DYNAMIC GROUNDWATER RESOURCES OF THE STATE OF TAMIL NADU (2020)

Prepared by

Government of Tamilnadu

State Ground and Surface Water Resources Data Centre

Public Works Department (WRD)

&

Government of India

Ministry of Jal Shakti

Central Ground Water Board

South Eastern Coastal Region

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FOREWARD

Estimation of Dynamic Groundwater Resources is a prerequisite for planning of groundwater development in an area. This report is on the Dynamic Groundwater Resource Estimation (2020) for the state of Tamilnadu. Dynamic Groundwater Resources pertain to the part of resources, which get replenished every year due to rainfall, applied irrigation water and seepage from surface water bodies. The computation involves balancing of recharge and discharge components, using water level fluctuations observed in the observation wells. The methodology adopted for the estimation is the on the lines of Groundwater Estimation Committee (GEC-15 methodology).

Recharge components include recharge from rainfall, canal, tanks, applied irrigation water & water conservation structures, while the discharge components include groundwater draft and base flow. Recharge & Discharge components have been estimated separately for Monsoon & Non monsoon period.

The estimation exercise is a joint effort of State Ground & Surface Water Resources Data Centre (SG&SWRDC), PWD, WRO, Government of Tamil Nadu & Central Ground Water Board, South Eastern Coastal Region, Ministry of Water Resources, Government of India through INGRES software designed by IITH & Vassar Lab Ltd. Hyderabad. The computed results have been validated with the filed situations so as to ensure that the results match the field situations.

The report elaborates the GEC-2015 methodology, data considered and the results of the estimation. An attempt has been made to furnish the results of the study in a more lucid manner and it is fondly hoped that the planners, managers of the precious groundwater would find the report useful in planning the sustainable development strategies of the region.

Dr. S. Subramaniam
Head of the Office

CHAPTER I

BACKGROUND

1.0 BACKGROUND FOR RE-ESTIMATING THE GROUND WATER RESOURCES OF THE STATE OF TAMIL NADU.

Quantification of the Ground Water recharge is essential for efficient Ground Water resources development. To achieve the above objective based on GEC-15 methodology, the dynamic Ground Water resources of State of Tamil Nadu, using the Firka as the assessing unit were estimate**d** with regard to ground water potential and extraction. In order to locate the favourable pockets within the administrative Blocks and also for effective implementation of various Plans/Schemes by the District Administration of the State and by the availability of easy segregation of Land Use and Agricultural Statistical Records in the State it was decided to take up the Resource Estimation for the year 2020 on basis of Revenue Firka villages of Tamil Nadu Accordingly, the 1166 Revenue Firkas belongs to 37 Districts was taken as assessment units and dynamic groundwater resources estimation as on March 2020 was carried out for the state of Tamilnadu with 2017-2020 as the resource year.

1.1 CONSTITUTION OF STATE LEVEL COMMITTEE AND STATE LEVEL WORKING GROUP COMMITTEE FOR GROUND WATER RESOURCES ESTIMATION

To review the present Ground Water resources estimation based on GEC-15 Norms, the parameters used for estimation, availability of site specific parameters for each hydrological situation and the need to collect data etc. and suggest suitable modifications, the Government of Tamil Nadu ordered the constitution of State level Committee.

The State Level Committee with Secretary, Public works Department as the Chairman of the committee and other members as given;

1	Principal Secretary to Government	Public Works Department	Chairman
2.	Additional Chief Secretary to Government	Finance Department	Member
2	Additional Chief Secretary to Government	Municipal Administration & Water Supply Department	Member
3	Principal Secretary to Government	Agriculture Department	Member
4	Principal Secretary to Government	Industries Department	Member
6	Chairman	Cauvery Technical Cell-Cum-Inter State Waters wing	Member

7	Principal Secretary to Government	Finance Department	Member
8	Chairman and Managing Director	SIPCOT	Member
9	Chairman	Tamil Nadu Pollution Control Board	Member
10	Engineering-in Chief, Water Resources Department	Public Works Department	Member
11	Regional Director	Central Ground Water Board, Chennai	Member
12	Head of Department of Civil Engineering	IIT, Chennai	Member
13	Head of Department-Geology	Anna University, Chennai	Member
14	Director	Department of Economics & Statics	Member
15	General Manager	NABARD	Member
16	Chief Engineer	Institute of Water Studies, Hydrology and Quality Control	Member
17	Engineering Director	TWAD Board	Member
18	Director	Agriculture Department	Member
19	Chief Engineer	Agricultural Engineering Department	Member
20	Chief Engineer	State Ground & Surface Water Resources Data Centre	Member Secretary
21	Special Invitees (if necessary)	-	Member

Chapter – 2

HYDROGEOLOGICAL CONDITION OF TAMIL NADU STATE

2.1 DESCRIPTION OF ROCK TYPES WITH AREA COVERAGE

Tamil Nadu State is underlain with various geological formations ranging in age from Archaean to Recent. The crystalline rocks of Archaean age like granites gneisses, charnockites etc., are of considerable interest as they occupy nearly 73% of the total geographical area of the State. Semi consolidated and consolidated formations ranging in age from Mesozoic to Recent, overlie the crystalline basement and their occurrence is confined to the east coast only. The general stratigraphic succession of the formations in the State is presented in Table-1

Table-1 :Stratigraphic Succession of Geological Formations in Tamil Nadu.

Era	Age	Stage	Lithology
Quaternary	Recent to Sub-recent	-	Soil, alluvium and beach sands Boulder, conglomerates, older alluvium and laterites.
Tertiary	Pliocene	Karaikal beds	Sands and clay with fossils
	Miocene	Cuddalore Sandstone	Mottled and friable sandstones, buff coloured clays and gravels.
Unconformity			
	Cretaceous	Ninniyur	Arenaceous limestones and sandstones.
		Ariyalur	Sandstones and clays
		Trichirapalli	Sandstones, clays and shell limestones
		Uttattur	Basal limestones, coral clays and sandy beds
	Jurassic	Satyavedu	Ferruginous sandstones and conglomerates
		Sriperumbudur	Clays, shales and feldspathic sandstones
Unconformity			
	Archaean	Archaean	Gneisses, charnockites and ultrabasic intrusives.

The crystalline complex of the Archaean age forms the oldest of the rock types in the state. Pink and grey granites are exposed in Cuddalore, Villupuram, Coimbatore, Madurai and Tirunelveli districts. Metasediments of the Khondalite group are well exposed in the southern districts of Tamil Nadu and are widely noticed in Kanyakumari, Tirunelveli, Coimbatore and Madurai districts. The ultramatic rocks are widespread in the districts of Vellore, Dharmapuri, Coimabatore and Salem. The widely exposed charnockite is more prominent in the northwestern part of Tamil Nadu, which is well exposed in the hill ranges of Javadi, Shevroy, Palani and Nilgiris.

The Mesozoic era is represented by the upper Gondwanas of Jurassic age and marine beds of Cretaceous age. The Gondwana beds occur as patches spread over in certain parts of Tiruvallur, Kancheepuram, and Vellore Districts. The cretaceous beds are well exposed in Tiruchirapalli Dist. The cretaceous beds overlie the granitic gneisses and charnockites along the western fringe and by alluvium in the north. They are also exposed at Viruddhachalam area of Cuddalore District.

The important Tertiary formations in the State include the cuddalore sandstones and Conjeevaram gravels. They occur in a wide stretch and extend from Karaikudi through Pudukkottai, Thanjavur, Cuddalore to Chennai. They are overlain by Alluvium and coastal sands in the coastal tract and in river valleys. The Panamparai sandstones of sub-recent age occur along the coastal tract of Tirunelveli District.

2.2 HYDROMETEOROLOGY - CLIMATE, RAINFALL DISTRIBUTION.

Generally sub tropical climate prevails throughout the State and there is no variation in climate. The temperature slowly raises to its maximum in summer up to May and from June shows the general decline. The maximum temperature ranges from 37°C to 44°C and the minimum temperature varies from 12° C to 17° C. During May (summer) the average relative humidity varies from 40% to 70 % and during October (winter) the average relative humidity varies from 60% to 85%.

The State receives rainfall during Southwest and Northeast monsoon. The intensity of rainfall is high during north east monsoon, moderate during south west monsoon and low during transitional period. The annual rainfall recorded from minimum 400 mm to maximum 1300 mm and the average annual rainfall is 925 mm based on 70 years rainfall.

Rainfall is the major source for Ground Water recharge and the rainfall pattern has got an important role on the water levels in the phreatic aquifer. There are three rainfall seasons in the state viz., i) South west monsoon ii) North east monsoon iii) Transitional dry season. The transitional dry season stretches from January to May and the state receives scanty rainfall. Southwest monsoon is expected between June and September. During the assessment year, the rainfall with high intensity has been observed in the Districts of Nilgiris, parts of Cuddalore, Kanyakumari, part of villupuram and Tiruvallur. The northeast monsoon from October to December is closely associated with seasonal depressions in the Bay of Bengal.

2.3 DESCRIPTION OF HYDROGEOLOGICAL UNITS, AQUIFER PARAMETERS.

The Geological set up, topography rainfall and drainage etc. are the main criteria for the occurrence of Ground Water. The occurrence of Ground Water is controlled by factors like geological conditions of the terrain and the hydrological parameters prevailing in a year. In hard rock terrain the occurrence of Ground Water is limited to top weathered, fissured and fractured zone which extends to maximum 30m on an average it is about 10-15m in Tamil Nadu. The sedimentary area which occupies the eastern part of the State along the coastal tract is relatively favorable. Ground Water occurs both in water table conditions and also in semi confined and confined conditions.

In the hard rock formations the yield of the open wells vary from 30 to 250 m^3/day and in bore well the yield varies between 260 to 430 m^3/day. In the sedimentary formation the yield of the well varies from 200 to 650 m^3/day.

HARD ROCK TERRAIN

- Ground Water occurs under the phreatic condition and wherever there is deep seated fractures, it occurs under semi-confined to confined conditions.
- Occurrence of Ground Water in hard rock depends upon the intensity and depth of weathering, fractures and fissures present in the rocks.
- Granites and gneisses yield moderately compared to the yield in Charnockites.
- Depth of well in hard rock generally ranges between 8 and 15m below ground level.
- Generally yield in open wells ranges from 30 to 250m^3/day and in bore well between 260 and 430 m^3/day.
- The weathered thickness varies from 2.5 m to 42m in general there are 3 to 5 fracture zones within 100 m and 1 to 4 fracture zones between 100 and 200 m. A few fracture zone are also encountered in highly tectonically disturbed areas of Salem, Namakkal, Coimbatore beyond 200 m down to 350 m bgl.
- The average aquifer parameters are given in the table below

1.	Coefficient of Transmissivity (T)	< 01 to 375 m^2/day
2.	Coefficient of storage (S)	2.6 x 10^{-6} to 3.6 x 10^{-2}
3.	Specific capacity	0.265 to 1316 lps/m of dd.
4.	Draw down	0.33 to 6.55 m
5.	Discharge	< 01 to 29.58 lps.

SEDIMENTARY TERRAIN

- Upper Gondwana formation covers about 1.90% of area (2626 sq.km.) of this State which do not contribute much to Ground Water because of its low transmissivity and compact nature.
- Ground Water occurs mostly in phreatic conditions
- The average aquifer parameters are given in table below

1.	Coefficient of Transmissibility (T)	2.0 to 870 m^2/day
2.	Coefficient of storage (S)	2.9 x 10^{-4} to 3.6 x 10^{-3}
3.	Specific capacity	5.7 to 322 lps/m of dd.
4.	Draw down	0.22 to 67 m
5.	Discharge	1 to 32.78 lps.

- Cretaceous formation occupies about 1.16% (about 1515 sq.km.) of this State, forms moderate source for Ground Water.
- Ground Water occurs under phreatic, semi-confined and confined conditions.
- The average aquifer parameters of the cretaceous terrain are given below

1.	Coefficient of Transmissibility (T)	295 to 540 m^2/day
2.	Coefficient of storage (S)	1.77 x 10^{-3} to 2.4 x 10^{-2}
3.	Specific capacity	3.6 to 217.24 lps/m of dd.
4.	Draw down	7.56 to 32.57 m
5.	Discharge	3.08 to 3.34 lps.

- The Tertiary - Cuddalore sand stone formation covers about 6.92% (8546 sq.km) of this State and forms potential source for Ground Water.
- They are highly permeable, confined aquifers and occur under aretesian/sub-aretesian conditions.
- The average aquifer characteristics of the tertiary sandstone are given below

1.	Coefficient of Transmissibility (T)	30 to 8492 m^2/day
2.	Coefficient of storage (S)	7.74 x 10^{-6} to 2.575 x 10^{-1}
3.	Specific capacity	5.22 to 1892 lps/m of dd.
4.	Draw down	0.26 to 23.45 m
5.	Discharge	3.0 to 68.9 lps.

- The Sub-Recent to Recent-Alluvium covers about 16.92% (i.e. about 22,018 sq.km.) of this State, apart from the river alluvium of Palar, Ponnaiyar, Kusasthalayar, Cauvery and Tamiraparani, above the river courses.
- Ground Water is found to occur in confined/semi-confined or water table conditions.
- The average aquifer characteristics of alluvium are given below

1.	Coefficient of Transmissibility (T)	7 to 4180 m^2/day
2.	Coefficient of storage (S)	1.2 x 10^{-3} to 7.55 x 10^{-4}
3.	Specific capacity	6.9 to 942 lps/m of dd.
4.	Draw down	2.4 to 24 m
5.	Discharge	1.0 to 39 lps.

2.4 GROUND WATER LEVEL CONDITIONS

The water level is being monitored by State Ground & Surface Water Resources Data Centre from 1971 onwards from a network of 1746 observation wells (shallow open wells) located all over the State. The water level readings are observed the first week of every month. The Central Ground Water Board also monitors the water level from 900 numbers of wells spread all over the State. They observe water level four times in a year. (i.e January, May, August and November). In addition to this, a network of observation wells has been increased under the Hydrology Project both in hard rock and sedimentary area. Totally 852 piezometers has been established all over the State The water level collected from these network of observation wells and piezometers are uploaded in GWDES software and database is being uploaded regularly. During the assessment year, additional 1580 wells are added for monitoring network and included for Resource Estimation computations.

The long term fluctuations of water levels have been studied. The minimum range of water level is 3 to 4 mts in many parts of the State. The analysis of water level reveals that the water level has gone down in the western and central parts of the State. The inference taken from the annual fluctuation is that the rainfall greatly affect the groundwater levels in phreatic aquifer. The seasonal fluctuation study reveals that due to necessity for development of ground water for drinking purpose and due to failure of monsoons, the water level has gone down.

2.5 GROUND WATER QUALITY

The rainfall is the main source for the availability of water both in surface and sub surface. The quantum of rainfall varies every year depending upon the monsoon. However the extraction of surface and sub surface water is increasing year by year. It leads to environmental impact on the water sources like depletion of water level, deterioration of water quality. It necessitates as the quantification of available water and also its quality for specific purposes like agriculture, industries, drinking and domestic purposes.

For the present assessment, the value of Total Dissolved Solids (TDS) has been considered for demarcation of good / bad quality areas. For this purpose, the TDS value of less than or equal to 3000 mg/l have been considered as good quality and the value more than 3000 mg/l have been considered as bad quality areas.

The presence of fluoride in natural Ground Water is having its merits and demerits depending upon the concentration. Presence of fluoride <1.0 mg/l in drinking water reduces dental diseases whereas higher level > 1.50 mg/l will affect the health and causes dental fluorosis. A part of Dharmapuri, Krishnagiri, Salem, Namakkal, Trichy and Madurai have fluoride above the prescribed limit. Nitrate is noted significantly in Ground Water due to use of chemical fertilizer for agriculture and other local pollution rocks and soils are also contributing nitrate to Ground Water. Arsenic is another poisonous heavy metal in Ground Water. The allowable limits for drinking purposes are 0.05 mg/l. In Tamil Nadu the Ground Water is not having the excess arsenic both in the shallow dug well and bore well.

2.6 AREA HAVING GROUND WATER DEVELOPMENT PROSPECTS.

The Firkas categorized as Safe and Semi-critical can be considered for further development. However, locating favorable site for digging dugwell and drilling bore/tubewells depend on hydrogeological conditions and scientific methods may be employed for locating the exact sites. The State of Tamil Nadu is characterized by varied hydrogeological environment. Nearly 73% of the State is underlain by hard rocks and the rest of the State is underlain by semi consolidated formations like Gondwana, cretaceous sediments, tertiary and unconsolidated deposits like recent alluvium. The hard rocks are seen in the districts of western parts of the State. The jointed and fractured forms a good ground water development zone. The sedimentary formations generally occur on the eastern portion along the coastal tracts of the State. They vary in age from Jurassic to recent and are generally suitable for ground water development in view of the high primary porosity and permeability. Further along the flood plains (alluvium formations) of the major rivers, canal command forms a good ground water development zones in the State of Tamil Nadu.

Chapter-III

3.0 GROUND WATER RESOURCES ESTIMATION METHODOLOGY

Ground water resource as in 2020 have been estimated following the guidelines mentioned in the GEC 2015 methodology using appropriate assumptions depending on data availability. The principal attributes of GEC 2015 methodology is given below:

The methodology recommends aquifer wise ground water resource assessment of both the Groundwater resources components, i.e., Replenishable ground water resources or Dynamic Ground Water Resources and In-storage Resources or Static Resources. 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 down to the depth of bed rock or 300 m, whichever is less. In caseof hard rock aquifers, the depth of assessment would be limited to 100 m. In case of confined aquifers, if it is known that groundwater extraction is being done from this aquifer, the dynamic as well as in-storage resources are to be estimated. If it is firmly established that there is no ground water extraction from this confined aquifer, then only in-storage resources of that aquifer has to be estimated. Until aquifer geometry is established on appropriate scale, the existing practice of using watershed in hard rock areas and blocks/mandals/ firkas in soft rock areas may be continued.

It is also pertinent to add that as it is advisable to restrict the groundwater development as far as possible to annual replenishable resources, the categorization also takes into account the relation between the annual replenishment and groundwater development. An area devoid of ground water potential may not be considered for development and may remain safe whereas an area with good groundwater potential may be developed and may become over exploited over a period of time. Thus, water augmentation efforts can be successful in such areas, where the groundwater potential is high and there is scope for augmentation.

3.1. GROUND WATER ASSESSMENT OF UNCONFINED AQUIFER

Though the assessment of ground water resources includes assessment of dynamic and in-storage resources, the development planning should mainly focus on dynamic resource as it gets replenishedon an annual basis. Changes in static or in-storage resources normally reflect long-term impacts of ground water mining. Such resources may not be replenishable annually and may be allowed to be extracted only during exigencies with proper planning for augmentationin the succeeding excess rainfall years.

3.1.1. Assessment of Annually Replenishable or Dynamic Ground Water Resources

The methodology for ground water resources estimation is based on the principle of water balance as given below –

$$Inflow - Outflow = Change\ in\ Storage\ (of\ an\ aquifer) \ldots\ldots (1)$$

Equation (1) can be further elaborated as –

$$\Delta S = R_{RF} + R_{STR} + R_C + R_{SWI} + R_{GWI} + R_{TP} + R_{WCS} \pm VF \pm LF - GE - T - E - B \ldots (2)$$

Where,

ΔS	-	Change is storage
R_{RF}	-	Rainfall recharge
R_{STR}	-	Recharge from stream channels
R_C	-	Recharge from canals
R_{SWI}	-	Recharge from surface water irrigation
R_{GWI}	-	Recharge from ground water irrigation
R_{TP}	-	Recharge from Tanks & Ponds
R_{WCS}	-	Recharge from water conservation structures
VF	-	Vertical flow across the aquifer system
LF	-	Lateral flow along the aquifer system (through flow)
GE	-	Ground Water Extraction
T	-	Transpiration
E	-	Evaporation
B	-	Base flow

It is preferred that all the components of water balance equation should be estimated in an assessment unit. Due to lack of data for all the components in most of the assessment units, it is proposed that at present the water budget may be restricted to the major components only, taking into consideration certain reasonable assumptions. The estimation is to be carried out using lumped parameter estimation approach keeping in mind that data from many more sources if available may be used for refining the assessment.

3.1.1.1. Rainfall Recharge

It is recommended that ground water recharge should be estimated on ground water level fluctuation and specific yield approach since this method takes into account the response of ground water levels to ground water input and output components. This, however, requires adequately spaced representative water level measurement for a sufficiently long period. It is proposed that there should be at least three spatially well distributed observation wells in the assessment unit, or one observation well per 100 sq. Km. Water level data should also be available for a minimum periodof 5 years (preferably 10years), along with corresponding rainfall data. Regarding frequency of waterlevel data, two water level readings, during pre and post monsoon seasons, are the minimum requirement. It would be ideal to have monthly water level measurements to record the peak rise and maximum fall in the ground water levels. In units or subareas where adequate data on ground water level fluctuations are not available as specified above, ground water recharge may be estimated using rainfall infiltration factor method only. The rainfall recharge during non-monsoon season may be estimated using rainfall infiltration factor method only.

3.1.1.1.1. Ground Water Level Fluctuation Method

The ground water level fluctuation method is to be used for assessment of rainfall recharge in the monsoon season. The ground water balance equation in non-command areas is given by

$$\Delta S = R_{RF} + R_{STR} + R_{SWI} + R_{GWI} + R_{TP} + R_{WCS} \pm VF \pm LF - GE - T - E - B \text{....(3)}$$

Where,

ΔS - Change is storageR_{RF} - Rainfall recharge
R_{STR} - Recharge from stream channels
R_{SWI} - Recharge from surface water irrigation
R_{GWI} - Recharge from ground water irrigation
R_{TP} - Recharge from Tanks& Ponds
R_{WCS}- Recharge from water conservation structures
VF - Vertical flow across the aquifer system
LF - Lateral flow along the aquifer system (through flow)
GE - Ground water extraction
T - Transpiration
E - Evaporation
B - Base flow

Whereas the water balance equation in command area will have another term i.e., Recharge due tocanals (R_C) and the equation will be as follows:

$$\Delta S = RRF + RSTR + RC + RSWI + RGWI + RTP + RWCS \pm VF \pm LF - GE - T - E - B \text{..... (4)}$$

A couple of important observations in the context of water level measurement must be followed. It is important to bear in mind that while estimating the quantum of ground water extraction, the depth from which ground water is being extracted should be considered. One should consider only the draft from the same aquifer for which the resource is being estimated.

The change in storage can be estimated using the following equation:

$$\Delta S = \Delta h \times A \times S_Y \text{............ (5)}$$

Where, ΔS - Change is storage
Δh - rise in water level in the monsoon seasonA - Area for computation of recharge
S_Y - Specific Yield

Substituting the expression in equation (5) for storage increase ΔS in terms of water level fluctuationand specific yield, the equations (3) & (4) becomes (6) & (7) for non-command and command sub- units,

$$R_{RF} = \Delta h \times A \times S_Y - R_{STR} - R_{SWI} - R_{GWI} - R_{TP} - R_{WCS} \pm VF \pm LF + GE + T + E + B \text{..........(6)}$$

$$R_{RF} = \Delta h \times A \times S_Y - R_{STR} - R_C - R_{SWI} - R_{GWI} - R_{TP} - R_{WCS} \pm VF \pm LF + GE + T + E + B \text{....(7)}$$

Where base flow/ recharge to/from streams have not been estimated, the same is assumed to be zero. The rainfall recharge obtained by using equation (6) and (7) provides the recharge in any particular monsoon season for the associated monsoon season rainfall. This estimate is to be normalized for the normal monsoon season rainfall as per the procedure indicated below.

Normalization of Rainfall Recharge

Let R_i be the rainfall recharge and r_i be the associated rainfall. The subscript "i" takes values 1 to N where N is the number of years for which data is available. This should be at least 5. The rainfall recharge, R_i is obtained as per equation (6) & equation (7) depending on the sub-unit for which the normalization is being done.

After the pairs of data on R_i and r_i have been obtained as described above, a normalisation procedure is to be carried out for obtaining the rainfall recharge corresponding to the normal monsoon season rainfall. Let r(normal) be the normal monsoon season rainfall obtained as the average of recent 30 to 50 years of monsoon season rainfall. Two methods are possible for the normalisation procedure. The first method is based on a linear relationship between recharge and rainfall of the form

$$R = ar \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..\ldots\ldots\ldots.(8)$$

Where,

R = Rainfall recharge during monsoon season

r = Monsoon season rainfall

a = a constant

The computational procedure to be followed in the first method is as given below:

$$R_{RF}(normal) = \frac{\sum_{i=1}^{N} [R_i \frac{r(normal)}{r_i}]}{N} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..\ldots\ldots\ldots\ldots..(9)$$

Where,

R_{RF}(normal) - Normalized Rainfall Recharge in the monsoon season

R_i - Rainfall Recharge in the monsoon season for the i^{th} year

r(normal) - Normal monsoon season rainfall

r_i - Rainfall in the monsoon season for the i^{th} year

N - No. of years for which data is available

The second method is also based on a linear relation between recharge and rainfall. However, thislinear relationship is of the form,

$$R_{RF}(normal) = a \times r(normal) + b \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (10)$$

Where,

R_{RF}(normal) - Normalized Rainfall Recharge in the monsoon season
r(normal) - Normal monsoon season rainfall
a and b - constants.

The two constants 'a' and 'b' in the above equation are obtained through a linear regression analysis. The computational procedure to be followed in the second method is as given below:

$$a = \frac{NS_4 - S_1S_2}{NS_3 - S^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (11)$$

Where,

$$b = \frac{S_2 - aS_1}{N} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (12)$$

$$S_1 = \sum_{i=1}^{N} r_i \;,\; S_2 = \sum_{i=1}^{N} R_i \;,\; S_3 = \sum_{i=1}^{N} r_i^2 \;,\; S_4 = \sum_{i=1}^{N} R_i r_i$$

3.1.1.1.2. Rainfall Infiltration Factor Method

The rainfall recharge estimation based on Water level fluctuation method reflects actual field conditions since it takes into account the response of ground water level. However the ground waterextraction estimation included in the computation of rainfall recharge using water level fluctuation approach is often subject to uncertainties. Therefore, it is recommended to compare the rainfall recharge obtained from water level fluctuation approach with that estimated using rainfall infiltration factor method. Recharge from rainfall is estimated by using the following relationship –

$$R_{RF} = RFIF \times A \times \frac{(R - a)}{1000} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (13)$$

Where,

R_{RF} - Rainfall recharge in
hamA - Area in hectares
RFIF - Rainfall Infiltration
FactorR - Rainfall in mm

a - Minimum threshold value above which rainfall induces ground water recharge in mm

The threshold limit of minimum and maximum rainfall event which can induce recharge to the aquifer is to be considered while estimating ground water recharge using rainfall infiltration factor method. The minimum threshold limit is in accordance with the relation shown in equation (13) and the maximum threshold limit is based on the premise that after a certain limit, the rate of storm rain is too high to contribute to infiltration and they will only contribute to surface runoff. It is suggested that 10% of Normal annual rainfall may be taken as minimum rainfall threshold and 3000 mm as maximum rainfall limit. While computing the rainfall recharge, 10% of the normal annual rainfall is tobe deducted from the monsoon rainfall and balance rainfall would be considered for computation of rainfall recharge. The same recharge factor may be used for both monsoon and non-monsoon rainfall, with the condition that the recharge due to non-monsoon rainfall may be taken as zero, if the normal rainfall during the non-monsoon season is less than 10% of normal annual rainfall. In using the method based on the specified norms, recharge due to both monsoon and non-monsoon rainfall may be estimated for normal rainfall, based on recent 30 to 50 years of data.

3.1.1.1.3. Percent Deviation

After computing the rainfall recharge for normal monsoon season rainfall using the ground water level fluctuation method and rainfall infiltration factor method these two estimates have to be compared with each other. A term, Percent Deviation (PD) which is the difference between the two expressed as a percentage of the later is computed as

$$PD = \frac{R_{RF}(normal, \mathrm{w}tfm) - R_{RF}(normal, rifm)}{R_{RF}\ (normal, rifm)} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (14)$$

R_{RF} (normal, wlfm) = Rainfall recharge for normal monsoon season rainfall estimated bythe ground water level fluctuation method

R_{RF} (normal, rifm) = Rainfall recharge for normal monsoon season rainfall estimated by the rainfall infiltration factor method

The rainfall recharge for normal monsoon season rainfall is finally adopted as per the criteria givenbelow:

- If PD is greater than or equal to -20%, and less than or equal to +20%, R_{RF} (normal) is takenas the value estimated by the ground water level fluctuation method.
- If PD is less than -20%, R_{RF} (normal) is taken as equal to 0.8 times the value estimated by therainfall infiltration factor method.
- If PD is greater than +20%, R_{RF} (normal) is taken as equal to 1.2 times the value estimated bythe rainfall infiltration factor method.

3.1.1.2. Recharge from Other Sources

Recharge from other sources constitutes recharges from canals, surface water irrigation, ground water irrigation, tanks & ponds and water conservation structures in command areas where as in non-command areas it constitutes the recharge due to surface water irrigation, ground water irrigation, tanks & ponds and water conservation structures. The methods of estimation of recharge from different sources are as follows.

Sl. No.	Source	Estimation Formula	Parameters
1	Recharge fromCanals	$RC = \mathrm{WA} \times SF \times Days$	R_C = Recharge from CanalsWA = Wetted Area SF = Seepage Factor Days = Number of Canal Running Days
2	Recharge from Surface Water Irrigation	$RSWI = AD \times Days \times RFF$	R_{SWI} = Recharge due to applied surface waterirrigation AD = Average Discharge Days = Number of days water is discharged tothe Fields RFF = Return Flow Factor
3	Recharge from Ground Water Irrigation	$RGWI = GEIRR \times RFF$	R_{GWI} = Recharge due to applied ground waterirrigation GE_{IRR} = Ground Water Extraction for IrrigationRFF = Return Flow Factor

Sl. No.	Source	Estimation Formula	Parameters
4	Recharge dueto Tanks & Ponds	$R_{TP} = AWSA \times N \times RF$	R_{TP} = Recharge due to Tanks & PondsAWSA = Average Water Spread Area N = Number of days Water is available in theTank/Pond RF = Recharge Factor
5	Recharge dueto Water ConservationStructures	$R_{WCS} = GS \times RF$	RWCS = Recharge due to Water ConservationStructures GS = Gross Storage = Storage Capacitymultiplied by number of fillings. RF = Recharge Factor

3.1.1.3. Lateral Flow Along the Aquifer System (Through Flow)

In equations 6 & 7, if the area under consideration is a watershed, the lateral flow across boundaries can be considered as zero in case such estimates are not available. If there is inflow and outflow across the boundary, theoretically, the net inflow may be calculated using Darcy law, by delineating the inflow and outflow sections of the boundary. Besides such delineation, the calculation also requires estimate of transmissivity and hydraulic gradient across the inflow and outflow sections. These calculations are most conveniently done in a computer model. It is recommended to initiate regional scale modelling with well-defined flow boundaries. Once the modelling is complete, the lateral throughflows (LF) across boundaries for any assessment unit can be obtained from the model.In case Lateral Flow is calculated using computer model, the same should be included in the water balance equation.

3.1.1.4. Base Flow and Stream Recharge

If stream gauge stations are located in the assessment unit, the base flow and recharge from streams can be computed using Stream Hydrograph Separation method, Numerical Modelling and Analytical solutions. If the assessment unit is a watershed, a single stream monitoring station at the mouth of the watershed can provide the required data for the calculation of base flow. Any other information on local-level base flows such as those collected by research centres, educational institutes or NGOs may also be used to improve the estimates on base flows.

Base flow separation methods can be divided into two main types: non-tracer-based and tracer- based separation methods. Non-tracer methods include Stream hydrograph analysis, water balance method and numerical ground water modelling techniques. Digital filters are available for separatingbase flow component of the stream hydrograph.

Hydro-chemical tracers and environmental isotope methods also use hydrograph separation techniques based on mass balance approach. Stream recharge can be computed either using modelling techniques or simply by applying the Darcy Law.

Base flow assessment and Stream recharge should be carried out in consultation with Central Water Commission in order to avoid any duplicity in the estimation of total water availability in a river basin.

3.1.1.5. Vertical Inter Aquifer Flow

This can be estimated provided aquifer geometry and aquifer parameters are known. This can be calculated using the Darcy's law if the hydraulic heads in both aquifers and the hydraulic conductivity and thickness of the aquitard separating both the aquifers are known. Ground water flow modelling is an important tool to estimate such flows. As envisaged in this report regional scale modelling studies will help in refining vertical inter aquifer flow estimates.

3.1.1.6. Evaporation and Transpiration

Evaporation can be estimated for the aquifer in the assessment unit if water levels in the aquifer are within the capillary zone. It is recommended to compute the evaporation through field studies. If field studies are not possible, for areas with water levels within 1.0mbgl, evaporation can be estimated using the evaporation rates available for other adjoining areas. If depth to water level is more than 1.0mbgl, the evaporation losses from the aquifer should be taken as zero.

Transpiration through vegetation can be estimated if water levels in the aquifer are within the maximum root zone of the local vegetation. It is recommended to compute the transpiration through field studies. Even though it varies from place to place depending on type of soil &vegetation, in the absence of field studies the following estimation can be followed. If water levels are within 3.5m bgl, transpiration can be estimated using the transpiration rates available for other areas. If it is greater than3.5m bgl, the transpiration should be taken as zero.

For estimating evapotranspiration, field tools like Lysimeters can be used to estimate actual evapotranspiration. Usually agricultural universities and IMD carry out lysimeter experiments and archive the evapotranspiration data. Remote sensing based techniques like SEBAL (Surface Energy Balance Algorithm for Land) can be used for estimation of actual evapotranspiration. Assessing offices may apply available lysimeter data or other techniques for estimation of evapotranspiration. In case where such data is not available, evapotranspiration losses can be empirically estimated fromPET data provided by IMD.

3.1.1.7. Recharge During Monsoon Season

The sum of normalized monsoon rainfall recharge and the recharge from other sources and lateral and vertical flows into & out of the sub unit and stream inflows & outflows during monsoon seasonis the total recharge/ accumulation during monsoon season for the sub unit. Similarly, this is to be computed for all the sub units available in the assessment unit.

3.1.1.8. Recharge During Non-Monsoon Season

The rainfall recharge during non-monsoon season is estimated using rainfall infiltration factor Method only when the non-monsoon season rainfall is more than 10% of normal annual rainfall. Thesum of non-monsoon rainfall recharge and the recharge from other sources and lateral and vertical flows into & out of the sub unit and stream inflows & outflows during non-monsoon season is the total recharge/ accumulation during non-monsoon season for the sub unit. Similarly, this is to be computed for all the sub units available in the assessment unit.

3.1.1.9. Total Annual Ground Water Recharge

The sum of the recharge/ accumulations during monsoon and non-monsoon seasons is the total annual ground water recharge/ accumulations for the sub unit. Similarly, this is to be computed for all the sub units available in the assessment unit.

3.1.1.10. Annual Extractable Ground Water Resource (EGR)

The Annual Extractable Ground Water Resource (EGR) is computed by deducting the Total Annual Natural Discharge from Total Annual Ground Water Recharge.

The ground water base flow contribution limited to the ecological flow of the river should be determined which will be deducted from Annual Ground Water Recharge to determine Annual Extractable Ground Water Resources (EGR). The ecological flows of the rivers are to be determinedin consultation with Central Water Commission and other concerned river basin agencies. In case base flow contribution to the ecological flow of rivers is not determined then following assumptionis to be followed.

In the water level fluctuation method, a significant portion of base flow is already accounted for by taking the post monsoon water level one month after the end of rainfall. The base flow in the remaining non-monsoon period is likely to be small, especially in hard rock areas. In the assessment units, where river stage data are not available and neither the detailed data for quantitative assessment of the natural discharge are available, present practice (GEC 1997) of allocation of unaccountable natural discharges to 5% or 10% of annual recharge may be retained. If the rainfall recharge is assessed using water level fluctuation method this will be 5% of the annual recharge and if it is assessed using rainfall infiltration factor method, it will be 10% of the annual recharge. The balance will account for Annual Extractable Ground Water Resources (EGR).

3.1.1.11. Estimation of Ground Water Extraction

Ground water draft or extraction is to be assessed as follows.

$$GE_{ALL} = GE_{IRR} + GE_{DOM} + GE_{IND} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (15)$$

Where,

GE_{ALL} = Ground water extraction for all uses
GE_{IRR} = Ground water extraction for irrigation
GE_{DOM} = Ground water extraction for domestic uses
GE_{IND} = Ground water extraction for industrial uses

The methods for estimation of ground water extraction are as follows.

Unit Draft Method: – In this method, season-wise unit draft of each type of well in an assessment unit is estimated. The unit draft of different types (eg. Dug well, Dug cum bore well, shallow tube well, deep tube well, bore well etc.) is multiplied with the number of wells of that particular type to obtain season-wise ground water extraction by that particular structure.

Crop Water Requirement Method: – For each crop, the season-wise net irrigation water requirement is determined. This is then multiplied with the area irrigated by ground water abstraction structures. The database on crop area is obtained from Revenue records in Tehsil office, Agriculture Census and also by using Remote Sensing techniques.

Power Consumption Method: –Ground water extraction for unit power consumption (electric) is determined. Extraction per unit power consumption is then multiplied with number of units ofpower consumed for agricultural pump sets to obtain total ground water extraction for irrigation.

3.1.1.11.1. Ground Water Extraction for Domestic Use (GE_{DOM})

There are several methods for estimation of extraction for domestic use(GEDOM). Some of the commonly adopted methods are described here.

Unit Draft Method: – In this method, unit draft of each type of well is multiplied by the number of wells used for domestic purpose to obtain the domestic ground water extraction.

Consumptive Use Method: – In this method, population is multiplied with per capita consumption usually expressed in litre per capita per day (lpcd). It can be expressed using following equation.

$$GE_{DOM} = Population \times Consumptive\ Requirement \times L_g \ldots\ldots\ldots\ldots\ldots\ldots \mathbf{(16)}$$

Where,

L_g = Fractional Load on Ground Water for Domestic Water Supply.

The Load on Ground water can be obtained from the Information based on Civic water supply agencies in urban areas.

3.1.1.11.2. Ground Water Extraction for Industrial Use (GE_{IND})

The commonly adopted methods for estimating the extraction for industrial use are as below:

Unit Draft Method: - In this method, unit draft of each type of well is multiplied by the number of wells used for industrial purpose to obtain the industrial ground water extraction.

***Consumptive Use Pattern Method:* –** In this method, water consumption of different industrial units is determined. Numbers of Industrial units which are dependent on ground water are multiplied with unit water consumption to obtain ground water extraction for industrial use.

$$GEIND = Number\ of\ Industrial\ Units \times Unit\ Water\ Consumption \times Lg \ldots(17)$$

Where,

L_g = Fractional load on ground water for industrial water supply.

The load on ground water for industrial water supply can be obtained from water supply agencies in the Industrial belt.

Ground water extraction obtained from different methods need to be compared and based on field checks, the seemingly best value may be adopted. At times, ground water extraction obtained by different methods may vary widely. In such cases, the value matching the field situation should be considered. The storage depletion during a season, where other recharges are negligible can betaken as ground water extraction during that particular period.

3.1.1.12. Stage of Ground Water Extraction

The stage of ground water extraction is defined by,

$$Stage\ of\ GW\ Extraction = \frac{Existing\ Gross\ GW\ Extraction\ for\ all\ Uses}{Annual\ Extractable\ GW\ Resources} \times 100 \ldots(18)$$

The existing gross ground water extraction for all uses refers to the total of existing gross ground water extraction for irrigation and all other purposes. The stage of ground water extraction shouldbe obtained separately for command areas, non-command areas and poor ground water quality areas.

3.1.1.13. Validation of Stage of Ground Water Extraction

The assessment based on the stage of ground water extraction has inherent uncertainties. In view ofthis, it is desirable to validate the ‘Stage of Ground Water Extraction’ with long term trend of ground water levels.

Long term Water Level trends are prepared for a minimum period of 10 years for both pre-monsoon and post-monsoon period. If the ground water resource assessment and the trend of long term water levels contradict each other, this anomalous situation requires a review of the ground water resource computation, as well as the reliability of water level data. The mismatch conditions are enumerated below.

SOGWE	Ground Water Level Trend	Remarks
≤ 70%	Significant decline in trend in both pre-monsoon and post-monsoon	Not acceptable and needs reassessment
> 100%	No significant decline in both pre-monsoon and post-monsoon long term trend	Not acceptable and needs reassessment

3.1.1.14. Categorisation of Assessment Unit

As emphasised in the National Water Policy, 2012, a convergence of Quantity and Quality of ground water resources is required while assessing the ground water status in an assessment unit. Therefore, it is recommended to separate estimation of resources where water quality is beyond permissible limits for the parameter salinity.

3.1.1.14.1. Categorisation of Assessment Unit Based on Quantity

The categorisation based on status of ground water quantity is defined by Stage of Ground Water Extraction as given below:

Stage of Ground Water Extraction	Category
≤ 70%	Safe
> 70% and ≤90%	Semi-critical
> 90% and ≤100%	Critical
> 100%	Over Exploited

3.1.1.14.2. Categorisation of Assessment Unit Based on Quality

As it is not possible to categorize the assessment units in terms of the extent of quality hazard, basedon the available water quality monitoring mechanism and database on ground water quality, the Committee recommends that each assessment unit, in addition to the Quantity based categorization (safe, semi-critical, critical and over-exploited) should bear a quality hazard identifier. If any of the three quality hazards in terms of Arsenic, Fluoride and Salinity are encountered in the assessment sub unit in mappable units, the assessment sub unit may be tagged with the particular Quality hazard.

3.1.1.15. Allocation of Ground Water Resource for Utilisation

The Annual Extractable Ground Water Resources are to be apportioned between domestic, industrial and irrigation uses. Among these, as per the National Water Policy, requirement for domestic water supply is to be accorded priority. This requirement has to be based on population as projected to the year 2025, per capita requirement of water for domestic use, and relative load on ground water for urban and rural water supply. In situations where adequate data is not available to make this estimate, the following empirical relation is recommended.

Where, $Alloc$ **= 22 ×** N **×** L_g $mm\ per\ year$ **… … … … … … … … … . … … … … … … … . (19)**

Alloc = Allocation for domestic water requirement
N = population density in the unit in thousands per sq. km.
L_g = fractional load on ground water for domestic water supply (≤ 1.0)

In deriving equation (19), it is assumed that the requirement of water for domestic use is 60 lpd per head. The equation can be suitably modified in case per capita requirement is different. If by chance,the estimation of projected allocation for future domestic needs is less than the current domestic extraction due to any reason, the allocation must be equal to the present day extraction. It cannever be less than the present day extraction as it is unrealistic.

3.1.1.16. Net Annual Ground Water Availability for Future Use

The water available for future use is obtained by deducting the allocation for domestic use and current extraction for Irrigation and Industrial uses from the Annual Extractable Ground Water Recharge. The resulting ground water potential is termed as the net annual ground water availabilityfor future use. The Net annual ground water availability for future use should be calculated separately for non-command areas and command areas. As per the recommendations of the R&D Advisory committee, the ground water available for future use can never be negative. If it becomes negative, the future allocation of Domestic needs can be reduced to current extraction for domestic use. Even then if it is still negative, then the ground water available for future uses will be zero.

3.1.1.17. Additional Potential Resources under Specific Conditions 2.1.1.17.1. Potential Resource Due to Spring Discharge

Spring discharge occurs at the places where ground water level cuts the surface topography. The spring discharge is equal to the ground water recharge minus the outflow through evaporation and evapotranspiration and vertical and lateral sub-surface flow. Thus, Spring Discharge is a form of 'Annual Extractable Ground Water Recharge'. It is a renewable resource, though not to be used for Categorisation. Spring discharge measurement is to be carried out by volumetric measurement of discharge of the springs. Spring discharges multiplied with time in days of each season will give the quantum of spring resources available during that season. The committee recommends that in hilly areas with substantial potential of spring discharges, the discharge measurement should be made at least 4 times a year in parity with the existing water level monitoring schedule.

$$Potential\ ground\ water\ resource\ due\ to\ springs = O \times No.\ of\ days \textbf{..(20)}$$

Where,

Q = Spring Discharge
No of days = No of days spring yields.

3.1.1.17.2. Potential Resource in Waterlogged and Shallow Water Table Areas

In the area where the ground water level is less than 5m below ground level or in waterlogged areas,the resources up to 5m below ground level are potential and would be available for development in addition to the annual recharge in the area. The computation of potential resource to ground water reservoir in shallow water table areas can be done by adopting the following equation:

$$Potential\ ground\ water\ resource\ in\ shallow\ water\ table\ areas = (5 - D) \times A \times SY \ldots (21)$$

Where,

D = Depth to water table below ground surface in pre-monsoon period in shallow aquifers.

A = Area of shallow water table zone.

S_Y = Specific Yield

3.1.1.17.3. Potential Resource in Flood Prone Areas

Ground water recharge from a flood plain is mainly the function of the following parameters-

3.1.1.17.3.1. Areal extent of flood plain

3.1.1.17.3.2. Retention period of flood

3.1.1.17.3.3. Type of sub-soil strata and silt charge in the river water which gets deposited and controlsseepage

Since collection of data on all these factors is time taking and difficult, in the meantime, the potential resource from flood plain may be estimated on the same norms as for ponds, tanks and lakes. This has to be calculated over the water spread area and only for the retention period using the following formula.

$$Potential\ ground\ water\ resource\ in\ Flood\ Prone\ Areas = 1.4 \times N \times \frac{A}{1000} \ldots\ldots\ldots\ldots (22)$$

Where,

N = No. of Days Water is Retained in the AreaA = Flood Prone Area

3.1.1.18. Apportioning of Ground Water Assessment from Watershed to Development Unit

Where the assessment unit is a watershed, there is a need to convert the ground water assessment in terms of an administrative unit such as block/ taluka/ mandal/ firka. This may be done as follows.

A block may comprise of one or more watersheds, in part or full. First, the ground water assessment in the subareas, command, non-command and poor ground water quality areas of the watershed may be converted into depth unit (mm), by dividing the annual recharge by the respective area. The contribution of this subarea of the watershed to the block, is now calculated by multiplying this depth with the area in the block occupied by this sub-area. This procedure must be followed to calculate the contribution from the sub-areas of all watersheds occurring in the block, to work out the total ground water resource of the block.

The total ground water resource of the block should be presented separately for each type of sub- area, namely for command areas, non-command areas and poor ground water quality areas, as inthe case of the individual watersheds.

3.1.2. Assessment of In-Storage Ground Water Resources or Static Ground Water Resources

The computation of the static or in-storage ground water resources may be done after delineating the aquifer thickness and specific yield of the aquifer material. The computations can be done as follows: -

$$SGWR = A \times (Z_2 - Z_1) \times S_Y \quad \text{....................................} (23)$$

Where

,

SGWR = Static or in-storage ground water resources
A = Area of the assessment unit
Z_2= Bottom of unconfined aquifer
Z_1 = Pre-monsoon water level
S_Y = Specific yield in the in-storage zone

3.1.3. Assessment of Total Ground Water Availability in Unconfined Aquifer

The sum of Annual Exploitable Ground Water Resource and the In-storage Ground Water Resources of an unconfined aquifer is the Total Ground Water Availability of that aquifer.

3.2. GROUND WATER ASSESSMENT OF CONFINED AQUIFER SYSTEM

The assessment of the ground water resources of the confined aquifers is done by following ground water storage approach. If the areal extent of the confined aquifer is "A" then the total quantity of water added to or released from the entire aquifer is

$$O = S \times A \times \Delta h \quad \text{..} (24)$$

Where

,

Q = Quantity of water confined aquifer can release (m^3)S = Storativity
A = Areal extent of the confined aquifer (m^2)
Δh = Change in Piezometric head (m)

Once the piezometric head reaches below the top confining bed, it behaves like an unconfined aquifer and directly dewaters the aquifer and there is a possibility of damage to the aquifer as wellas topography. The quantity of water released in confined aquifer due to change in pressure can be computed between piezometric head (ht) at any given time 't' and the bottom of the top confining layer (ho) by using the following equation.

$$Q_P = S \times A \times \Delta h = S \times A \times (h_t - h_0) \qquad (25)$$

Where,

Q_P = Ground Water Potential of Confined Aquifer
S = Storativity
A = Areal extent of the confined aquifer
Δh = Change in Piezometric head
h_t = Piezometric head at any particular time
h_0 = Bottom of the top Confining Layer

If any development activity is started in the confined aquifer, the assessment is done for both thedynamic as well as in-storage resources of the confined aquifer.

3.2.1. Dynamic Ground Water Resources of Confined Aquifer

To assess the dynamic ground water resources of the confined aquifer the following equation can beused with the pre and post monsoon piezometric heads of the particular aquifer.

$$Q_D = S \times A \times \Delta h = S \times A \times (h_{POST} - h_{PRE}) \qquad (26)$$

Where,

Q_D = Dynamic Ground Water Resource of Confined Aquifer (m^3)
S = Storativity
A = Areal extent of the confined aquifer (m^2)
Δh = Change in piezometric head (m)
h_{POST} = Piezometric head during post-monsoon period (m amsl)
h_{PRE} = Piezometric head during pre-monsoon period (m amsl)

3.2.2. In-storage Ground Water Resources of Confined Aquifer

For assessing the in- storage ground water potential of a confined aquifer, one has to compute the resources between the pre-monsoon piezometric head and bottom of the top confining layer. That can be assessed using the following formula:

$$Q_I = S \times A \times \Delta h = S \times A \times (h_{PRE} - h_0) \text{......................................(27)}$$

Where,

Q_I =In-storage Ground Water Resource of Confined Aquifer (m^3)

S = Storativity

A = Areal extent of the confined aquifer (m^2)

Δh = Change in piezometric head (m)

h_0 = Bottom level of the top confining layer (m amsl)

h_{PRE}= Piezometric head during pre-monsoon period (m amsl)

If the confined aquifer is not being exploited for any purpose, the dynamic and static resources of the confined aquifer need not be estimated separately. Instead the in-storage ground water resource of the aquifer can be computed using the following formula.

$$Q_P = S \times A \times \Delta h = S \times A \times (h_{POST} - h_0) \text{..(28)}$$

Where,

Q_P = In-storage Ground Water Resource of Confined Aquifer or the quantity of water underpressure (m^3)

S = Storativity

A = Areal extent of the confined aquifer (m^2)

Δh = Change in piezometric head (m)

h_0 = Bottom level of the top confining layer (m amsl)

h_{POST} = Piezometric head during post-monsoon period (m ams)

The calculated resource includes small amount of dynamic resource of the confined aquifer also, which replenishes every year. But to make it simpler this was also computed as part of the static or in-storage resource of the confined aquifer.

3.2.3. Assessment of Total Ground Water Availability of Confined Aquifer

If the confined aquifer is being exploited, the Total Ground Water Availability of the confined aquiferis the sum of Dynamic Ground Water Resources and the In-storage Ground Water Resources of that confined aquifer whereas if it is not being exploited, the Total Ground Water Availability of the confined aquifer comprises of only one component i.e. the In-storage Ground Water Resources of that confined aquifer.

3.3. GROUND WATER ASSESSMENT OF SEMI-CONFINED AQUIFER SYSTEM

The Assessment of Ground Water Resources of a semi-confined aquifer has some more complications. Unless and until, it is well studied that the recharge to this is not computed either in the over lying unconfined aquifer or underlying/overlying semi confined aquifers, it should not be assessed separately. If it is assessed separately, there is a possibility of duplication of estimating the same resource by direct computation in one aquifer and as leakage in the other aquifer. As it is advisable to under estimate rather than to overestimate the resources, it is recommended not to assess these resources separately as long as there is no study indicating its non-estimation. If it is found through field studies that the resources are not assessed in any of the aquifers in the area, these resources are to be assessed following the methodology similar to that used in assessing the resources of Confined aquifers.

3.4. TOTAL GROUND WATER AVAILABILITY OF AN AREA

The Total Ground Water Availability in any area is the sum of dynamic and static/in-storage ground water resources in the unconfined aquifer and the dynamic and In-storage ground water resources of the Confined aquifers and semi-confined aquifers in the area.

3.5. GROUND WATER ASSESSMENT IN URBAN AREAS

The Assessment of Ground Water Resources in urban areas is similar to that of rural areas. Because of the availability of draft data and slightly different infiltration process and recharge due to other sources, the following few points are to be considered.

- Even though the data on existing ground water abstraction structures are available, accuracyis somewhat doubtful and individuals cannot even enumerate the well census in urban areas. Hence it is recommended to use the difference of the actual demand and the supply by surface water sources as the withdrawal from the ground water resources.

- The urban areas are sometimes concrete jungles and rainfall infiltration is not equal to that of rural areas unless and until special measures are taken in the construction of roads and pavements. Hence, it is proposed to use 30% of the rainfall infiltration factor proposed for urban areas as an adhoc arrangement till field studies in these areas are done and documented field studies are available.

- Because of the water supply schemes, there are many pipelines available in the urban areas and the seepages from these channels or pipes are huge in some areas. Hence this component is also to be included in the other resources and the recharge may be estimated. The percent losses may be collected from the individual water supply agencies, 50% of whichcan be taken as recharge to the ground water system.

- In the urban areas in India, normally, there is no separate channels either open or sub surface for the drainage and flash floods. These channels also recharge to some extent the ground water reservoir. As on today, there is no documented field study to assess the recharge. The seepages from the sewerages, which normally contaminate the ground water resources with nitrate also contribute to the quantity of resources and hence same percent as in the case of water supply pipes may be taken as norm for the recharge on the quantityof sewerage when there is sub surface drainage system. If estimated flash flood data is available the same percent can be used on the quantum of flash floods to estimate the recharge from the flash floods. Even when the drainage system is open channels, till further documented field studies are done same procedure may be followed.

- It is proposed to have a separate ground water assessment for urban areas with population more than 10 lakhs.

3.6. GROUND WATER ASSESSMENT IN COASTAL AREAS

The assessment of ground water resources in coastal areas is similar to that of other areas. Because of the nature of hydraulic equilibrium of ground water with sea water, care should be taken in assessing the ground water resources of this area. While assessing the resources in these areas, following few points are to be considered.

- The ground water resources assessment in coastal areas includes the areas where the influence of sea water has an effect on the existence of fresh water in the area. It can be demarcated from the Coastal Regulatory zone or the Geomorphological maps or from the maps where sea water influences are demarcated.
- Wherever, the pre monsoon and post monsoon water levels are above mean sea level the dynamic component of the estimation will be same as other areas.
- If both these water levels are below sea level, the dynamic component should be taken as zero.
- Wherever, the post monsoon water table is above sea level and pre monsoon water table is below sea level the pre monsoon water table should be taken as at sea level and fluctuation is to be computed.
- The static or in storage resources are to be restricted to the minimum of 40 times the pre monsoon water table or the bottom of the aquifer.

3.7. GROUND WATER ASSESSMENT IN WATER LEVEL DEPLETION ZONES

There may be areas where ground water level shows a decline even in the monsoon season. The reasons for this may be any one of the following: (a) There is a genuine depletion in the ground water regime, with ground water extraction and natural ground water discharge in the monsoon season (outflow from the region and base flow) exceeding the recharge. (b) There may be an error in water level data due to inadequacy of observation wells.

If it is concluded that the water level data is erroneous, recharge assessment may be made based on rainfall infiltration factor method. If, on the other hand, water level data is assessed as reliable, the ground water level fluctuation method may be applied for recharge estimation. As ΔS in equation 3&4 is negative, the estimated recharge will be less than the gross ground water extraction in the monsoon season. It must be noted that this recharge is the gross recharge minus the natural discharges in the monsoon season. The immediate conclusion from such an assessment in water depletion zones will be that the area falls under the over-exploited category which requires micro level study.

3.8. MICRO LEVEL STUDY FOR NOTIFIED AREAS

In all areas which are 'Notified' for ground water regulation by the Central and/ or State Ground Water Authorities, it is necessary to increase the density of observation wells for carrying out micro- level studies to reassess the ground water recharge and draft. Following approach may be adopted:

- The area may be sub-divided into different hydrogeological sub-areas and into rechargearea, discharge area and transition zone and also on quality terms.
- The number of observation wells should be increased to represent each such sub-areas with at least one observation well with continuous monitoring of water levels.
- Hydrological and hydrogeological parameters particularly the specific yield should be collected for different formations in each sub-area.
- Details regarding other parameters like seepage factor from canals and other surface water projects should be collected after field studies, instead of adopting recommended norms. Base flow should be estimated based on stream gauge measurement.
- The data of number of existing structures and unit draft should be reassessed after fresh surveys and should match with the actual irrigation pattern in the sub-area.
- All data available with Central Ground Water Board, State Ground Water Departments and other agencies including research institutions and universities etc. should be collected forthe watershed/sub-areas and utilised for reassessment.
- Ground water assessment for each sub-area may be computed adopting the recommended methodology and freshly collected values of different parameters. The assessment may be made separately for monsoon and non-monsoon period as well as for command, non-command and poor ground water quality areas.
- The ground water potential so worked out may be cross-checked with behaviour of ground water levels in the observation wells and both should match. If it does not, the factor that causes such an anomaly should be identified and the revised assessment should be re- examined.
- Based on the micro-level studies, the sub-areas within the unit and the unit as a whole may be classified adopting norms for categorisation as recommended elsewhere in the methodology.

3.9. NORMS TO BE USED IN THE ASSESSMENT

The committee recommends that the state agencies should be encouraged to conduct field studies and use these computed norms in the assessment. For conducting field studies, it is recommended to follow the field-tested procedures for computing the norms. There is the possibility of error creeping in at various levels in the field study and hence the committee is of the opinion to give a maximum and minimum values for all the norms used in the estimation. The committee can foresee the handicap of the state agencies which are not able to compute the norms by their own field study. In such cases, it suggests an average of the range of norms to be used as the recommended value for the norm.

3.9.1. Specific Yield

Recently under Aquifer Mapping Project, Central Ground Water Board has classified all the aquifers into 16 Principal Aquifers which in turn were divided into 42 Major Aquifers. Hence, it is required to assign Specific Yield values to all these aquifer units. The values recommended in the **Table 2.1** may be followed in the future assessments. The Major aquifer map can be obtained from Regional officesof Central Ground Water Board.

The recommended Specific Yield values are to be used for assessment, unless sufficient data based on field studies are available to justify the minimum, maximum or other intermediate values. The Norms suggested below are nothing but the redistribution of norms suggested by GEC-1997 methodology and hence people are encouraged to conduct field studies and strengthen the Norms database.

Table 3.1: Norms Recommended for Specific Yield

Sl. No.	Principal Aquifer	Major Aquifers		Age	Recommended (%)	Minimum (%)	Maximum (%)
		Code	Name				
1	Alluvium	AL01	Younger Alluvium (Clay/Silt/Sand/ Calcareousconcretions)	Quaternary	10	8	12
2	Alluvium	AL02	Pebble / Gravel/ Bazada/ Kandi	Quaternary	16	12	20
3	Alluvium	AL03	Older Alluvium (Silt/Sand/Gravel/Lithomargic clay)	Quaternary	6	4	8
4	Alluvium	AL04	Aeolian Alluvium (Silt/ Sand)	Quaternary	16	12	20
5	Alluvium	AL05	Coastal Alluvium (Sand/Silt/Clay)	Quaternary	10	8	12
6	Alluvium	AL06	Valley Fills	Quaternary	16	12	20
7	Alluvium	AL07	Glacial Deposits	Quaternary	16	12	20
8	Laterite	LT01	Laterite / Ferruginous concretions	Quaternary	2.5	2	3
9	Basalt	BS01	Basic Rocks (Basalt) - Weathered, Vesicular or Jointed	Mesozoic to Cenozoic	2	1	3
10	Basalt	BS01	Basic Rocks (Basalt) - Massive Poorly Jointed	Mesozoic to Cenozoic	0.35	0.2	0.5
11	Basalt	BS02	Ultra Basic - Weathered, Vesicular or Jointed	Mesozoic to Cenozoic	2	1	3

12	Basalt	BS02	Ultra Basic - Massive Poorly Jointed	Mesozoic to Cenozoic	0.35	0.2	0.5
13	Sandstone	ST01	Sandstone/Conglomerat e	Upper Palaeozoic to Cenozoic	3	1	5
14	Sandstone	ST02	Sandstone with Shale	Upper Palaeozoic to Cenozoic	3	1	5
15	Sandstone	ST03	Sandstone with shale/ coalbeds	Upper Palaeozoic to Cenozoic	3	1	5
16	Sandstone	ST04	Sandstone with Clay	Upper Palaeozoic to Cenozoic	3	1	5
17	Sandstone	ST05	Sandstone/Conglomerat e	Proterozoic to Cenozoic	3	1	5
18	Sandstone	ST06	Sandstone with Shale	Proterozoic to Cenozoic	3	1	5
19	Shale	SH01	Shale with limestone	Upper Palaeozoic to Cenozoic	1.5	1	2
20	Shale	SH02	Shale with Sandstone	Upper Palaeozoic to Cenozoic	1.5	1	2
21	Shale	SH03	Shale, limestone and sandstone	Upper Palaeozoic to Cenozoic	1.5	1	2
22	Shale	SH04	Shale	Upper Palaeozoic to Cenozoic	1.5	1	2
23	Shale	SH05	Shale/Shale with Sandstone	Proterozoic to Cenozoic	1.5	1	2
24	Shale	SH06	Shale with Limestone	Proterozoic to Cenozoic	1.5	1	2
25	Limestone	LS01	Miliolitic Limestone	Quartenary	2	1	3
26	Limestone	LS01	Karstified Miliolitic Limestone	Quartenary	10	5	15
27	Limestone	LS02	Limestone / Dolomite	Upper Palaeozoic to Cenozoic	2	1	3
28	Limestone	LS02	Karstified Limestone / Dolomite	Upper Palaeozoic to Cenozoic	10	5	15
29	Limestone	LS03	Limestone/Dolomite	Proterozoic	2	1	3
30	Limestone	LS03	Karstified Limestone/Dolomite	Proterozoic	10	5	15
31	Limestone	LS04	Limestone with Shale	Proterozoic	2	1	3
32	Limestone	LS04	Karstified Limestone with Shale	Proterozoic	10	5	15
33	Limestone	LS05	Marble	Azoic to Proterozoic	2	1	3
34	Limestone	LS05	Karstified Marble	Azoic to Proterozoic	10	5	15
35	Granite	GR01	Acidic Rocks (Granite,Syenite, Rhyolite etc.) - Weathered ,Jointed	Mesozoic to Cenozoic	1.5	1	2

36	Granite	GR01	Acidic Rocks (Granite,Syenite, Rhyolite etc.)-Massive or Poorly Fractured	Mesozoic to Cenozoic	0.35	0.2	0.5
37	Granite	GR02	Acidic Rocks (Pegmatite, Granite, Syenite, Rhyolite etc.) - Weathered, Jointed	Proterozoic toCenozoic	3	2	4
38	Granite	GR02	Acidic Rocks (Pegmatite, Granite, Syenite, Rhyolite etc.) - Massive, Poorly Fractured	Proterozoic toCenozoic	0.35	0.2	0.5
39	Schist	SC01	Schist - Weathered, Jointed	Azoic to Proterozoic	1.5	1	2
40	Schist	SC01	Schist - Massive, Poorly Fractured	Azoic to Proterozoic	0.35	0.2	0.5
41	Schist	SC02	Phyllite	Azoic to Proterozoic	1.5	1	2
42	Schist	SC03	Slate	Azoic to Proterozoic	1.5	1	2
43	Quartzite	QZ01	Quartzite - Weathered, Jointed	Proterozoic to Cenozoic	1.5	1	2
44	Quartzite	QZ01	Quartzite - Massive, Poorly Fractured	Proterozoic to Cenozoic	0.3	0.2	0.4
45	Quartzite	QZ02	Quartzite - Weathered, Jointed	Azoic to Proterozoic	1.5	1	2
46	Quartzite	QZ02	Quartzite- Massive, Poorly Fractured	Azoic to Proterozoic	0.3	0.2	0.4
47	Charnockite	CK01	Charnockite - Weathered, Jointed	Azoic	3	2	4
48	Charnockite	CK01	Charnockite - Massive, Poorly Fractured	Azoic	0.3	0.2	0.4
49	Khondalite	KH01	Khondalites, Granulites - Weathered, Jointed	Azoic	1.5	1	2
50	Khondalite	KH01	Khondalites, Granulites - Mssive, Poorly Fractured	Azoic	0.3	0.2	0.4
51	Banded Gneissic Complex	BG01	Banded Gneissic Complex - Weathered, Jointed	Azoic	1.5	1	2
52	Banded Gneissic Complex	BG01	Banded Gneissic Complex -Massive, Poorly Fractured	Azoic	0.3	0.2	0.4
53	Gneiss	GN01	Undifferentiated metasedimentaries/ Undifferentiated metamorphic - Weathered, Jointed	Azoic to Proterozoi c	1.5	1	2
54	Gneiss	GN01	Undifferentiated metasedimentaries / Undifferentiated metamorphic - Massive, Poorly Fractured	Azoic to Proterozoi c	0.3	0.2	0.4
55	Gneiss	GN02	Gneiss -Weathered, Jointed	Azoic to Proterozoic	3	2	4
56	Gneiss	GN02	Gneiss-Massive, Poorly Fractured	Azoic to Proterozoic	0.3	0.2	0.4
57	Gneiss	GN03	Migmatitic Gneiss - Weathered, Jointed	Azoic	1.5	1	2

58	Gneiss	GN03	Migmatitic Gneiss - Massive, Poorly Fractured	Azoic	0.3	0.2	0.4
59	Intrusive	IN01	Basic Rocks (Dolerite, Anorthosite etc.) - Weathered, Jointed	Proterozoic to Cenozoic	2	1	3
60	Intrusive	IN01	Basic Rocks (Dolerite, Anorthosite etc.) - Massive, Poorly Fractured	Proterozoic to Cenozoic	0.35	0.2	0.5
61	Intrusive	IN02	Ultrabasics (Epidiorite, Granophyre etc.) - Weathered, Jointed	Proterozoic to Cenozoic	2	1	3
62	Intrusive	IN02	Ultrabasics (Epidiorite, Granophyre etc.) - Massive, Poorly Fractured	Proterozoic to Cenozoic	0.35	0.2	0.5

3.9.2. Rainfall Infiltration Factor

It is recommended that to assign Rainfall Infiltration Factor values to all the aquifer units recently classified by the Central Ground Water Board. The values recommended in **Table 2.2** may be followed in the future assessments. The recommended Rainfall Infiltration Factor values are to be used for assessment, unless sufficient data based on field studies are available to justify the minimum, maximum or other intermediate values.

An additional 2% of rainfall recharge factor may be used in such areas or parts of the areas where watershed development with associated soil conservation measures are implemented. This additional factor is subjective and is separate from the contribution due to the water conservation structures such as check dams, nalla bunds, percolation tanks etc. The norms for the estimation of recharge due to these structures are provided separately. This additional factor of 2% is at this stage,only provisional, and will need revision based on pilot studies.

The Norms suggested below are nothing but the redistribution of norms suggested by GEC-1997 methodology and hence people are encouraged to conduct field studies and strengthen the Norms database.

Table 3.2: Norms Recommended for Rainfall Infiltration Factor

Sl. No.	Principal Aquifer	Major Aquifers		Age	Recommended (%)	Minimum (%)	Maximum (%)
		Code	Name				
1	Alluvium	AL01	Younger Alluvium (Clay/Silt/Sand/ Calcareousconcretions)	Quaternary	22	20	24
2	Alluvium	AL02	Pebble / Gravel/ Bazada/ Kandi	Quaternary	22	20	24
3	Alluvium	AL03	Older Alluvium (Silt/Sand/Gravel/Lithomargic clay)	Quaternary	22	20	24
4	Alluvium	AL04	Aeolian Alluvium (Silt/ Sand)	Quaternary	22	20	24
5	Alluvium	AL05	Coastal Alluvium (Sand/Silt/Clay) -East Coast	Quaternary	16	14	18

5	Alluvium	AL05	Coastal Alluvium (Sand/Silt/Clay) - West Coast	Quaternary	10	8	12
6	Alluvium	AL06	Valley Fills	Quaternary	22	20	24
7	Alluvium	AL07	Glacial Deposits	Quaternary	22	20	24
8	Laterite	LT01	Laterite / Ferruginous concretions	Quaternary	7	6	8
9	Basalt	BS01	Basic Rocks (Basalt) - Vesicular or Jointed	Mesozoic to Cenozoic	13	12	14
9	Basalt	BS01	Basic Rocks (Basalt) - Weathered	Mesozoic to Cenozoic	7	6	8
10	Basalt	BS01	Basic Rocks (Basalt) - Massive Poorly Jointed	Mesozoic to Cenozoic	2	1	3
11	Basalt	BS02	Ultra Basic - Vesicular or Jointed	Mesozoic to Cenozoic	13	12	14
11	Basalt	BS02	Ultra Basic - Weathered	Mesozoic to Cenozoic	7	6	8
12	Basalt	BS02	Ultra Basic - Massive Poorly Jointed	Mesozoic to Cenozoic	2	1	3
13	Sandstone	ST01	Sandstone/Conglomera te	Upper Palaeozoic to Cenozoic	12	10	14
14	Sandstone	ST02	Sandstone with Shale	Upper Palaeozoic to Cenozoic	12	10	14
15	Sandstone	ST03	Sandstone with shale/ coal beds	Upper Palaeozoic to Cenozoic	12	10	14
16	Sandstone	ST04	Sandstone with Clay	Upper Palaeozoic to Cenozoic	12	10	14
17	Sandstone	ST05	Sandstone/Conglomera te	Proterozoic to Cenozoic	6	5	7
18	Sandstone	ST06	Sandstone with Shale	Proterozoic to Cenozoic	6	5	7
19	Shale	SH01	Shale with limestone	Upper Palaeozoic to Cenozoic	4	3	5
20	Shale	SH02	Shale with Sandstone	Upper Palaeozoic to Cenozoic	4	3	5
21	Shale	SH03	Shale, limestone and sandstone	Upper Palaeozoic to Cenozoic	4	3	5
22	Shale	SH04	Shale	Upper Palaeozoic to Cenozoic	4	3	5
23	Shale	SH05	Shale/Shale with Sandstone	Proterozoic to Cenozoic	4	3	5
24	Shale	SH06	Shale with Limestone	Proterozoic to Cenozoic	4	3	5
25	Limestone	LS01	Miliolitic Limestone	Quarternary	6	5	7
27	Limestone	LS02	Limestone / Dolomite	Upper Palaeozoic to Cenozoic	6	5	7
29	Limestone	LS03	Limestone/Dolomite	Proterozoic	6	5	7
31	Limestone	LS04	Limestone with Shale	Proterozoic	6	5	7
33	Limestone	LS05	Marble	Azoic to Proterozoic	6	5	7
35	Granite	GR01	Acidic Rocks (Granite,Syenite, Rhyolite etc.) - Weathered ,Jointed	Mesozoic to Cenozoic	7	5	9

36	Granite	GR01	Acidic Rocks (Granite,Syenite, Rhyolite etc.)-Massive or Poorly Fractured	Mesozoic to Cenozoic	2	1	3
37	Granite	GR02	Acidic Rocks (Pegmatite, Granite, Syenite, Rhyolite etc.) - Weathered, Jointed	Proterozoic to Cenozoic	11	10	12
38	Granite	GR02	Acidic Rocks (Pegmatite, Granite, Syenite, Rhyolite etc.) - Massive, Poorly Fractured	Proterozoic to Cenozoic	2	1	3
39	Schist	SC01	Schist - Weathered, Jointed	Azoic to Proterozoic	7	5	9
40	Schist	SC01	Schist - Massive, Poorly Fractured	Azoic to Proterozoic	2	1	3
41	Schist	SC02	Phyllite	Azoic to Proterozoic	4	3	5
42	Schist	SC03	Slate	Azoic to Proterozoic	4	3	5
43	Quartzite	QZ01	Quartzite - Weathered, Jointed	Proterozoic to Cenozoic	6	5	7
44	Quartzite	QZ01	Quartzite - Massive, Poorly Fractured	Proterozoic to Cenozoic	2	1	3
45	Quartzite	QZ02	Quartzite - Weathered, Jointed	Azoic to Proterozoic	6	5	7
46	Quartzite	QZ02	Quartzite- Massive, Poorly Fractured	Azoic to Proterozoic	2	1	3
47	Charnockite	CK01	Charnockite - Weathered, Jointed	Azoic	5	4	6
48	Charnockite	CK01	Charnockite - Massive, Poorly Fractured	Azoic	2	1	3
49	Khondalite	KH01	Khondalites, Granulites - Weathered, Jointed	Azoic	7	5	9
50	Khondalite	KH01	Khondalites, Granulites - Mssive, Poorly Fractured	Azoic	2	1	3
51	Banded Gneissic Complex	BG01	Banded Gneissic Complex - Weathered, Jointed	Azoic	7	5	9
52	Banded Gneissic Complex	BG01	Banded Gneissic Complex -Massive, Poorly Fractured	Azoic	2	1	3
53	Gneiss	GN01	Undifferentiated metasedimentaries/ Undifferentiated metamorphic - Weathered, Jointed	Azoic to Proterozoi c	7	5	9
54	Gneiss	GN01	Undifferentiated metasedimentaries / Undifferentiated metamorphic - Massive, Poorly Fractured	Azoic to Proterozoi c	2	1	3
55	Gneiss	GN02	Gneiss -Weathered, Jointed	Azoic to Proterozoic	11	10	12
56	Gneiss	GN02	Gneiss-Massive, Poorly Fractured	Azoic to Proterozoic	2	1	3
57	Gneiss	GN03	Migmatitic Gneiss - Weathered, Jointed	Azoic	7	5	9

58	Gneiss	GN03	Migmatitic Gneiss - Massive, Poorly Fractured	Azoic	2	1	3
59	Intrusive	IN01	Basic Rocks (Dolerite, Anorthosite etc.) - Weathered, Jointed	Proterozoic to Cenozoic	7	6	8
60	Intrusive	IN01	Basic Rocks (Dolerite, Anorthosite etc.) - Massive, Poorly Fractured	Proterozoic to Cenozoic	2	1	3
61	Intrusive	IN02	Ulrta Basics (Epidiorite, Granophyre etc.) - Weathered, Jointed	Proterozoic to Cenozoic	7	6	8
62	Intrusive	IN02	Ulrta Basics (Epidiorite, Granophyre etc.) - Massive, Poorly Fractured	Proterozoic to Cenozoic	2	1	3

3.9.3. Norms for Canal Recharge

Unlike other norms, the Recharge factor for calculating recharge due to canals is given in two units viz. ham/million m^2 of wetted area/day and cumecs per million m^2 of wetted area. As all other norms are in ham, the committee recommends the norm in ham/million m^2 of wetted area for computing the recharge due to canals.

There is a wide variation in the values of the recharge norms proposed by GEC 1997.The Canal seepage norm is approximately 150 times the other recharge norms. In the absence of any field studies to refine the norms it is decided by the committee to continue with the same norms. The committee strongly recommends that each state agency must conduct one filed study at least one in each district before completing the first assessment using this methodology. The committee also suggests a recommended value and minimum and maximum values as in the case of other norms. Where specific results are available from case studies in some states, the adhoc norms are to be replaced by norms evolved from these results.

The Norms suggested in **Table 2.3** below are nothing but the rationalization and redistribution of norms suggested by GEC-1997 methodology and hence people are encouraged to conduct field studies and strengthen the Norms database.

Table 3.3: Norms Recommended for Recharge due to Canals

Formation	Canal Seepage factor ham/day/million square meters of wetted area		
	Recommended	Minimum	Maximum
Unlined canals in normal soils with some clay content along with sand	17.5	15	20
Unlined canals in sandy soil with some silt content	27.5	25	30
Lined canals in normal soils with some clay content along with sand	3.5	3	4
Lined canals in sandy soil with some silt content	5.5	5	6
All canals in hard rock area	3.5	3	4

3.9.4. Norms for Recharge Due to Irrigation

The Norms Suggested by GEC-1997 gives for only three ranges of water levels and it creates a problem in the boundary conditions. For instance, as a result of the variation in water level from 24.9 to 25.1m bgl in the adjoining blocks, change occurs in the return flow from irrigation in the range of 10% to 15%. Hence to reduce the discrepancy it is recommended to have linear relationship of the norms in between 10m bgl water level and 25m bgl water level. It is proposed to have the same norm of 10m bgl zone for all the water levels less than 10m. Similarly, the norm recommended for 25m may be used for the water levels more than 25m as well. The Recommended Norms are presented in Table 2.4.

For surface water, the recharge is to be estimated based on water released at the outlet. For ground water, the recharge is to be estimated based on gross draft. Where continuous supply is used instead of rotational supply, an additional recharge of 5% of application may be used. Where specific results are available from case studies in some states, the adhoc norms are to be replaced by norms evolved from these results.

Table 3.4: Norms Recommended for Recharge from Irrigation

DTW m bgl	Ground Water		Surface Water	
	Paddy	Non-paddy	Paddy	Non-paddy
≤ 10	45.0	25.0	50.0	30.0
11	43.3	23.7	48.3	28.7
12	40.4	22.1	45.1	26.8
13	37.7	20.6	42.1	25.0
14	35.2	19.2	39.3	23.3
15	32.9	17.9	36.7	21.7
16	30.7	16.7	34.3	20.3
17	28.7	15.6	32.0	18.9
18	26.8	14.6	29.9	17.6
19	25.0	13.6	27.9	16.4
20	23.3	12.7	26.0	15.3
21	21.7	11.9	24.3	14.3
22	20.3	11.1	22.7	13.3
23	18.9	10.4	21.2	12.4
24	17.6	9.7	19.8	11.6
≥ 25	20.0	5.0	25.0	10.0

3.9.5. Norms for Recharge due to Tanks & Ponds

As the data on the field studies for computing recharge from Tanks & Ponds are very limited, it is recommended to follow the same norm as followed in GEC 1997 in future assessments also. Hence the norm recommended by GEC-2015 for Seepage from Tanks & Ponds is 1.4 mm / day.

3.9.6. Norms for Recharge due to Water Conservation Structures

Even though the data on the field studies for computing recharge from Water Conservation Structures are very limited, it is recommended that the Recharge from the water conservation structures is 40% of the Gross Storage based on the field studies by Non-Government Organizations. Hence, the norm recommended by GEC-2015 for the seepage from Water Conservation Structures is 40% of gross storage during a year which means 20% during monsoon season and 20% during non- monsoon Season.

3.9.7. Norm for Per Capita Requirement

As the option is given to use the actual requirement for domestic needs, the Requirement Norm recommended by the committee is 60 lpcd for domestic needs. This can be modified if the actual requirement is known.

3.9.8. Norm for Natural Discharges

The Discharge Norm used in computing Unaccounted Natural Discharge is 5% if water table fluctuation method is used or 10% if rainfall infiltration factor method is used for assessing the Rainfall recharge. This committee recommends to compute the base flow for each assessment unit. Wherever, there is no assessment of base flow, earlier norms recommended by GEC 1997 i.e. 5% or 10% of the Total Annual Ground Water Recharge as the Natural Discharges may be continued.

3.9.9. Unit Draft

GEC-1997 methodology recommends to use well census method for computing the ground water draft. The norm used for computing ground water draft is the unit draft. The unit draft can be computed by field studies. This method involves selecting representative abstraction structure and calculating the discharge from that particular type of structure and collecting the information onhow many hours of pumping is being done in various seasons and number of such days during each season. The Unit Draft during a particular season can be computed using the following equation:

$$Unit\ Draft = Discharge\ in\ m^3/hr \times No.\ of\ pumping\ hours\ in\ a\ day \times No.\ of\ days \ldots\ldots\ldots \quad (29)$$

One basic drawback in the methodology of computing unit draft is that there is no normalization procedure for the same. As per GEC-1997 guidelines, the recharge from rainfall is normalized for a normal rainfall. It means that even though the resources are estimated in a surplus rainfall year or in a deficit rainfall year, the assessment is normalised for a normal rainfall which is required for planning. For recharge from other sources, average figures/ values are taken. If the average figures are not available for any reason, 60% of the design figures are taken. This procedure is very much essential as the planning should be for average resources rather than for the recharge due to excess rainfall or deficit rainfall. But the procedure that is being followed for computing unit draft does not have any normalization procedure. Normally, if the year in which one collects the draft data in the field is an excess rainfall year, the abstraction from ground water will be less. Similarly, if the year of the computation of unit draft is a drought year the unit draft will be high. Hence, there is a requirement to devise a methodology that can be used for the normalization of unit draft figures. The following are the two simple techniques, which can be followed. If the unit draft values for one rainfall cycle are available for at least 10 years second method shown in equation 31 is to be followed or else the first method shown in equation 30 may be used.

$$Normalised\ Unit\ Draft = \frac{Unit\ Draft \times Rainfall\ for\ the\ year}{Normal\ Rainfall} \ldots\ldots \quad (30)$$

$$Normalised\ Unit\ Draft = \frac{\sum_{i=1}^{n} Unit\ Draft_i}{Number\ of\ Years} \ldots\ldots \quad (31)$$

Although GEC-1997 methodology recommends a default value for the unit drafts, each State is using its own values, generally after conducting field studies, even though without a documentation. Hence, it is felt that this norm may be computed by the state agency, which is going to assess the norms before commencement of the assessment. But it is strongly recommended that the field studies should be documented and submitted along with the results of the assessment.

3.10. INDIA -GROUNDWATER RESOURCE ESTIMATION SYSTEM (IN-GRES)

"INDIA-GROUNDWATER RESOURCE ESTIMATION SYSTEM (IN-GRES) is a Software/Web-based Application developed by CGWB in collaboration with IIT-Hyderabad. It will provide common and standardized platform for Ground Water Resource Estimation for the entire country and its pan- India operationalization (Central and State Governments). The system will take 'Data Input' through Excel as well as Forms, compute various ground water components (recharge, extraction etc.) and classify assessment units into appropriate categories (safe, semi-critical, critical and over-exploited). The Software uses GEC 2015 Methodology for estimation and calculation of Groundwater resources. It allows for unique and homogeneous representation of groundwater fluxes as well as categoriesfor all the assessment units (AU) of the country.

The detailed description about IN-GRES Software is given in **Appendix-C**.

URL of IN-GRES http://ingres.iith.ac.in

CHAPTER IV

4.0 PROCEDURES FOLLOWED IN THE PRESENT ASSESSMENT INCLUDING ASSUMPTIONS

4.1 DATA SOURCE FOR EACH OF THE DATA ELEMENT

- The Geographical area, Hilly area, water spread area, canals etc., have been collected from the Revenue Records (Mostly from the villagewise 'G' Returns for the respective years of the assessment period.
- While computing the Geographical area of the Firka, in some of the Firkas the unclassified forest and Reserve Forest area are not added in the State Village wise 'G' returns records. However, some part of this area was added in the earlier exercise for computation. It is also noted that most of the above area is mainly of hilly area having a slope of more than 20%.
- Rainfall Data have been collected from IMD and State Records.
- Based on the permissible limits (<=3000mg/l) of water quality parameter viz., TDS,
- Good / poor quality area has been considered.
- Wells and Cropping Pattern data have been collected from Statistical and Field Records.
- Domestic and Industrial requirement in most of the Districts based on the population, per capita water requirement etc., have been collected from State Departments.
- The other parameters such as water level data have been utilized both from the State and Central Departments.

4.2 CHANGES IF ANY, APPLIED IN THE ORIGINAL METHODOLOGY PROPOSED BY GEC ALONG WITH JUSTIFICATION:

The various parameters and data could not be compiled at watershed level and hence the computations have been done directly for micro level i.e Firka wise basis. Further, data also could not be segregated into command and non-command and hence it has been carried out combined as non-command. The area of hard rock and sedimentary has been used to define the Specific yield and Infiltration factor for the rock. In short, the computations have been carried out directly at the level of Firka as per tha availability of State Records. No other changes in the guidelines or norms have been made in the present assessment for all the Revenue Firkas in the State of Tamil Nadu.

4.3 VARIOUS NORMS USED IN THE COMPUTATIONS

On the basis of electricity consumption, the sample meter installed by TNEB and groundwater draft has been segregated into monsoon and non monsoon draft. The norms as prescribed in GEC 15 Methodology have been used for the computation of the present assessment. No other changes have been made in the norms suggested by GEC-15 methodology.

CHAPTER V

5.0 COMPUTATION OF GROUNDWATER RESOURCES IN THE STATE OF TAMIL NADU

5.1 SALIENT FEATURES OF ASSESSMENT

In Tamil Nadu, the Resource Estimation was being carried out on Macro level i.e on Block wise basis upto 2009 and from 2013 assessment is being carried out on Micro Level Basis i.e on firka wise basis. Since the ground water movement is not bound by watershed boundary on surface and for effective implementation of policies, physical and financial implications, welfare measures etc., by the District administration of Tamil Nadu State and also by the easy segregation of available State Records and in coordination with Central Ground Water Board, Chennai this Resource Estimation computations have now been carried out on Micro Level Basis with Revenue Firka as the assessment unit and in the absence of data on command and non command area, they have been estimated together. The present assessment is estimated based on water table aquifer. The base year for data collection is 2017 -20 and the resources computed to March 2020.

5.2 NORMS USED IN THE ASSESSMENT

5.2.1 PARAMETERS

The specific yield computed on the basis of water level fluctuation during non-monsoon period has been used wherever, it is found realistic and in other places, the values have been assumed from the norms provided in the methodology. Further, the local hydrogeological conditions have also been considered while assuming the values for the parameters. The parameters considered in the computations have been summarised below.

- **Specific Yield**

Crystallines	:	1 to 1.5%
Sandstone	:	6 to 13 0%
Alluvium consisting of clay, silt and sand admixture (Cauvery Delta)	:	6 to 22%

- **Infiltration Factor**

Crystallines	:	2 to 9 %
Sandstone	:	10 to 12%
Alluvium consisting of clay, silt and sand admixture (Cauvery Delta)	:	5 – 14%

5.2.2 GROUNDWATER DRAFT

Ground water draft has been computed using unit draft method. The unit draft multiplied by total number of structures has yielded the groundwater draft.

5.2.3 RETURN FLOW FROM GROUNDWATER IRRIGATION

Crop water requirement has been calculated on the basis of cropped area and average water requirement. Return flow from ground water irrigation has been computed on the basis of the percentage as given in the methodology in relation to depth to water level.

5.2.4 RETURN FLOW FROM SURFACE WATER IRRIGATION

The data on cropped area has been grouped into paddy and non paddy. Average water requirements of 1.20 m & 0.53 m have been assumed for paddy & non paddy crops. The crop water requirement has been worked out and the return flow from surface water irrigation has been computed on the basis of percentage of applied irrigation water on the basis of the percentage as given in the methodology.

5.2.5 SEEPAGE FROM CANALS

The canal length, wetted perimeter, days of flow (monsoon & non monsoon) and the seepage factor (given in the methodology manuscript) have been used to determine the seepage from canal for monsoon & non-monsoon periods separately. The data on canal details have been assumed to be the same as there will be little change in the functioning of a canal. In areas of shallow water table, the canal seepage is sometimes overestimated, as the storage space is not available. In Cauvery delta, comprising, Thanjavur, Tiruvarur and Nagapattinam districts, there are three types of canals, viz., Canal/River, Canal A Type/Channel and BCD Type Canals. GEC-2015 has suggested that seepage factor can be suitably reduced in case of shallow water table areas or water logged areas, which is the case during the release of water in the canal and the factor has been reduced accordingly and canal seepage has been computed.

5.2.6 SEEPAGE FROM TANKS

Water spread area, days of water availability (monsoon & non monsoon) and seepage from tank (given in the methodology) have been used to determine the seepage from tanks for monsoon and non monsoon separately.

5.2.7 SEEPAGE FROM CHECK DAMS/NALAS:

The seepage from water conservation structures has been estimated as per norms given in GEC – 15 methodology.

5.2.8 BASE FLOW COMPUTATIONS

In Tamil Nadu it has been assumed as 10% of annual ground water recharge as per GEC-15 methodology.

5.2.9 ALLOCATION FOR DOMESTIC & INDUSTRIAL REQUIREMENT

The population density (thousand per sq.km), fractional load on ground water for domestic purposes and area (sq.km) have been used to determine the domestic demand as suggested in the manual. The data on actual fractional load is not available for each block and TWAD Board, which is responsible for water supply, informed that in general the share of ground water (load on ground water) for domestic water supply in rural & urban area is taken as 0.7 & 0.3 respectively. In hilly areas the load is taken as 0.3. Accordingly, the allocation for domestic & industrial purposes has been computed. This present exercise, about 7300 extraction points of Tamil Nadu Water Supply and Drainage Board and about 16900 extraction points of Tamil Nadu Pollution Control Board were also included and computed for allocation of Domestic and Industrial requirement.

5.2.10 WATER LEVEL TRENDS

The average water levels of National Hydrograph Stations of CGWB and observation wells of PWD (GW), Govt. of Tamil Nadu for the period five years has been worked out for every year between 2015-2020 for pre monsoon and post monsoon separately. The long-term trend has been worked out for these average water levels for pre monsoon and post monsoon separately.

5.2.11 NORMALIZATION OF RAINFALL RECHARGES

The rainfall recharge has been determined using a linear relationship between recharge and rainfall in the form of

$R = ar + b$

where,

R = Rainfall recharge

r = Rainfall

a & b = Constants.

Percentage Departure has also been determined and accordingly either Water Level Fluctuation approach or rainfall infiltration method (ad-hoc) has been used to determine the rainfall recharge.

5.2.12 Dynamic Ground Water Resources Estimation – Categorization of Firkas as on March 2020 for the state of Tamilnadu

Tamil Nadu state is underlain by diverse hydrogeological formations. Nearly 73 % of the state is occupied by hard rocks, semi-consolidated and consolidated formations which are mainly confined to the eastern part including the coastal tract. In the hard rock areas, groundwater is developed through dug wells tapping the weathered zone and dug cum bore wells and bore wells tap the deeper fractures down to a depth of 300 m. In semi consolidated and unconsolidated formation, shallow zones are tapped by filter points and shallow tube wells and deeper zones through deeper tube wells. The yield of open wells vary from 1 to 3 lps, where as in dug wells tapping soft rocks including sedimentary formations, the yield is up to 10 lps. The yield from unconsolidated and semi consolidated formations are in general 10 to 20 lps and also as high as 40 lps are also noticed at select places.

The ground water resources for the State have been assessed firka-wise. Total Annual Ground Water Recharge of the State has been assessed as 19.59 bcm and Annual

Extractable Ground Water resources as 17.7 bcm. The Annual Ground Water Extraction is 14.67 bcm and Stage of Ground Water Extraction as 82.9 %.

Out of 1166 assessment units (firkas), 435 units (37.31 %) have been categorized as 'Over Exploited',63 units (5.4 %) as 'Critical', 225 units (19.3 %) as 'Semi-Critical', 409 units (35.08 %) as 'Safe' and 34 units (2.92 %) have been categorized as 'Saline'. Similarly out of 108367.38 sq km recharge worthy area of the State, 39907.51 sq km (36.83 %) area are under 'Over-Exploited', 6075.97 sq km (5.61 %)under 'Critical', 21409.28 sq km (19.76 %) under 'Semi-critical', 37852.37 sq km (34.93 %) under 'Safe' and 3122.25 sq km (2.88 %) area under 'Saline' categories of assessment units. Out of total 17690.07 mcm annual extractable ground water resources of the State, 5744.07 mcm (32.47 %) are under 'Over-exploited', 1050.93 mcm (5.94 %) under 'Critical', 3921.48 mcm (22.17 %) under 'Semi-critical' and 6973.59 mcm (39.42 %) are under 'Safe' categories of assessment units.

As compared to 2017 assessment, Total Annual Ground Water Recharge has decreased from 20.22 to 19.59 bcm. The Annual Extractable Ground Water Resources has decreased from 18.2 to 17.7 bcmand the annual ground water extraction has decreased from 14.73 to 14.67 bcm. Consequently, there is an increase in the stage of ground water extraction from 80.94 % to 82.42 %. The marginal reduction in recharge is due to changes in rainfall recharge and decreased extraction is due to revision of well census data.

Annexure - I

The following are the category of firkas as on March 2020 resources estimation:

SL. NO	CATEGORY OF FIRKA	NUMBER OF FIRKAS (MARCH 2020)
1	Safe	409
2	Semi-critical	225
3	Critical	63
4	Over exploited	435
5	Poor quality/Saline	34
TOTAL		1166

Annexure - II

Ground Water Resources of State (Tamilnadu) Comparison of Resources & categorisation

Description	2017 GW Resource Assessment		2020 GW Resource Assessment		Remarks
	Unit		**Unit**		
Total Annual Ground Water Recharge	**bcm**	**20.22**	**bcm**	**19.59**	Reduction by 0.63 bcm
a. Recharge from Rainfall	bcm	8.56	bcm	8.09	
b. Recharge from Other Sources	bcm	11.67	bcm	11.50	
Annual Extractable Ground Water Resources	**bcm**	**18.20**	**bcm**	**17.69**	Reduction by 0.51 bcm
Current Total Annual Ground Water Extraction	**bcm**	**14.73**	**bcm**	**14.67**	Reduction by 0.06 bcm
a. Current Annual Ground Water Extraction for Irrigation	bcm	13.06	bcm	13.52	
b. & c. Current Annual Ground Water Extraction for Industrial & Current Annual Ground Water Extraction for Domestic	bcm	1.67	bcm	1.15	
Stage of GW Extraction	%	81	%	83	
Total number of GW Assessment Units (Block/Taluka/Mandal etc.)	Nos.	**1166**	Nos.	**1166**	
a. Number of **Over-Exploited** GW Assessment Units (Block/Taluka/Mandal etc.)	Nos.	462	Nos.	435	
b. Number of **Critical** GW Assessment Units (Block/Taluka/Mandal etc.)	Nos.	79	Nos.	63	
c. Number of **Semi-Critical** GW Assessment Units (Block/Taluka/Mandal etc.)	Nos.	163	Nos.	225	
Total number of **OCS** GW Assessment Units (Block/Taluka/Mandal etc.)					
d. Number of **Saline** GW Assessment Units (Block/Taluka/Mandal etc.)	Nos.	35	Nos.	34	
e. Number of **Safe** GW Assessment Units (Block/Taluka/Mandal etc.)	Nos.	427	Nos.	409	

CONTRIBUTORS' PAGE

State Ground and Surface Water Resources Data Centre Public Works Department (WRD) Govt. of Tamil Nadu	Central Ground Water Board, South Eastern Coastal Region, Chennai Ministry of Jal Shakti Government of India
1. Sh. Raja, Deputy Director **2. Dr. Kathiravan, Deputy Director** **3. All Deputy Directors** **4. All Assistant Directors** **5. All Assistant Geologists**	**1. Dr. S. Subramaniam, Scientist-D** **2. Dr. N. Ramesh Kumar, Scientist-B** **3. J. Sivaramakrishnan, Scientist-B**

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The Regional Director
Central Ground Water Board
South Eastern Coastal Region
Rajajaji Bhavan, Besant nagar, Chennai
Email: rdsecr-cgwb@nic.in Web: cgwb.gov.in