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Quantitative Evaluation of Dynamic Groundwater Resource Potential and Its Stage of Development in the Interfluves of the Rivers Brahmaputra and Kolong, Assam

Satyajit Kataki*

Author's Affiliations:
Associate Professor, Department of Geology, Cotton University, Panbazar, Guwahati, Kamrup (M), Assam 781001, India.

***Corresponding Author Satyajit Kataki**, Associate Professor, Department of Geology, Cotton University, Panbazar, Guwahati, Kamrup (M), Assam 781001, India.

E-mail: satyaccg1@gmail.com

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ABSTRACT

Groundwater is a renewable natural resource and dynamic groundwater resource is the part which is recharged annually and exploited largely. The study area is situated on the southern bank of River Brahmaputra. The main source of groundwater recharge in the area is precipitation. The study is an attempt to evaluate the groundwater dynamic resource potential by quantifying the gross annual natural groundwater recharge and to find out the stage of development of groundwater in the area for a better planning and development. Water table fluctuation method, rainfall infiltration factor method and empirical methods have been applied for the quantitative evaluation of the dynamic groundwater resource potential in the area. A point recharge zone map was prepared in GIS by the interpolation of thirteen years data on average fluctuation values. The result obtained by point recharge zone method using groundwater-level fluctuation & specific yield data gives a more realistic assessment of groundwater recharge, which is found to be 484 MCM. The stage of groundwater development is found to be less than 70% and no long-term decline in groundwater levels has been observed. The study area comes under the safe area category and the groundwater potentiality in the area is found to be very good.

KEYWORDS: *Dynamic Groundwater resource, Evaluation, Interfluves, Kolong, Brahmaputra*

INTRODUCTION

Groundwater is among the Nation's most precious natural resources and tops the list in terms of the quantity being used annually. Groundwater has steadily emerged as the backbone of India's agriculture and drinking water security. Contribution of groundwater is nearly 62% in irrigation, 85% in rural water supply and 45% in urban water supply (CGWB, MoWR, RD & GR, 2019). Moreover, increasing deterioration of surface water quality in different parts of the country has increased the stress on groundwater aquifers as an alternative source resulting indiscriminate extraction ignoring the recharge capacities of the aquifers. The 'National Water Policy (2012) adopted by the Government of India regards water as a scarce natural resource, fundamental to life, livelihood, food security and sustainable development (GEC-2015). The sustainable development of groundwater resource requires precise quantitative assessment based on reasonably valid scientific principles (GEC-2009). As in March, 2017, the total annual groundwater recharge in India has been estimated as 432 BCM. Keeping an allocation for natural discharge, the annual extractable groundwater resource is 393 BCM. The total current annual groundwater extraction (as in March, 2017) is 249 BCM. The average stage of groundwater extraction for the country as a whole works out to be about 63 % (CGWB, MoWR, RD & GR, 2019

Ground water resources have two components – Replenishable ground water resources or Dynamic ground water resources and In-storage resources or Static resources (GEC-2015). The dynamic groundwater resource is replenished every year mainly through precipitation and other minor sources and forms the exploitable quantity that is available in the zone of water-level fluctuation. It is also termed as annually replenishable groundwater resource. The planning of groundwater development should mainly depend on dynamic groundwater resource only as it gets replenished every year. Therefore, this replenishable part of groundwater can be quantitatively evaluated based on the component of annual recharge; however, the rate of recharge is not the same for all aquifers. Groundwater recharge is defined in a general sense as the downward flow of water reaching the water table, forming an addition to the groundwater reservoir. Groundwater recharge over a certain area is normally considered to be equal to infiltration excess over the same area. The main source of replenishable ground water resources is recharged through rainfall, which contributes to nearly 67% of the total annual ground water recharge (CGWB, MoWR, RD & GR, 2019). Therefore, groundwater is a renewable natural resource and certain amount of storage is replenished every year mainly through precipitation and other minor sources. The withdrawal of groundwater by pumping is the most significant human activity that alters the amount of ground water in storage. Sustainability of groundwater is a function of recharge (Sophocleous and Devlin, 2004). Thus, groundwater recharge in terms of storage change must be quantified for the sustainable development of groundwater resource.

Scope of the Study

Some of the greatest groundwater needs occur in the area and groundwater is the only dependable source of water for many users. The people mainly depend on dug wells and deep tube wells for their day to day use of water. The dynamic groundwater resource in the zone of water-table fluctuation reflects the seasonal recharge and discharge of aquifers. Without recharge, groundwater resources go on depleting. Therefore, the quantitative evaluation of dynamic groundwater resource is a pre-requisite for the development of groundwater resources in the area in an optimal manner. Moreover, data pertaining to the quantification of groundwater is very much essential for planning and implementation of groundwater supply.

Hypotheses

1. Recharge is an important process through which groundwater in aquifers is replenished by precipitation (rain water) moving down through the soil and rock layers of the ground and also by infiltration from surface water sources such as rivers and lakes (GWRPH, 1986; Bhattacharya et al., 2003).
2. Water levels in aquifers reflect a dynamic balance between groundwater recharge, storage, and discharge. Because recharge and discharge are not distributed uniformly in space and time, ground-water levels are continuously rising or falling to adjust to the resulting imbalances. Water levels in wells reflect these changes in recharge and discharge and provide the principal means of tracking changes in groundwater storage over time (Conlon et at., 2005).

Objectives of the Study

The objectives of this study are to –
1. Evaluate the groundwater dynamic resource potential by quantifying the gross annual natural groundwater recharge and,
2. Determine the stage of development of groundwater in the area on the basis of annual gross groundwater draft for all uses, for a better planning and development of groundwater resource in the area.

Background of the Study Area

Geographically the study area is situated on the southern bank of River Brahmaputra and falls between longitudes 91º57'6"E and 93º4'46"E and latitudes 26º9'2"N and 26º37'17"N. The Quaternary Group of sediments represented by unconsolidated alluvium comprises of sands of various grades with minor silt and clay, covers large part of the study area. The older alluvial deposits are compositionally similar to the younger deposits, but are more consolidated and less transmissible. Therefore, older alluvium deposits are considered to be less favourable for groundwater recharge compared to younger alluvium. The Proterozoic group of rocks is confined to the exposures on north-eastern, south-western and western parts of the area. The hills are mainly the continuation of the Meghalaya Plateau and the Mikir Hills. The rocks composed of granites and gneisses are trending NE-SW with moderate dip towards NW. The rocks are weathered to some extent and fissures are found in them. They have a very sharp contact with the surrounding unconsolidated formations. These residual hills occupy an area of about 34 sq. km. This unit represents a high runoff zone that contributes significantly to groundwater recharge in the plains. Precipitation is the main source of groundwater recharge in the area. In a major part of the study area, groundwater-level fluctuations are found in the range of 1.5 m to 2 m. However, in north-eastern part of the area and in the southern part along the Kolong River, groundwater-level fluctuations have been found above 2 m. The general direction of groundwater flow in the study area is from north-eastern part towards the central part and finally towards the river Brahmaputra in the north. The water table conforms to the general topography of the area (Kataki, 2020).

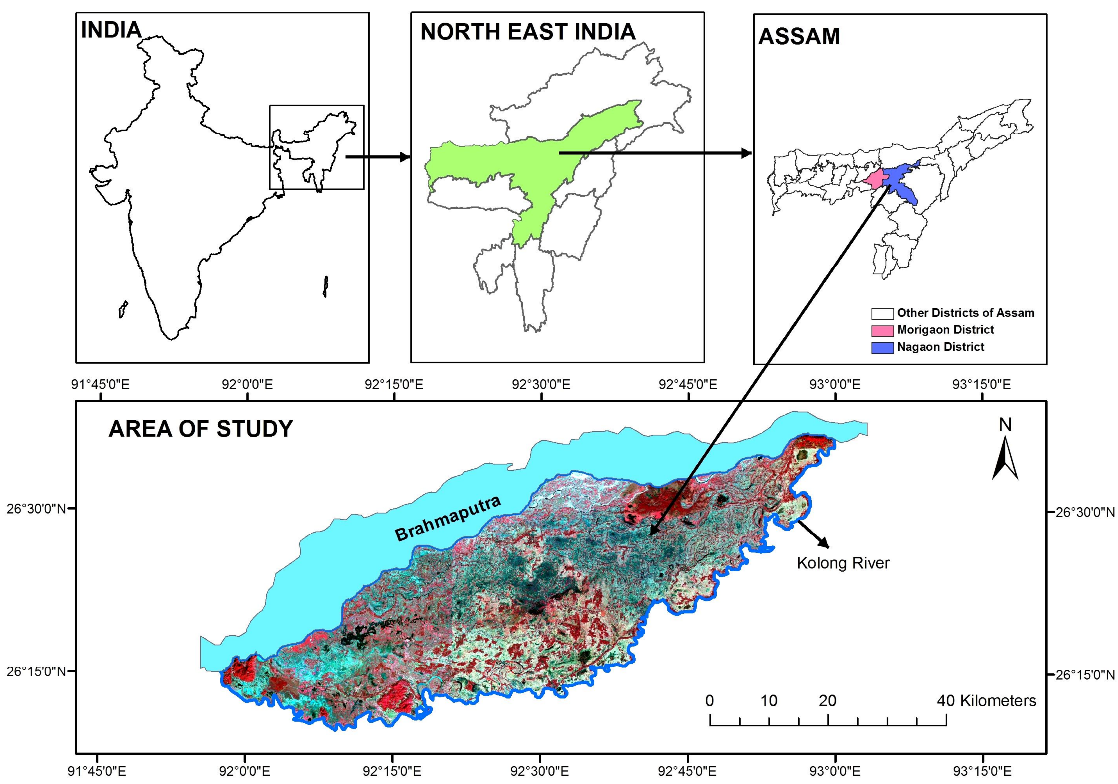

Figure 1: Location map of the study area

LITERATURE REVIEW

The literatures on previous work about the hydrogeological studies in the study area are very scanty. However, hydrogeology and ground water potentiality of the region had been discussed in the publication of Central Ground Water Board, NER, Guwahati in "Hydrogeology of Assam and Scope for Ground Water Development", Technical Report Series: D, 2009 (CGWB, NER, 2009). The Groundwater Estimation Committee (GEC) has recommended several methodologies for estimation of groundwater resource potential in India. As per the recommendation of groundwater estimation committee, groundwater recharge estimation should be done by using groundwater-level fluctuation and specific yield method. However, in areas, where requisite data on long-term groundwater-level monitoring is not available, rainfall infiltration factor method may be used as an alternative for the estimation of groundwater estimation. The revised methodology (GEC-2015) recommends estimation of replenishable and in-storage ground water resources for both unconfined and confined aquifers. Wherever the aquifer geometry has not been firmly established for the unconfined aquifer, the in-storage ground water resources have to be assessed in the alluvial areas up to the depth of bed rock or 300 m, whichever is less.

Thenmozhi and Mayilswami (2015) had estimated the annual groundwater recharge in Vadachitur watershed, Parambikulam-Aliyar-Palar basin, Coimbatore district of Tamil Nadu state, by using water table fluctuation method and empirical methods. They also made a comparison between these two methods (Thenmozhi and Mayilswami, 2015). Kumar and Seethapathi (2002) had conducted a detailed seasonal groundwater balance study in Upper Ganga Canal command area for the period 1972-73 to 1983-84 to determine groundwater recharge from rainfall. Based on the water level fluctuations and rainfall amounts in Ganga-Yamuna doab, Chaturvedi in 1936, derived an empirical relationship to arrive at the recharge as a function of annual precipitation. This formula was later modified by further work at the U.P. Irrigation Research Institute, Roorkee (Kumar and Seethapathi, 2002) (https://www.researchgate.net). Mohan and Ramani Bai (2000) carried out a critical study on the different methods of estimating the groundwater potential and compared to arrive at the most suitable technique for practical utility. In their article they discussed the methods of estimation of groundwater recharge on a 250 km long reach of the Vaigai river in southern part of Tamil Nadu. A comparative evaluation was also made on these methods.

METHODOLOGY

No single comprehensive method has yet been developed for the estimation of dynamic groundwater resource potential accurately. The Groundwater Resource Estimation Committee (GEC) has recommended several methodologies for the estimation of groundwater resource potential in India. In the present study, following are the three methodologies applied for the quantitative evaluation of the dynamic groundwater resource potential in the area-

Groundwater Level Fluctuation and Specific Yield Method

The major components required for this method are the data on changes in groundwater levels over time and, specific yield value of the aquifer material. In order to evaluate the annual groundwater recharge in the study area, thirteen-year data (2001 to 2013) on water level fluctuations between pre- and post-monsoon periods (i.e. net rise) of 12 nos. of key wells of CGWB, are used (Table 1). A point recharge zone map was prepared in GIS by the interpolation of this thirteen years data on average fluctuation values. This map was then reclassified into 6 different point recharge zones at an interval of 0.5 m and the average fluctuation value of each point recharge zone was taken for the determination of point recharge value. The annual groundwater recharge was calculated from different point recharge zones on the basis of the net rise of groundwater levels in each key well in the area. The area of influence of each well as a whole has been considered as the effective area of point recharge zone. The point recharge value for each point recharge zone was determined by multiplying the average water level fluctuation value of each point recharge zone with the corresponding specific yield value. The average fluctuations of groundwater level (2001-2013) in the area are graphically presented in Figure 2 and the point recharge zone map prepared by using these average groundwater fluctuations is presented in Figure 3.

The specific yield (*Sy*) of a rock or soil, with respect to water, is the ratio of the volume of water which, after being saturated, it will yield by gravity to its own volume (Meinzer, 1959). As the actual value of Sy for the aquifer depends on several factors, the Specific yield value has been taken from the specific yield test carried out by CGWB, under the World Bank project on the shallow tube wells and considered the specific yield value 12% for the alluvial tract and 2% for the hilly tract underlain by weathered granite rocks (CGWB, 1997). This point recharge value was then multiplied by the corresponding area of each point recharge zone to get the value of groundwater recharge of each point recharge zone. The summation of groundwater recharges of all the six-point recharge zones gives the gross groundwater recharge of the area.

Table 1: Groundwater Level Fluctuation in the Study Area (2001 - 2013) Source: CGWB

Sl. No.	NHN Station (Well No.)	Latitude / Longitude	Average Fluctuation (m)
1	Silghat (83B2D6)	26.60323 / 92.92654	3.83
2	Sulung (83B3D8)	26.57917 / 92.88055	3.25
3	Rangagora (83B3D1)	26.47083 / 92.87611	2.57
4	Samuguri (83B3D7)	26.4080 / 92.8290	1.74
5	Bebejia (83B3C7)	26.30225 / 92.62643	1.46
6	Bordowa (83B3C2)	26.37674 / 92.59601	1.23
7	Dhing (83B3D6)	26.43467 / 92.52429	2.31
8	Moirabari (83B3B3)	26.45435 / 92.42199	1.61
9	Morigaon (83B3B10)	26.25723 / 92.34467	1.15
10	Baghara (83B4B2)	26.22668 / 92.27586	2.44
11	Nasatra (83B4A5)	26.2250 / 92.2170	1.15
12	Pobitora	26.23354 / 92.03499	1.95

Rainfall Infiltration Factor Method

Rainfall is the major source of recharge to groundwater. Rainfall infiltration factor method may be adopted in those areas where monitoring of groundwater level is not sufficient enough in space and time. Estimation of groundwater recharge by rainfall infiltration factor method is done by the following formula –

R_{rf} = A x Normal rainfall x f ------------- (1)

Where,
R_{rf} = rainfall recharge
A = Area of computation for recharge
f = Rainfall Infiltration Factor

It has been recommended that 10% of normal annual rainfall should be taken as minimum rainfall threshold and 3000 mm can be taken as maximum rainfall. To compute the recharge from rainfall, 10% of the normal annual rainfall should be deducted from the rainfall of monsoon season and the balance rainfall should be considered for estimation of recharge from rainfall. Same recharge factor may be taken for monsoon and non-monsoon seasons. If normal rainfall during the non-monsoon season is less than 10% of normal annual rainfall, then recharge due to non-monsoon rainfall may be taken as zero (Kumar et al., 2019). For the present study, the Rainfall Infiltration factor for the estimation of rainfall recharge has been taken from the norms suggested and recommended by GEC 1997 & 2015. Therefore, the recharge estimation has been determined separately for alluvial areas and residual hill areas. Rainfall data from the year 2001 to 2011 of three rain gauge stations were procured from Regional Meteorological Centre, Guwahati.

Empirical Methods

Based on the studies undertaken by different scientists and organisations regarding correlation of ground water level fluctuation and rainfall, some empirical relationships have been derived for computation of natural recharge to ground water from rainfall (Kumar and Seethapathi, 2002). One such relationship used for the present study is as follows:

(a) Chaturvedi formula: Chaturvedi (1973) derived an empirical relationship based on the groundwater-level fluctuations and rainfall amounts in Ganga Yamuna doab, to arrive at the amount of rainfall that penetrates the ground when rainfall exceeds 15.7 inch.

$$Rp = 2.0\,(P - 15)^{0.4} \qquad \text{------------------ (2)}$$

where,
Rp = annual rainfall penetration (i.e., recharge) in inches
P = Annual precipitation, in inches.

b) The Chaturvedi's formula was later modified by further work at the U. P. Irrigation Research Institute, Roorkee, (Kumar, 1977; Chandra, 1979) and the modified form of the formula is,

$$Rp = 1.35\,(P - 14)^{0.5} \qquad \text{------------------ (3)}$$

The Chaturvedi formula has been widely used for preliminary estimations of groundwater recharge due to rainfall. It may be noted that there is a lower limit of the rainfall below which the recharge due to rainfall is zero. The percentage of rainfall recharged commences from zero at P = 14 inches, increases up to 18% at P = 28 inches, and again decreases. The lower limit of rainfall in the formula may account for the soil moisture deficit, the interception losses and potential evaporation. These factors being site specific, one generalized formula may not be applicable to all the alluvial areas (Kumar and Seethapathi, 2002).

The stage of development of groundwater resource in the area was computed on the basis of annual gross groundwater draft as follows-

$$\frac{\text{Existing gross groundwater draft for 'All Uses'}}{\text{Net annual ground water availability}} \times 100 \qquad \text{----------------- (4)}$$

RESULTS AND DISCUSSIONS

Quantitative evaluation by Groundwater-level Fluctuation and Specific Yield Method:

Quantitative evaluation by Groundwater-level fluctuation and specific yield method was carried out on the basis of point recharge value of each key well. From the spatial database of point recharge, it has been observed that point recharge is the maximum (0.44 m) within the >3.5 m zone in the northeastern part of the area near Silghat, which receives the maximum amount of rainfall throughout the year. This is followed by the point recharge zone 3 m -- 3.5 m, where point recharge value is 0.39 m. In this area most of the tributaries and distributaries of the River Brahmaputra are originating and form the major recharge zones in the whole study area. Point recharge value is found to be minimum (0.16 m) in <1.5 m zone in the southern part of the area along the river Kolong. The maximum areal extent of point recharge zone belongs to 1.5 m - 2 m zone category with the net rise of water level being 1.75 m and the minimum areal extent belongs to the more than 3.5 m zone category with a net rise of water level of 3.67 m. The 1.5 m -- 2 m point recharge zone is a comparatively low-lying area which occupies around 62% of the total study area. But due to the large areal extent this zone accounts the maximum groundwater recharge in terms of volume.

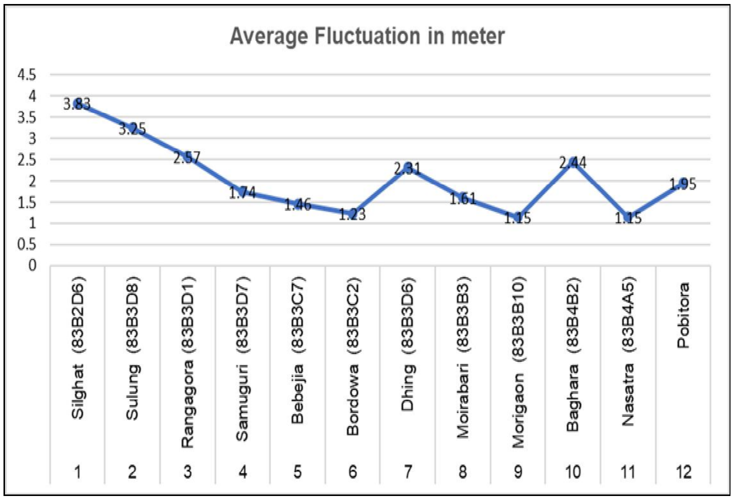

Figure 2: Average fluctuations of groundwater levels of 12 nos. key wells in the study area (2001-2013)

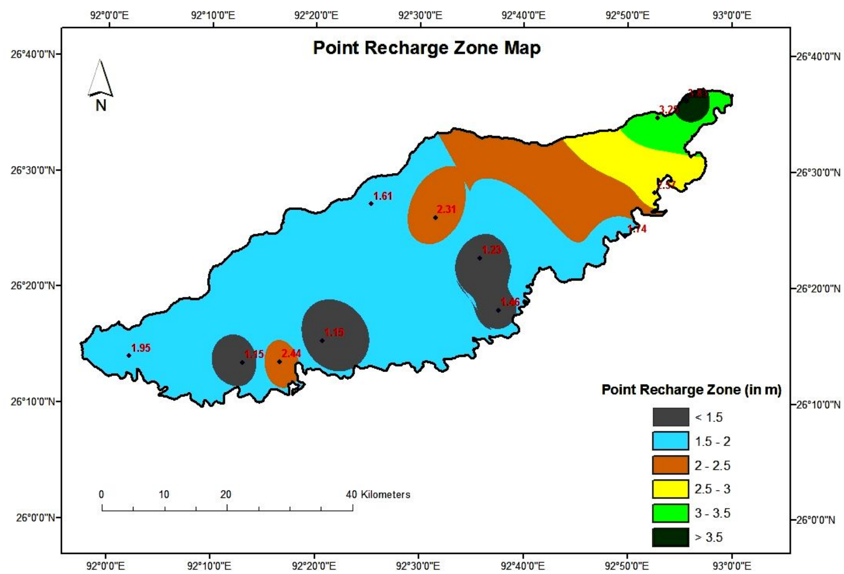

Figure 3: Point Recharge Zone Map of the Study Area

Table 2: Estimation of Gross Recharge by Point Recharge Zone Method

Point recharge zones (1)	**GW level fluctuation (m) (2)**	**Specific yield (3)**	**Point recharge value (m) (4) = (2)x(3)**	**Area (km²) (5)**	**Gross Recharge (MCM) (6) = (4)x(5)**
Less than 1.5 m	1.33	12%	0.16	225	36
1.5 m --- 2 m	1.75	12%	0.21	1295	271.95
2 m --- 2.5 m	2.25	12%	0.27	365	98.55
2.5 m --- 3 m	2.75	12%	0.33	123	40.59
3 m --- 3.5 m	3.25	12%	0.39	71	27.69
More than 3.5 m	3.67	12%	0.44	21	9.24
			Av.=0.30		**Total= 484.02**

The average groundwater point recharge value is found to be 0.30 m (30 cm), and the gross groundwater recharge in the area is found to be 484.02 MCM (Table 2).

Quantitative Evaluation by Rainfall Infiltration Factor Method

Estimation of groundwater recharge by rainfall infiltration factor method in the study area has been carried out by taking the recommended value of rainfall infiltration factor as 22% for alluvial areas and 11% for the hilly areas, which is underlain by hard rocks i.e., weathered granites and gneisses. The normal rainfall data that have been procured from Regional Meteorological Department, Guwahati, gives the normal annual rainfall of the area is 1526.72 mm (1.53 m). For the computation of recharge, 10% (152.67 mm) of the normal annual rainfall has been deducted from the rainfall and the balance rainfall considered for estimation of recharge amounts to 1374.05 mm (1.37 m).

The total alluvial area has been obtained by subtracting the built-up area/settlement area (345.92 sq. km) and the residual hill area (34 sq. km) from the total study area (2100 sq. km) and is found to be 1720.08 sq. km. putting these values in equation 1:

R^{rf} = Groundwater recharge in alluvial areas = 1720.08 sq. km. x 1.37 m x 22% = 518.43 MCM
R^{rf} = Groundwater recharge in residual hill areas **=** 34 sq. km. x 1.37 m x 11% = 5.12 MCM

Total Groundwater Recharge = Groundwater recharge in alluvial areas + Groundwater recharge in residual hill areas = 518.43 MCM + 5.12 MCM = 523.55 MCM

Thus, the total groundwater recharge computed by the rainfall infiltration factor method in the study area is found to be the order of 523.55 MCM.

Quantitative Evaluation by Empirical Method

a) On the basis of the actual rainfall received by the area, the annual ground water recharge has been estimated by the relationship given Chaturvedi (1973). The annual rainfall from the three raingauge stations in the study area is 1844.93 mm (72.64 inches). Putting the values in Eq. 2, the value of Rp is estimated as follows:

$Rp = 2.0\,(72.64 - 15)^{0.4}$
$= 2.0\,(57.64)^{0.4}$
= 10.12 inches = 25.71 cm = 0.26 m

The total areal extent of study area is 2100 sq km, out of which 345.92 sq km (16.47%) is covered by settlement area (Built up area), and 34 sq.km. (1.62%) is covered by hard rocks where rainfall penetration is considered to be negligible. Hence the total effective area through which rainfall penetration takes place is found to be 1720.13 sq.km.

The total groundwater Recharge = Rp x Effective area
= (0.26 m x 1720.08 sq. km) x 10^6 cubic meter
= 447.22 MCM

b) Putting the values in Eq. 3, the modified Chaturvedi's formula, Rp is estimated as follows-
$Rp = 1.35\,(P-14)^{0.5}$
$= 1.35\,(58.64)^{0.5}$
= 10.34 inches
= 26.26 cm
= 0.26 m

Total groundwater recharge = (0.26 m x 1720.08 sq.km) x 10^6 cubic meter = 447.22 MCM

The annual groundwater recharge estimated by using these two empirical methods give the same amount of recharge which is found to be 447.22 MCM.

The results of the gross annual natural groundwater recharge evaluated by the three methods are presented in Table 3.

Table 3: Summarized quantitative results of gross annual natural groundwater recharge

Methodology	Annual Recharge (MCM)
i) Groundwater Level Fluctuation & Specific Yield Method (on the basis of Point Recharge Value)-	484.02
ii) Rainfall Infiltration Factor Method-	523.55
iii) Empirical Methods – a) Chaturvedi Formula- b) Chaturvedi Formula (Modified form) -	 447.22 447.22

Groundwater Development in the Study Area

The groundwater development in the study area has been assessed by considering the gross groundwater recharge of the area, 484.02 MCM found by computing the point recharge method i.e., groundwater level fluctuation and specific yield method. The base flow in rivers is a regenerated ground water resource and is sometimes committed for lift irrigation schemes and other surface irrigation works. It is, therefore, recommended that 15% of total ground water resources be kept for committed base flow and to account for the irrecoverable losses. The remaining 85% of the gross resource is the net utilizable groundwater resource (GEC-2009).

Therefore,

The net utilizable groundwater resource = Total gross resource - 15% of the gross resource

= (484.02 – 72.60) MCM = 411.42 MCM

Groundwater Draft

The existing groundwater draft in the area has been computed from the number of groundwater structures tapping the shallow zone and their average annual draft. Among the shallow groundwater structures are: dug wells mostly used for drinking and domestic purposes, shallow tube wells, hand pumps and Tara pumps used for irrigation as well as drinking purposes and the irrigation wells used specifically for irrigation purpose only. The position of the irrigation and domestic water supply in the area is as given in Table 4. The total annual groundwater draft from the 7652 nos. of existing groundwater structures has been found to be 251.90 MCM (Table 4).

Table 4: Details of Groundwater Draft in the study area (Source: CGWB, 2009)

Sl. No.	Type of Groundwater Structure	No. of existing wells	Average Rate of Discharges from Groundwater Structure	No. of Drafting hours in a Year	Draft per well per year (MCM)	Annual Water Draft (MCM)
1	Dug well	830	--	--	0.002	1.66
2	PHE Tube well	388	30 m^3 / hr	1600	0.048	18.62
3	STW (under State irrigation Scheme)	284	30 m^3 / hr	1200	0.036	10.22
4	No. of irrigation wells funded by other User Agencies	6150	30 m^3 / hr	1200	0.036	221.4
	Total	7652				251.90

Stage of Groundwater Development

The net utilizable groundwater resource in the study area is found to be 411.42 MCM and the annual groundwater draft computed from the total number of existing groundwater structures tapping the shallow aquifer zone is found to be 251.90 MCM. Thus, the stage of groundwater development in the study area is 61.23%.

CONCLUSIONS

The groundwater recharge obtained by the infiltration factor method is on the higher side of the recharge estimated by groundwater level fluctuation & specific yield method (difference is +39.53 MCM) while the recharge estimated by the empirical methods are on the lower side (difference is -36.80 MCM). Both the differences found to be less than 10% while comparing with groundwater level fluctuation method. As the groundwater level fluctuation & specific yield method gives a more realistic assessment of groundwater recharge to an area, the result obtained by this method which is intermediate between the other two results, i.e. 484 MCM, may be justly taken as the annual groundwater recharge in the area under study.

The stage of groundwater development in the area is found to be 61.23%, which is less than 70% and no long-term decline in groundwater levels has been observed. Thus, the study area comes under the safe area category. The pre- and post-monsoon water levels show a fairly stable trend, which indicates that there is a balance between recharge, draft and natural discharge in the unit. Therefore, it can be concluded that the groundwater potentiality in the area is very good with a scope for further groundwater development.

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REFERENCES

1. Bhattacharya, S. K., Froehlich, K., Aggarwal, P. K., and Kulkarni, K. M., 2003. Isotopic variation in Indian monsoon precipitation: Records from Bombay and New Delhi. Geophysical Research Letters 30, 2285– 2288.
2. Central Ground Water Board (2019). National Compilation on Dynamic Ground Water Resources of India, 2017. Government of India, Ministry of Jal Shakti, Department of Water Resources, RD & GR, Central Ground Water Board, Faridabad.
3. Central Ground Water Board, (2009**).** Hydrogeology of Assam and Scope for Ground Water Development. Technical Report Series: D. Central Ground Water Board, NER, Ministry of Water Resources, Government of India.
4. Central Ground Water Board, (1997). Hydrogeology and Ground Water Conditions in Nagaon District, Assam. Technical Series D No.35, Central Ground Water Board, NER, Ministry of Water Resources, Government of India.
5. Chandra, S., (1979). Estimation and measurement of recharge to groundwater from Rainfall, Irrigation and Influent Seepage, Proc. of Inter. Seminar on Development and Management of Groundwater Resources, Univ. of Roorkee, India, pp. III 9 - III 17.
6. Chaturvedi, R. S., (1973). A Note on the Investigation of Ground Water Resources in Western Districts of Uttar Pradesh, Annual Report, U. P. Irrigation Research Institute, pp. 86-122.
7. Conlon, T. D., Wozniak, K. C., Woodcock, D., Herrera, N. B., Fisher, B. J., Morgan, D. S., Lee, K. K. and Hinkle, S. R., (2005). Ground-water Hydrology of the Williamette Basin, Oregon. Scientific Investigations Report, 2005-5168, U. S. Geological Survey.
8. GEC-2015; Ground Water Resource Estimation Committee, 2015. Methodology: Ministry of Water Resources, River Development & Ganga Rejuvenation Government of India, New Delhi October, 2017, 137 p.

9. GEC-2009; Ground Water Resource Estimation Committee, 2009. Ground Water Resource Estimation Methodology: Ministry of Water Resources, Government of India, New Delhi, 107 p.
10. GEC-1997; Groundwater Water Resource Estimation Committee, 1997. Ground Water Resource Estimation Methodology: Ministry of Water Resources, Government of India, New Delhi, 219 p.
11. Ground Water Resource Protection Handbook (GWRPH), (1986). Basic ground water hydrology. Washington State, Department of Ecology.
12. Kataki, S., (2020). Delineation of Aquifer Zones in the Interfluves of the Rivers Brahmaputra and Kolong, Assam. Bulletin of Pure and Applied Sciences; Vol. 39F, Geology, No. 1, January-June 2020: P. 32-46, P: ISSN No. 0970-4639; E: ISSN: 2320-3234.
13. Kumar, C. P., Krishan, G. and Verma, S. K., (2019). Norms for Groundwater Resource Estimation in India; International Journal of Engineering Technologies and Management Research, vol. 6 (1), ISSN: 2454-1907 PP.17-31.
14. Kumar, C. P., (2012). Assessment of Groundwater Potential; The International Journal of Engineering and Science (IJES); Vol: 1; Issue 1; ISSN: 2319 – 1813 ISBN: 2319 – 1805; PP. 64-79.
15. Kumar, C. P. and Seethapathi, P. V., (2002). Assessment of Natural Ground Water Recharge in Upper Ganga Canal Command Area.
16. Kumar C. P., (1977). Estimation of Natural Ground Water Recharge. ISH Journal of Hydraulic Engineering, Vol.3, No.1, pp. 61-74.
17. Meinzer, O. E., (1959). The Occurrence of Groundwater in the United States, with a Discussion of Principles. U. S. Geological Survey Water-Supply Paper 489, 321p. https: / / link.springer.com / article / 10.1007 / s10040-020-02152-8
18. Mohan, S. and Ramani Bai, V. (2000). Groundwater Potential Estimation - A Comparative Analysis Section-7: Ground Water and Hydrogeology; Lake 2000.
19. Sophocleous M, and Devlin JF, (2004). Is natural recharge relevant to groundwater sustainable development? Letter to the Editor, Ground Water. 2004; 42:618.
20. Taylor Charles J. and alley, William M., (2001). Ground-Water-Level Monitoring and the Importance of Long-Term Water-Level Data; U. S. Geological Survey Circular 1217; Denver, Colorado 2001.
21. Thenmozhi, M. and Mayilswami, C., (2015). Estimation and Comparison of Groundwater Recharge by Using Water Table Fluctuation Method and Empirical Formulae in Vadachithur Watershed of Parambikulam-Aliyar-Palar (PAP) Basin; Trends in Biosciences 8 (22), Print: ISSN 0974-8431, 6306-6312, 2015, 2015.