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Combined uses of chloride mass balance and soil water balance methods to investigate natural groundwater recharge in Abakaliki, Southern, Nigeria

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ABSTRACT
This study estimates the total amount of the groundwater recharge in Abakaliki using the chloride mass balance and soil water balance methods. The chloride mass balance method was applied in the area, to estimate the recharge in the year 2021. Based on the variation of chloride concentrations measured in groundwater and rainwater samples taken from 15 wells and 15 open rainwater collectors in 2021, the estimated annual groundwater recharge in the study area ranged from 452.74 mm to 1016.61 mm, with an average of 672.3 mm. The mean annual recharge represents 6.7 % of the total annual rainfall of 1729.3 mm. The results show that soil water balance equation ranged from 712.37 mm in 2018 to 1065.51 mm in 2016. Based on soil water balance equation, the estimated annual recharge ranged from 712.37 mm in 2018 to 1065.51 mm in 2016. The mean recharge was 857.78 mm in 2006, representing 8.59 % of the average annual rainfall of 1769.78 mm.

Keywords: Combined Uses, Chloride mass balance, Soil water balance, Natural groundwater recharge

INTRODUCTION
The importance of water, particularly freshwater, has been recognized since the beginning of man. In every human society anywhere on the planet earth, water is said to be life because all aspects of life depend on it. It is a necessary input for many sectors of the global economy. In many world regions, particularly in developing regions like Africa, availability and access to freshwater largely determines patterns of economic growth and social development (Odada, 2006).

Africa as a continent has an immense supply of rainfall, with an average annual of 744 mm, and relatively low withdrawals of water for its three major water sectors, namely agriculture, community water supply and industry (FAO, 2003). However, natural phenomena such as rainfall variability and global climate change, and human factors such as over-exploitation and pollution, create a serious threat to the sustainability of Africa's freshwater resources.

Estimating natural groundwater recharge is one of the prerequisites for effective groundwater resource management but it is probably the most difficult of all measures in the evaluation of groundwater resources (De Vries and Simmers, (2002). Estimates are normally and almost inevitably subject to large errors. No single comprehensive estimation technique can yet be identified from the spectrum of those available, which gives reliable results. Recharge estimation can be based on a wide variety of models which are designed to represent the actual physical processes. The methods, commonly in use for estimation of natural ground water recharge, include chloride mass balance method, ground water balance method, soil water balance method, zero flux plane method, one-dimensional soil water flow model, inverse modelling technique, and isotope and solute profile techniques. The major aim of this study is to estimate groundwater recharge in Abakaliki using chloride mass balance and soil water balance equations.

LOCATION OF THE STUDY AREA

The study was conducted in Abakaliki of Ebonyi State. The geographical coordinate lies within 06°04’0″N Latitude and 08° 65’0″ E Longitude and falls within the Upper Benue Basin which has a catchment area of about 203,000km^2. Abakaliki occupies the eastern axis of Ebonyi state, covering a land area of about 584 km^2. The elevation of the area ranges from 40m to 100m above mean sea level. The area is characterized by a uniform sloping drainage slightly tilted eastward. Surface drainage in the study area is controlled majorly by the Ivo, Eze-Aku and Ikwo rivers. These rivers traverse the entire study area with its eminent tributaries and distributaries transporting its hydrochemical attributes from one point to another.

This region has two distinct seasons; the wet and the dry seasons. The wet season starts from April and ends in October while the dry season starts from November and ends in March. The rain has high intensity of thunderstorms, particularly at the beginning and towards the end of the raining season. Temperature in the dry seasons ranges from 20°C to 38° C.

GEO-HYDROLOGY

Abakaliki area is located in the sedimentary basin of Southeastern Nigeria, and forms part of the Abakaliki Basin in the Southern Benue Trough. Abakaliki is underlain by Asu River Group (Albain Age) which is the oldest sedimentary sequences of southern Nigeria. Scattered intermediate intrusive rocks of various sizes and forms also occur commonly (Figure 1). Agumanu (1989) stated that the lithofacies of Asu River Group consists of alternating shales and siltstones with presences of fine grained micaceous and feldspathic sandstones, mudstones, and limestones.

The Asu River Group, which has an average thickness of roughly 500 m, is predominantly shale, dark grey in colour, blocky and non-micaceous in every location. It is deeply folded, faulted and fractured by the series of tectonic activities which has acted on the rocks (Ezeh and Anike, 2009). This has given the shales the potential to bear groundwater in a large quantity in few areas, while its nature as aquiclude still persist in other areas where fracturing is not pronounced. It is calcareous (calcite-cemented) and deeply weathered to brownish clay in the deeper part of the formation. The major part of the Abakaliki is underlain by aquiclude; except in locations or zones where secondary aquiferous conditions were made possible by syn- and post depositional circumstances. The syn-depositional circumstance is the occurrence of lenses of sandstone or siltstone beds, while the post depositional circumstances include weathering, fracturing or shearing, and volcanic intrusions. The zones are recharged mostly in the peak of rainy season and by surface waters in the area.

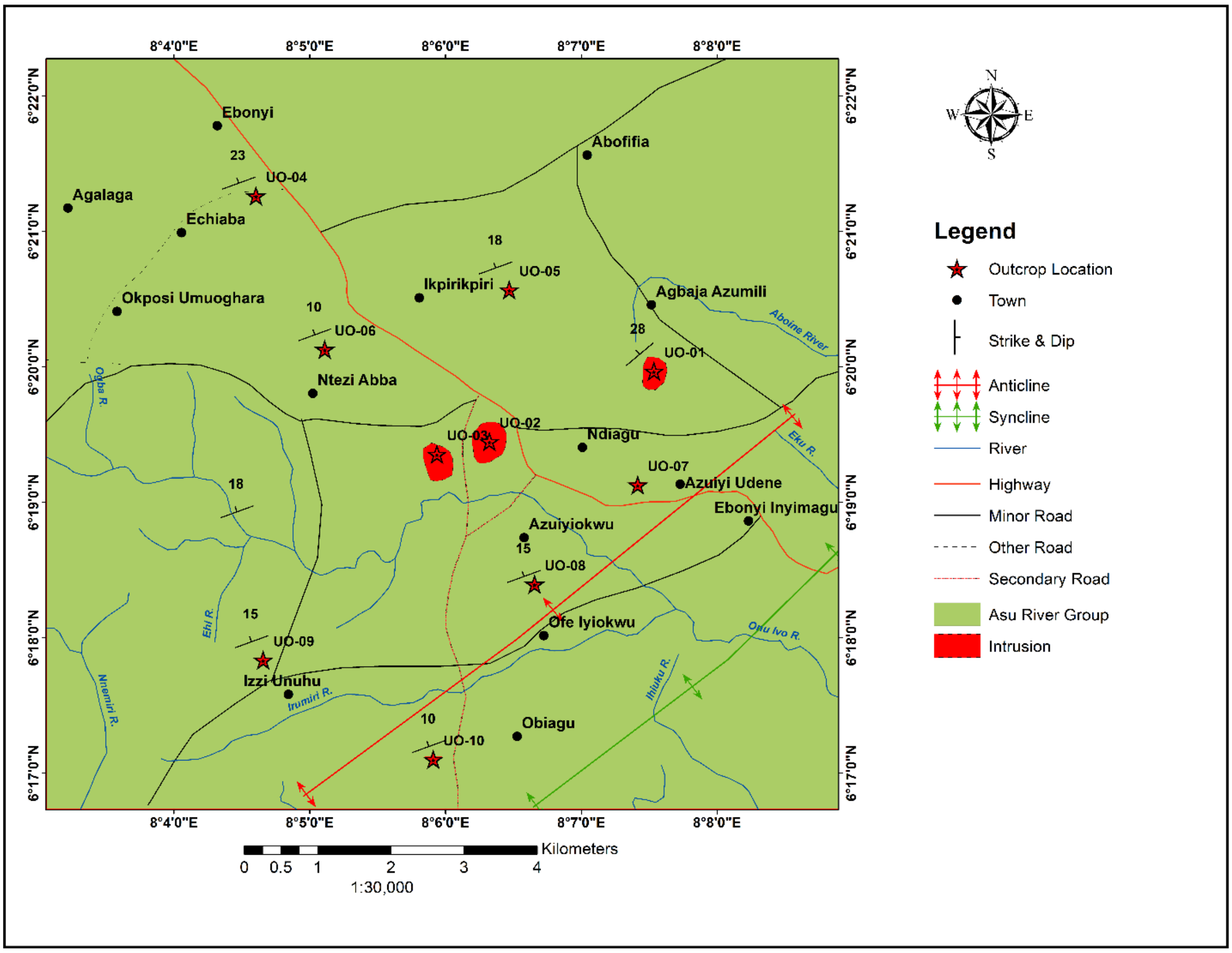

Figure 1. Geologic map of the study area

MATERIALS AND METHODS

Water Sampling, Preparation and Analysis

Thirty (30) samples were collected from fifteen (15) existing wells and from fifteen (15) open rainwater collector at different locations (Figure 2). The co-ordinates of the well and open rainwater collector points were established using the hand-held GARMIN 12 model GPS. These samplings were conducted on a monthly basis for 6-months during raining season with the first sampling starting from April 22, 2021 to the last sampling on September 27, 2021. Water samples were collected in sterilized, 1.5-liter plastic bottles with tight fitting plastic caps. The collected water samples were labeled, stored in an ice packed cooler and taken to the laboratory for chloride analyses within 24 hours. Chloride concentration were also measured in the laboratory by appropriate titrimetric methods.

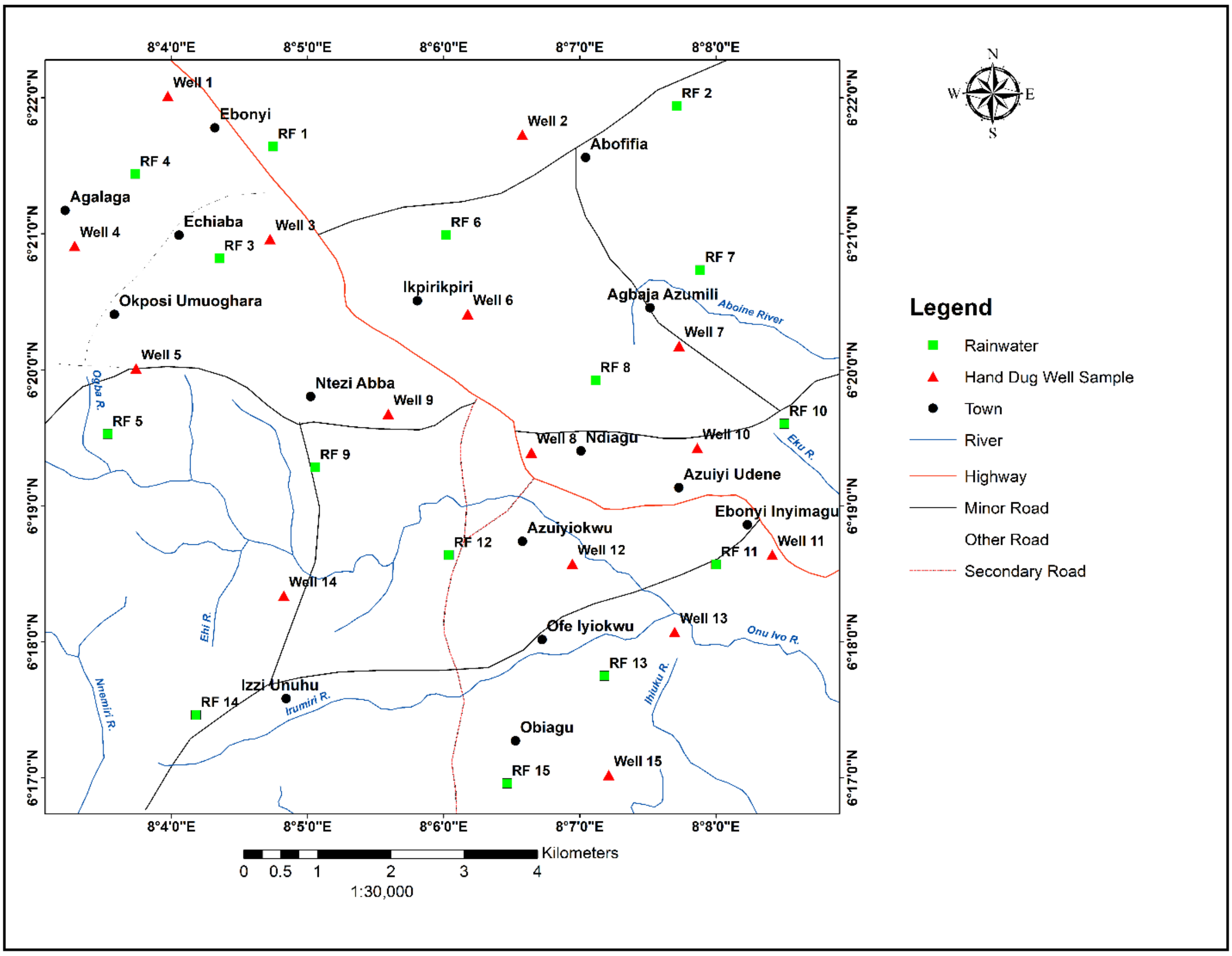

Figure 2. Groundwater and precipitation sampling map of the study area

Chloride Mass Balance

The CMB method uses chloride anions to calculate the recharge rate. The method, developed by Eriksson and Khunakasem (1969), has been described by many researchers (Subyani and Sen, 2005; Gee and Hillel, 1988) and has been applied in several climates and in every continent. The recharge rate using chloride mass-balance can be calculated using (Equation 1):

$$R = P \times \frac{C_r}{C_g} \qquad (1)$$

where R the effective recharge rate ($L^3\ T^{-1}$), P the annual precipitation ($L^3\ T^{-1}$), C_r the chloride concentration in rainwater (ML^{-3}), C_q the concentration of groundwater chlorides (ML^{-3}).

Soil Water Balance Method

The soil water method can be described as in equation 2 (Kumar 1997; Thornthwaite and Mather 1955; Thornthwaite 1948):

$$R = P - ET + W - R_o \qquad (2)$$

Where:

R = Groundwater Recharge.

P = Precipitation.

ET = Actual Evapotranspiration.

W = Soil Water Storage.
R_o = Runoff.

Data Used

The weather data used in this work was acquired from the Nigerian Meteorological Agency (NIMET), Anambra River Basin Development Authority (ARBDA) and Centre for Basic Space Science, University of Nigeria Nsukka (CBSS). The data are monthly rainfall, evapotranspiration, soil water storage and runoff. The data were collected for 10 years from 2012 – 2021 (Table 1).

Table 1. Yearly precipitation, evapotranspiration, soil water storage and runoff data in the study area

Year	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
P	1725.8	1891	1737.7	1716.5	2084.3	1891.7	1482.3	1769.7	1669.5	1729.3
E_T	252	388	268.9	283	492.5	335.1	316.4	407.4	409.9	433.5
W	78.80	83.14	75.50	82.90	96.41	91.56	80.57	71.57	98.35	99.36
R_O	639.8	766.6	568.3	678.4	622.7	710.3	534.1	713.8	500.9	657.5

RESULTS AND DISCUSION

Chloride Concentration in Precipitation

Table 2. Result of chloride concentration in rainfall samples

Date of Sampling/Location	**April 22, 2021**	**May 26, 2021**	**June 17, 2021**	**July 6, 2021**	**August 3, 2021**	**September 27, 2021**	**Average**
Ebonyi	26.08	36.00	31.34	33.17	41.51	23.80	**31.98**
Abofifia	22.30	19.34	20.68	31.12	22.00	40.12	**25.93**
Echiaba	30.15	22.20	41.18	46.00	50.11	43.10	**38.79**
Agalagu	22.01	25.35	31.50	40.26	32.08	52.98	**34.03**
Okposi Umuoghara	25.10	33.81	29.00	42.56	40.43	25.16	**32.68**
Ikpirikpiri	23.00	34.00	19.31	24.30	15.11	21.31	**22.84**
Agbaja Azumili	16.00	41.54	40.15	28.17	22.24	15.28	**27.23**
Ndiagu	24.12	34.11	23.10	31.33	46.55	17.16	**29.39**
Ntezi Abba	35.98	40.18	42.01	20.16	19.18	16.34	**28.98**
Azuiyi Udene	16.31	21.31	20.22	16.90	17.28	39.65	**21.95**
Ebonyi Inyimagu	20.34	40.10	30.12	17.22	37.37	17.29	**27.07**
Azuiyiokwu	26.18	38.32	16.18	18.14	26.83	24.13	**24.96**
Ofe Iyiokwu	19.99	27.41	33.76	16.46	34.54	17.42	**24.93**
Izzi Umuhu	24.11	25.13	17.10	30.37	26.12	36.11	**26.49**
Obiagu	27.09	32.06	34.39	33.10	27.61	19.31	**28.93**

The Abakaliki and environs experiences unimodal rainfall, which occurs from March to November. Average monthly chloride in precipitation for the 6 months during rainy season ranged from 21.95 mg/l to 38.79 mg/l for the months from April to September, respectively (Table 2). The maximum monthly chloride concentration in rainwater was 38.79 mg/l at Echiaba open rainwater sample collector (RW 3). The minimum monthly chloride concentration in rainwater of 21.95 mg/l was measured in Azuiyi Udene open rainwater collector (RW 10).

Chloride Concentration in Groundwater

Table 3. Result of chloride concentration in groundwater samples

Date of Sampling/Location	**April 22, 2021**	**May 26, 2021**	**June 17, 2021**	**July 6, 2021**	**August 3, 2021**	**September 27, 2021**	**Average**
Ebonyi	75.56	40.14	71.37	86.00	65.80	86.25	**70.85**
Abofifia	80.12	40.08	96.20	97.30	85.00	85.11	**80.64**
Echiaba	50.43	90.07	80.15	71.22	51.27	94.12	**72.87**
Agalagu	60.40	50.42	65.43	64.42	50.62	83.27	**62.43**
Okposi Umuoghara	50.32	20.25	64.18	65.27	60.19	73.31	**55.59**
Ikpirikpiri	60.47	70.67	89.40	88.07	92.41	67.19	**78.04**
Agbaja Azumili	80.10	105.9	55.16	42.44	71.77	70.32	**70.95**
Ndiagu	132.0	65.53	59.09	73.23	92.1	85.2	**84.53**
Ntezi Abba	98.87	92.52	66.13	80.10	62.11	79.09	**79.80**
Azuiyi Udene	120.0	105.9	54.86	48.22	83.04	91.04	**83.84**
Ebonyi Inyimagu	76.46	94.71	67.24	57.35	50.12	56.44	**67.05**
Azuiyiokwu	94.27	85.65	73.18	49.54	66.23	53.18	**70.34**
Ofe Iyiokwu	44.15	53.09	80.77	60.28	49.87	91.41	**63.26**
Izzi Umuhu	39.56	61.23	92.31	77.22	58.14	80.10	**68.09**
Obiagu	71.80	74.17	60.59	50.50	63.41	65.53	**64.33**

Table 3 offers the monthly chloride concentration in groundwater, which are used to estimate recharge at each groundwater sampling site. The average monthly chloride concentration in each point during the sampling period (April to September 2021) ranged from 55.59 mg/l to 84.53 mg/l, where the highest chloride concentration in groundwater was measured at Ndiagu hand dug well (HDW 8) and the lowest chloride concentration in groundwater was recorded at Okposi Umuoghara hand dug well (HDW 5).

Groundwater Recharge Estimation Using Chloride Mass-Balance

Table 4. Groundwater estimated recharge for the year 2021

Sampling Location	**Annual Precipitation**	**Cl_r in Precipitation**	**Cl_g in Groundwater**	**Estimated Recharge (mm/yr)**	**% of Recharge (mm/yr)**
Ebonyi	1729.3	31.98	70.85	780.56	7.8
Abofifia	1729.3	25.93	80.64	556.06	5.6
Echiaba	1729.3	38.79	72.87	920.54	9.2
Agalagu	1729.3	34.03	62.43	942.63	9.4

Okposi Umuoghara	1729.3	32.68	55.59	1016.61	10.2
Ikpirikpiri	1729.3	22.84	78.04	506.11	5.1
Agbaja Azumili	1729.3	27.23	70.95	663.69	6.6
Ndiagu	1729.3	29.39	84.53	601.35	6.0
Ntezi Abba	1729.3	28.98	79.80	628.01	6.3
Azuiyi Udene	1729.3	21.95	83.84	452.74	4.5
Ebonyi Inyimagu	1729.3	27.07	67.05	698.17	7.0
Azuiyiokwu	1729.3	24.96	70.34	613.64	6.1
Ofe Iyiokwu	1729.3	24.93	63.26	600.1	6.0
Izzi Umuhu	1729.3	26.49	68.09	621.98	6.2
Obiagu	1729.3	28.93	64.33	777.69	7.8
Average	**-**	**-**	**-**	**672.3**	**6.7**

Table 4 indicates the recharge estimates from all the study boreholes of study water year 2021. The chloride mass balance method indicates that the Abakaliki and environs experienced recharge ranging between 452.74 to 1016.61 mm, representing 4.5 % to 10.2 % of the total precipitation received in the area, with Okposi Umuoghara areas receiving high recharge estimates (Figure 3).

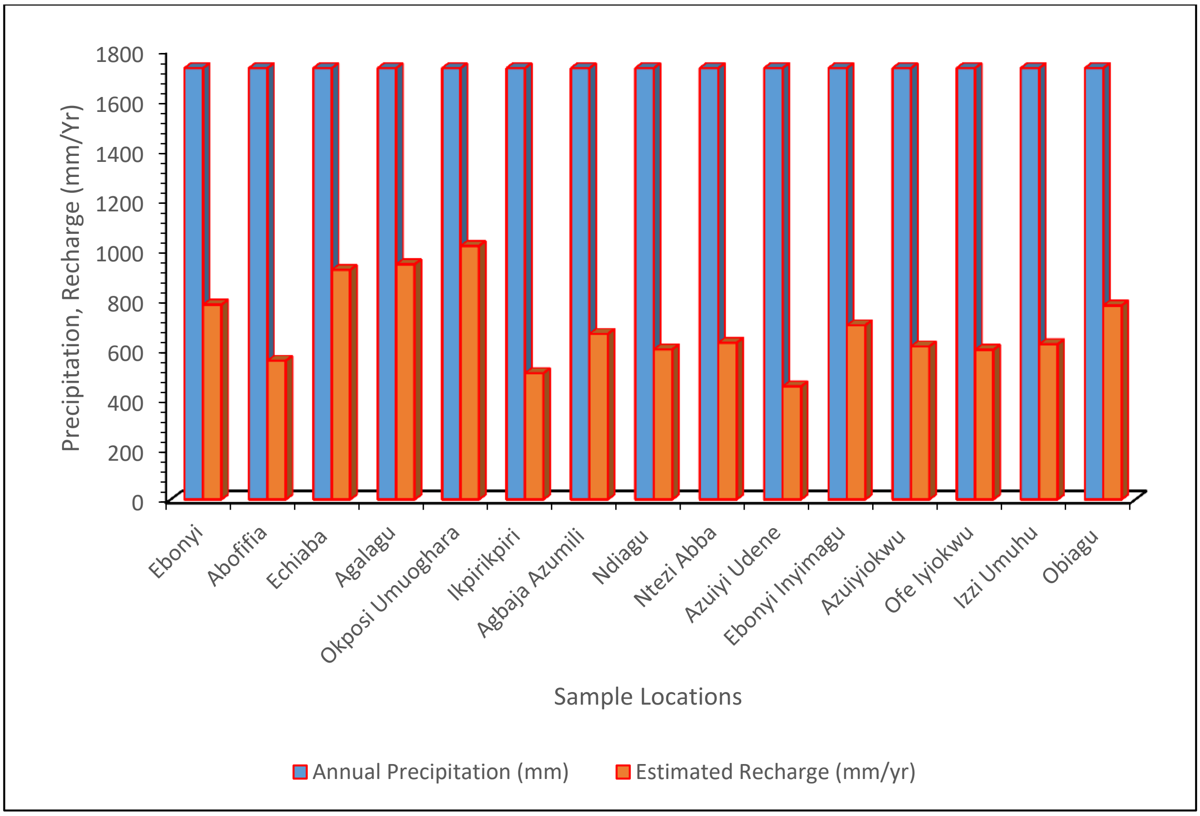

Figure 3. The estimated groundwater recharge using chloride mass balance method

Soil Water Balance Method

The amount of the estimated groundwater recharge is presented in Table 5 below.

Table 5. Estimated groundwater recharge using the soil water balance method.

Water year	Precipitation	Evapotranspiration	Estimated Recharge	% of Recharge
2012	1725.8	252	912.8	9.1
2013	1891	388	819.54	8.2
2014	1737.7	268.9	976.9	9.8
2015	1716.5	283	838	8.4
2016	2084.3	492.5	1065.51	10.7
2017	1891.7	335.1	937.86	9.4
2018	1482.3	316.4	712.37	7.1
2019	1769.7	407.4	720.07	7.2
2020	1669.5	409.9	857.05	8.6
2021	1729.3	433.5	737.66	7.4
Average	**1769.78**	**358.67**	**857.78**	**8.59**

The estimated groundwater recharge was found to be between 712.37 mm and 1065.51 mm with an average of 857.78 mm.

Figure 4 shows the relationship between groundwater recharge, deviation from average precipitation, and deviation from average evapotranspiration. It is seen from the figure that as precipitation increases, recharge increases, and as evapotranspiration increases, recharge decreases. In the year 2018, a decrease in precipitation, but also a decrease in evapotranspiration was seen; however, the estimated recharge increased for that combination. Whereas in 2016, there was an increase in precipitation but evapotranspiration was essentially normal and estimated recharge increased.

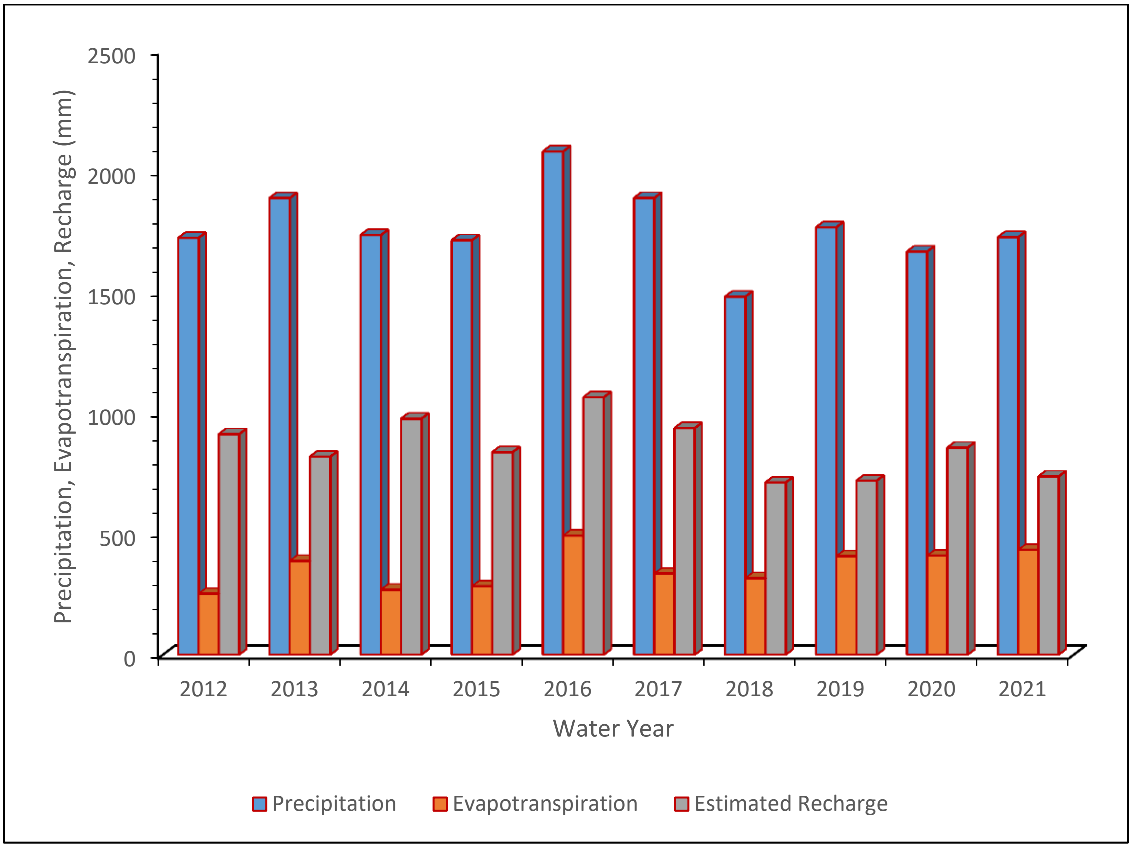

Figure 4. Comparison of the estimated groundwater recharge using soil water method with precipitation and evapotranspiration.

CONCLUSION

Groundwater recharge can be computed using different methods and models depending on the availability of data. In the present study, chloride mass balance and soil water balance equations were used to estimate the quantity of natural groundwater recharge in Abakaliki. The meteorological date (annual precipitation, evapotranspiration and surface runoff) obtained from Nigerian Meteorological Agency (NIMET), Anambra River Basin Development Authority (ARBDA) and Centre for Basic Space Science, University of Nigeria Nsukka (CBSS) were used for the estimation of the groundwater recharge. Findings from the two methods show that annual recharge to the groundwater in Abakaliki is between 6.7 % to 8.59 % of the average annual rainfall of 1769.78 mm. This figure is expected to rise by about 15 % in the future as a result of future climate change in the area.

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