Sedimentology at the University of Reading for analyses. These were not acidified since other anions were to be analysed. Analysis was performed by ion chromatography using Dionex 2001I.

4.1. Location of catchment areas

4.1.1 Selected Areas for water balance computation

The study area was divided into two sub-catchment areas (Figure 2) based on the availability of data. The first sub-catchment is the White Volta River from Pwalugu on the Upper East/Northern Region border to Nawuni in the Northern Region. This catchment is located between latitudes 9° 30' and 10° 30' N and longitudes 0° 30' and 1° 15' E and covers an area of 29 578 km^2. The main White Volta sub-catchment extends from the fringes of the Basement Complex rocks at Pwalugu to the Voltaian sandstones and traverses the V2 at Walewale before reaching Nawuni (in the V3). The Nawuni-Pwalugu comprises other sub-catchments such as the Nasia, Nabogo and the Kulpawn Rivers. The Nasia River basin occupies an area of 5170 km^2 and the Nabogo 2960 km^2. The remaining area occupies 21 448 km^2 is contributed mainly by the White Volta from Pwalugu.

The second catchment is located on the Black Volta River between Lawra in the Upper West Region and Bui in the Northern Region. This catchment occupies an area of 33 589 km^2 and is situated between latitudes 8° 15' and 10° 30' N and longitudes 2° 15' and 2° 55' E. (Figure 2). The weathered metamorphic rocks have higher permeability UNDP/FAO (1967). High infiltration occurs more in fractured and faulted areas and where most sandy soils are developed. Lawra gauge station was selected because there was no rating curve to convert the staff-gauge reading at Chache that is located in the Northern Region.

5.0 Method of analyses

5.1 Assumptions for water balance calculation

Several procedures are available in the literature for obtaining the water balance in a basin. Three methodologies adopted here to compute the water balance are: (i) use of hydrological quantities, (ii) base flow analysis and (iii) application of chemical parameters.

Evapotranspiration was estimated from pan evaporation taking into consideration the vegetation of the area. This conversion was accomplished by transforming the pan evaporation using factors for various months (Ayoade 1983). If the total annual evapotranspiration exceeds precipitation no net infiltration is assumed to take place. But where soils crack on drying out, it is also possible for recharge to occur locally through these features even though soil moisture deficit may be present. For simplification the latter information was not used. To recharge therefore, it was not practical to consider both the precipitation and evapotranspiration on monthly basis throughout the year. Instead, the following assumptions were made:

(a) From November to April is the period of dry season characterised by high daytime temperatures thus leading to high evaporation and transpiration. There is hardly any rainfall but if is any precipitation, it is used to satisfy the soil moisture deficit, which is rarely met during this period.
(b) Dry harmattan winds from the north between November and March reduce the relative humidity, plants transpire more readily and the soil loses its moisture more rapidly. In this case any rain will not cause any significant infiltration.
(c) Since very little precipitation occurs between November and March, it was assumed that mean evapotranspiration was equal to the mean precipitation on account of the fact that little moisture is available to support any evaporation and transpiration.

(d) Most of the rain falls between June and September resulting in the flooding of major rivers and the fields. Under these circumstances therefore infiltration during this period would occur

In the Basement Complex, infiltration occurs through fractures and joints since the rock mass is largely impermeable. Infiltration of water is also possible through the weathered regolith. In the Voltaian Formation, intergranular porosity is present as well as fractures in the more consolidated ones. The proportion of void space, and also the sizes and shapes of the pores, can influence infiltration.

5.2 Mathematical set up for water balance computation

The water balance in a catchment can be related to the input-output expression as; **Input = output – storage,** and put into measurable quantities as; $\mathbf{P = Q + ET + R \pm \Delta S}$ **2**

P, ET, Q have been defined earlier, R is the mean annual recharge and ΔS is the change in mean storage. The storage component comprises soil moisture and groundwater storage, as the change in channel storage will be negligible. Absolute values of these changes are very difficult to obtain but over a long period changes in storage becomes negligible in relation to precipitation and stream flow and therefore can be ignored (Johnson and Law 1991).

For recharge estimation from discharge measurements and climatic quantities, equation 2 can be separated into the input and output components:

Input = $\mathbf{P + Q_i + G_i}$ and Output = $\mathbf{ET + Q_o + G_o}$, where Q and G are the stream and groundwater contribution to the water budget for both the input and output components. If $Q_i = 0$, Q_o can be put equal to discharge at the gauge then the water budget equation becomes; $P + G_i = ET + Q_o + G_o + \Delta S$ **3**

If $G_o = G_i$ and ΔS is assumed to be negligible since the streams dry in the dry season, then rearranging; $\mathbf{P = ET + Q_o}$ **4**

The quantities P and ET are directly obtained from meteorological measurements. For the stream flow value Q_o, has two components, baseflow (Q_b) and quickflow (Q_s) as in the equation: $\mathbf{Q_o = Q_s + Q_b}$.
The equation 4 then becomes: $\mathbf{P = ET + Q_s + Q_b}$ **5**

The baseflow component $\mathbf{Q_b}$ represents the groundwater obtained from the separation from a hydrograph (Figure 3) and this approximates the recharge ($R=Q_b$) to groundwater.
Hence rearranging the equation, the recharge is given by:
$\mathbf{R = P - ET - Q_s}$. **6**

Rainfall stations upstream of the discharge gauge station were used for the estimation of P. For the Nawuni-Pwalugu catchment, the Walewale station was used. Although Tamale is close to Nawuni, its data was not used because it lies south of the catchment. Rainfall recorded at the Bole and Lawra stations were used for the Bui-Lawra (Figure 2).

In a catchment, the measurement of rainfall at only one station is not adequate since rainfall distribution varies in space and time, particularly where most rainfall results from convectional storms as in Ghana (Dickson and Benneh 1980). There are relatively few rain gauges in the area, so it was not possible to obtain area averages for the catchments. This may not totally invalidate the water balance, however, as there appears to be a good relationship between measured rainfall and stream flow. The Walewale-Nawuni rainfall/discharge hydrograph indicated a good relationship, with the expected delay between rainfall and stream flow leaving the catchment. Hence a regression coefficient up to 66% for Walewale-Nawuni rainfall/discharge hydrographs (Figure 4) was obtained. At the Bole-Bui catchment, lower regressions were obtained. The low regression between Bole and Bui could be attributed to water loses owing to relatively high evapotranspiration, a greater forest density (Peck and Williamson 1987; Sharma et al. 1987) and the bigger size of the channel at the point. On the other hand contributions from overland flow or interflow, especially during the wet season, can also affect the rainfall/discharge relationship. Contributions of P from streams in Côte d'Ivoire that were not considered could also affect the relationship.

5.3 Separation of baseflow from hydrograph

Derivation of a complete water balance requires the separation of any contribution from baseflow, which is the contribution from groundwater that sustains flow during the dry period. In the Northern Region most rivers dry out during the dry season but few others (such as the White Volta, the Oti and the Daka) are intermittent in character.

Several methods exist for separating baseflow from runoff in a hydrograph. One method is achieved by drawing a straight line from the sharp break of the slope where discharge begins to increase to some arbitrary chosen point on the recession limb of the hydrograph. This latter point may be the greatest curvature near the lower limb of the recession limb. Or the pre-storm flow recession curve may be projected below a peak point in the hydrograph and then connected by another line to the recession limb. Another method is to draw a horizontal line from where flow begins to increase to meet the recession line. A fourth method proposed uses the exponential or recession curve. In this case, the logarithm of discharge in the recession part of the curve is plotted against time and a recession constant K derived for the shallowest straight-line portion (Singh 1992).

The method used to separate baseflow from total runoff was that of the recession curve method as proposed by Barnes (1938) and used by, for instance, Chow et. al. (1964). The total discharge is a combination from interflow, overland flow and groundwater into any river or stream is expressed mathematically as follows:

$Q = Q_i e^{-K_e t} + Q_v e^{-K_v t} + Q_b e^{-K_b t}$ 7 where Q is the discharge at any time t, Q_i, Q_v and Q_b are the discharge at the beginning of the recession (t=0) for interflow, overland flow and baseflow respectively. The corresponding recession constants are respectively K_i,

K_v and K_b. The amount of contribution from each term depends on the magnitude of the recession constants. The recession constants for interflow and overland flow become increasingly small at large t (Szilagyi, 1999) and therefore can be ignored.

Hence, at large t the equation reduces to only the baseflow component; $\mathbf{Q = Q_b e^{-K_b t}}$ **Or** **8** $\mathbf{Log_{10}Q = Log_{10}Q_b - K_b t/2.303}$

Plots of log Q (cumecs) versus t (days) were produced for both Nawuni and Pwalugu discharges on the White Volta River and Yagaba for the Kulpawn River. Similar plots were produced for Bui and Lawra on the Black Volta sub-catchment. For Nawuni it was possible to obtain continuous records for 7 and 17 years. At Pwalugu, the discharge record was not continuous and also no flows from October/November to April/May, were zero for most years. This made the estimation of baseflow in this and similar locations difficult. Only 1963, 1964 and 1967 had significant flows during the dry period for which the base-flow component was estimated using the recession curve method.

By plotting log (Q) against t (days), for values from October to the end of the meteorological year, that is February, a straight line was obtained for the base-flow recession. New log (Q) values were obtained by extrapolating the straight line backwards. These were then inserted into the hydrograph for that particular year. The base-flow separation curve could then be obtained by joining a line from below the peak flow to meet the start of the rising limb of the hydrograph. This was printed on graph paper to facilitate the estimation of the areas covered by the baseflow and surface flow. The area under this separation curve and the total area under the discharge curve were calculated (Figure 3).

Assume the area of each segment is A_i, then the total area under the line representing the base-flow will be the sum of all the segments as:

$\mathbf{A_T = A_1 + A_2 + A_3 + \ldots\ldots + A_j = \Sigma A_{ij}}$ **9** where i=1 and j= total

number of segments This is the total area under the hydrograph.
The area under the hydrograph is proportional to the total discharge and that under the baseflow separation curve represents the base-flow volume. Hence, the ratio of the area under the baseflow curve (**A_b**) to the total area (**A_T**) represents the fraction for baseflow (X_b) component. **$X_b = A_b/A_T$ 10**
The baseflow (Q_b) was then calculated from the total runoff Q_T as follows:
$Q_b = Q_T \times A_b/A_T$ 11
As an illustration the water year 1960/61 for Bui was used as using the Figure 5A and B. The total area under the blue curve in Figure 5 $=1530.5mm^2$.
Area under the baseflow in hydrograph $=306\ mm^2$
Fraction of area of baseflow to total area (**$X_b = A_b/A_T$**) $=306/1530.5=0.20$
Fraction of area due to quickflow is therefore **$X_q=1-X_b=1-$** $0.20=0.80$
Results are tabulated for Bui, Lawra, Nawuni, Pwalugu and Yagaba in Table 1. Baseflow values obtained for Bui-Lawra catchment are comparable with values obtained in hard rock elsewhere. Farquharson and Bullock, (1992) obtained values ranging from 0 to 9% in Zimbabwe and 2 to 27% in Malawi of the mean annual rainfall.

Table 1: Estimation of baseflows and quickflows from two catchment areas.

Location	River	Q_T (mm)	X_b	Q_b (mm)	Q_q (mm)
Nawuni	White Volta	176	0.14	25	151
Pwalugu	White Volta	51	0.033	2	49
Yagaba	Kulpawn	70	0.13	11	59
Lawra	Black Volta	30	0.33	10	20
Bui	BlackVolta	208	0.20	42	166

Source: Field Survey

The value for Pwalugu appears very low and may be attributed partly to erratic nature of the data and partly the relatively higher evapotranspiration.

Recharge (R) to groundwater is dependent on P, ET and Q and it occurs only when P>ET $+Q_s$. This is only likely to occur during the very wet months of June, July, August, September and October. Precipitation and evapotranspiration for these months were therefore used to obtain the effective recharge to groundwater. The Nawuni station collects all discharges from smaller sub-catchments, for example the River Kulpawn, which is outside the area under consideration. The contribution from the smaller catchment (Kulpawn at Yagaba) was removed from the discharge at Nawuni.

5.4 Estimation of recharge using evapotranspiration and rainfall

The quantities P and ET were obtained from Bole for the Black Volta River and Walewale for the White Volta while discharge values at Bui and Lawra, and Pwalugu and Nawuni were used to obtain Q_s and Q_b for each of the respective catchments. There was no recorded evaporation data for Walewale. This was estimated from evaporation data from two nearest stations, Tamale and Navrongo (in the Upper East and north of Walewale for the latter).

Table 2: Converted evapotranspiration values for Walewale

7	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P	0.7	0.9	17.2	48.9	94.0	116.1	180.7	210.7	127.8	43.7	6.2	1.8
ET	222.1	192.7	206.6	164.6	143.0	123.9	108.5	142.9	149.6	153.1	160.0	172.0

Source: Field Survey

The converted ET values for Walewale are given in Table 2. The recharge (R_1) as obtained from P, ET and Q_s (by equation 6) was compared with values obtained from hydrograph separation (Q_b) and given in Table 3.

Table 3: Estimated recharge from baseflow and hydrological factors

Catchment	Period	P (mm)	ET (mm)	Q_s (mm)	R_1 (mm)	Q_b (mm)
Bui-Lawra	May-Oct	894	704	146	44 (4.92%)	42(4.69%)
Nawuni-Pwalugu	May -Sep	729	668	43	18 (2.47%)	12 (1.65%)

The results in the table indicate that recharge values obtained for both sub-catchments are close to the corresponding Q_b from the hydrograph separations.

Table 4: Recharge obtained from baseflow and climatic factors in (parenthesis) is percentage of regional rainfall

Catchment	Period	R(mm)	Q_b (mm)	Mean
Bui-Lawra	May-Oct	44 (4.2%)	42 (4%)	4.1
Nawuni-Pwalugu	May-Sep	18 (1.7%)	18 (1.1%)	1.4

The variation observed between R and Q_b could be attributed to the errors involved in obtaining the baseflow from the hydrographs. Percentage recharge relative to the regional rainfall (1050 mm) is also given in Table 4. This value corresponds closely with the estimated values obtained by Van Ess (1982).

5.4 Use of chloride for the chemical for recharge estimation

Recharge to groundwater is another form of pore water and can be related to recharge by the following expression:

$$\mathbf{P \times C_p = R \times C_{gw} \quad or \quad R = P \times C_p / C_{gw},}$$

Chloride concentrations in rainfall are obtained from sampled rainwater, and those in porewater from elutriated soils. However, if Cl from leached soils is not available then Cl concentration can be approximated to that in groundwater (Edmunds and Walton, 1980). For this study it was only possible to obtain rainwater samples (over 20) for Tamale and therefore recharge was estimated using Cl from boreholes located within this area (Table 5).

Table 5: Estimation of direct recharge from precipitation and groundwater Cl for selected locations in the study area.

Location	Geology	P (mm)	C_p (mg L^{-1})	C_g (mg L^{-1})	F	R (%)
Tamale	V3	1048	3.13	63.1	52.0	4.5

5.6 Groundwater Storage

The storage component of the groundwater was estimated using discharge values for the various stations in the catchment areas.

The change in storage DS_t remaining in a basin at time t is obtained from the equation:

$DS_t = -Q_t/\ln K_r$ (Linsley *et al.*, 1975). **12**

Where the discharge Q_t and the K_r is the recession constant at time (t) in the discharge-time equation as follows;

$Q_t = Q_0 e^{-K_r t}$ ===> $\ln(Q_t) = \ln(Q_0) - K_r t$ and transforming it to

$\log_{10}(Q_t) = \log_{10}(Q_0) - K_r t/2.303$ **13**

By plotting $\log_{10}(Q_t)$ against time(t) produces a gradient equals $-K_r/2.303$ (Figure 7).

Values for the recession limb were plotted and K_r was deduced from the gradients. Table 6 contains values for the recession constants with the corresponding storage calculated from the storage equation. For Bui, the gradient was:

-1.70×10^{-7} **and** $K_r = -(-1.70 \times 10^{-7} / 2.303) = 7.382 \times 10^{-8}$.

With a mean discharge of 208 mm, the storage is $-208/\ln(7.3817 \times 10^{-8}) = 12.67$ mm. The change in storage from the various different river basins in the two catchments is presented in Figure 5.

Table 6: Estimation of storage (mm) from recession constant.

Location	River	K_r	Q_t	ΔS_r
Bui	Black Volta R.	7.382×10^{-8}	208	12.67
Lawra	Black Volta R.	1.57×10^{-7}	30	2.00
Nawuni	White Volta R.	2.28×10^{-4}	176	21.00
Pwalugu	White Volta R.	6.14×10^{-8}	51	3.00
Yagaba	Kulpawn R.	1.44×10^{-7}	70	4.00

The results indicate that the amount that goes into storage is substantially less than quick runoff. From Table 6 the magnitude of the storage (ΔS_r) varies for all the stations and depends mainly on two factors; (i) it is inversely proportional to the magnitude of K_r and (ii) the amount of discharge (Q_t). Low Kr and high discharge produces high ΔS_r. There are also variations along the two basins in which the upper gauge stations (Lawra and Pwalugu) have lower discharges than the lower catchments in two rivers. Low storage suggests higher runoff, less infiltration, higher evapotranspiration and probably higher abstraction. Less infiltration to storage is dictated by the nature of geology, soil cover and topography. Less fractured or poorly weathered regolith together with the top strata of the soil normally covered by an impermeable iron pans restrict the infiltration and sample. The general low storage suggests low groundwater potential along such catchments.

6.0 Discussion of the results

The amount of recharge is dependent on parameters such as precipitation, evapotranspiration and runoff. The accuracy of recharge depends on field data collection and the method of analysis. For the chemical methods, Cl is usually easier to determine, but during this investigation the Cl concentration could only be obtained for rainwater samples from Tamale. Baseflow from the two catchments ranged from 12 to 42 mm. Runoff is dependent on the amount and frequency of the basin rainfall. The higher the rainfall amount and frequency, the more probable that higher runoff will be obtained. The Bui-Bole area has higher rainfall (1083 mm) than the Nawuni-Pwalugu (849 mm) catchment as the rainfall pattern in the country decreases northwards. Geological differences also exist between the two areas. The Black Volta River flows on crystalline rocks in a greater part in the Northern Region, while the White Volta River flows in a sedimentary basin, which is more permeable. The less permeable crystalline rocks enhance runoff while the Voltaian sedimentary rocks may enhance infiltration to the groundwater. Topographically, the Voltaian has a gentler slope from Pwalugu to

Nawuni (0.44) while the Lawra-Bui slope is relatively higher (0.75), which may explain the higher runoff at Bui. In addition the Black Volta catchment in totality is bigger and therefore higher volume of water than the White. Also Bui is nearer to the Volta Lake and therefore any backwater effect could affect its flow more than the Nawuni-Pwalugu catchment on the White Volta.

Recharge values obtained from the hydrological parameters were different in the two catchments. These values were 1.4% in the White Volta and 4.1% in the Black Volta. Estimated errors indicated that the hydrological parameters produced the highest error margin of 87%, the greatest source coming from evaporation measurements. The source of these errors is attributed to the use of pan water by animals and variation in vegetation from north to south.

Studies have revealed that areas with less vegetation tend to have higher recharge rates than more forested areas having similar annual rainfall. In the two catchments, Bui lies between the savannah zone and deciduous forest and therefore has much denser vegetation than the Nawuni-Pwalugu area. Hence, it is expected that the recharge rate would be lower for the Bui-Lawra sub-catchment, but this was not the case. Several factors may account for this. It is suggested that differences in vegetation density and type in the two catchments appear not to play any significant role in determining the rate of recharge. Recharge to groundwater also depends on soil structure and frequency of fractures within the terrain. Soils with lower hydraulic conductivity and presence of aquicludes tend to decrease recharge. Typical borehole logs in the Voltaian consists of lateritic topsoil overlying layers of clay, which are less permeable thus reducing infiltration to the water table. In the crystalline basement, although the weathered regolith may sometimes contain clay as weathering products, the nature of bedrock appears to control infiltration. Fracturing is very common in most rocks in the Birrimian and granites. These may offer wider openings for easy infiltration of precipitation.

Recharge rates using Cl were similar to that obtained by the use of hydrological parameters. Chloride from groundwater gives total recharge as against those of the other parameters as most of the Cl in the atmosphere is contained in either dry or wet deposition (Ting 1998). As a result the estimated recharge using Cl was slightly higher than the hydrological parameters.

Recharge rates using Cl from groundwater in the Tamale area (V3) was 4.1% of the mean annual rainfall. The areas underlain by more argillaceous rocks such as shale and mudstones of V3 and V2 (Tamale and Yendi respectively) had the lowest recharge rates. Transmissivity values were low ($<30\text{-m}^2 \text{ day}^{-1}$) for both the Basement and Voltaian Formations. For a given aquifer, the curve of depression is inversely related to transmissivity and storativity and directly proportional to pumping rate (Freeze and Cherry, 1979). This suggests that low transmissivity will develop deep drawdown cones and perhaps low pumping levels. Consequently shallow boreholes may easily become depleted of water and water crises will arise. Areas of high population densities with limited number of boreholes will also face a problem of over abstraction thus lowering of drawdown or water level. Such boreholes eventually dry out especially in the peak of the dry season. But in the wet season groundwater reserves may be replenished by infiltration.

The depth of weathering of the regolith may be important but not a good indication of probable good aquifer. Deeply weathered schist and clay-rich metasediments tend to yield little water as was observed in Kaduna in Northern Nigeria whereas less weathered but jointed quartzites may be better aquifers (Hazell et. al. 1992). Weathered mica-rich rocks may produce clay-rich material that limits storage. However, fractured granites containing feldspars but with low kaolinisation may show good prospects of groundwater. In the Northern Region loose deposits and zones of fractured rocks are good water bearing. Bedrocks are water-bearing in the upper profiles and in the highly fractured zones. The water bearing rocks within the Birrimian in the Northern Region are granites and grano-diorites. Tectonic zones that follow pegmatite veins produce good groundwater yields.

6.0 Conclusion

Permeabilities and hydraulic conductivities principally determine groundwater recharge. Factors affecting recharge in this area are (i) geological and (ii) climatic. Geologically, low permeabilities, hydraulic conductivities and storage coefficient results in low recharge. High evapotranspiration and runoff with low transit times also explain low recharge since little water is available for percolation. Hence, the Northern Region has all these factors operating and therefore it is very difficult to locate groundwater in the Voltaian Formation.

7.0 Recommendations

Groundwater location in the study area is influenced by both geological and climatic factors. It is recommended that deforestation and bush burning that will reduce vegetation cover and enhance evaporation from the soils should be checked through education of the citizens.

Northern Region has vast areas of arable land which prospective farmers take advantage off. Such people cultivate the land for only a short duration and abandon that plot and move into another thus leaving that previous place unused. Such farming activities should be checked and stopped. More intensive and well-managed farming practices should be adopted. To ensure adequate supply of potable water the people should adopt water conservation methods.

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