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No.: INCOH/SAR-7/95

NATURAL GROUND WATER RECHARGE ESTIMATION METHODOLOGIES IN INDIA

B.P.C. Sinha
Santosh Kumar Sharma

INDIAN NATIONAL COMMITTEE ON HYDROLOGY
(Committee Constituted by Minsitrry of Water Resources, Govt. of India)

INCOH SECRETARIAT
NATIONAL INSTITUTE OF HYDROLOGY
ROORKEE - 247 667, INDIA
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PREAMBLE

It has been estimated that the total world population will increase from 4.5 billion in 1980 to about 6.5 billion by the year 2000, with the most rapid growth in the developing countries. By that time, the countries within the humid tropics and the other warm humid regions will represent almost one-third of the total world population. This proportion will continue to rise in the twenty-first century. The developing and under-developed countries thus quite clearly are the regions facing potentially serious water problems. Hence, it is urgent to question as to whether the fields of hydrology and water resources management have the appropriate methods in place to meet the rising demands that will be made on the water resources. Hence it becomes very important and expeditious to review and update the state-of-art in different facets of hydrology and component processes. This calls for compiling and reporting present day technology in assessment of water resources and determining the quality of these water resources.

Rainfall is the most important source of natural ground water recharge. Rainfall infiltration to ground water regime depends on various attributes like duration and intensity of rainfall, soil moisture characteristics, physiographic and hydrogeologic situations. Quantification of the rainfall infiltration of ground water reservoirs involves precise determination of various components controlling and contributing to ground water movement. This state-of-art report deals with various methods of estimating ground water recharge which are being used in India. Relevant case studies have also been included.

The Indian National Committee on Hydrology is the apex body on hydrology constituted by the Government of India with the responsibility of coordinating the various activities concerning hydrology in the country. The committee is also effectively participating in the activities of Unesco and is the National Committee for International Hydrological Programme (IHP) of Unesco. In pursuance of its objective of preparing and periodically updating the state-of-art in hydrology in the world in general and India in particular, the committee invites experts in the country to prepare these reports on important areas of hydrology.

The Indian National Committee on Hydrology with the assistance of its Panel on Ground Water has identified this important topic for preparation of this state-of-art report and the report has been prepared by Mr. B.P.C. Sinha and Mr. Santosh Kumar Sharma of Central Ground Water Board. The guidance, assistance and review etc. provided by the Ground Water Panel are worth mentioning. The report has been compiled and finalised by Dr. K.K.S. Bhatia, Member Secretary of the Indian National Committee on Hydrology.

It is hoped that this state-of-art report would serve as a useful reference material to practicing engineers, researchers, field engineers, planners and implementation authorities, who are involved in correct estimation and optimal utilization of the water resources of the country.

(S.M. Seth)
Executive Member, INCOH
& Director, NIH

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INTRODUCTION

Ground water is one of the most important and widely distributed resources of the earth. The use of ground water in India has been known since times immemorial and at present around half of the irrigation demands in India are met from ground water resources. The ground water development forms bulk of irrigation development programme in most of the states of India. A growing recognition of the ground water resources as an important source of irrigation came to fore during the last two decades or so in all the parts of India, and more and more schemes were formulated based on ground water. The remarkable increase in food production in areas utilising ground water irrigation bears a testimony to realisation of ground water as an important source of irrigation.

For planned development of ground water resources it becomes essential to quantify the ground water resources of different administrative units/basins on realistic basis. Ground water being a dynamic and replenishable resource, its potential is generally estimated based on the component of annual recharge which could be developed by means of suitable ground water structures.

Rainfall is the most important source of natural ground water recharge. Rainfall infiltration to ground water regime depends on various attributes like duration and intensity of rainfall, soil moisture characteristics, physiographic and hydrogeologic situations. Quantification of the rainfall infiltration of ground water reservoir involves precise determination of various components controlling and contributing to ground water movement. Various methodologies have been developed for computation of natural ground water recharge. Some of the main methods in vogue in India are (i) empirical methods, (ii) hydrological budgeting methods (iii) ground water level fluctuations method. The paper deals with the various empirical methods developed and are normally being used in the areas with inadequate data required for natural recharge estimations. Hydrologic budgeting methods have been used in various Water Balance Projects in India to compute ground water recharge. Case histories utilising hydrologic budgeting methods for computation of ground water resources in semi-arid areas of various States of India like Punjab, Haryana and Rajasthan have been illustrated.

The method of computation of component of rainfall recharge utilising ground water level fluctuations and specific yield is one of the important and widely used methods in India. Studies in various hydrogeological and climatological set-ups have been undertaken in India to observe the effects of various input components on ground water levels. Based on the studies undertaken by Central Ground Water Board and other organisations connected with ground water surveys, the recharge estimation methodologies have been rationalised for adoption in various parts of India. Ground Water Estimation Committee (GEC) constituted by Government of India has recommended the norms (1984) for groundwater resource estimation.

RECHARGE ESTIMATION TECHNIQUES

Rainfall is the most important source of groundwater recharge in the country. In the major part of the India, the maximum fluctuation of ground water levels and the ground water recharge takes place during south-west monsoon but in some parts especially in south and south-eastern parts, north-east monsoon rainfall is the dominant source of recharge. Eleswhere in the country north-east monson rains are not only subdued but also sporadic, and thus of little significance on contributing to recharge.

Rainfall infiltration primarily depends upon duration and intensity of rainfall, soil moisture characteristics, topographic slopes, land use pattern, agronomic practices, weather conditions preceding, during and succeeding rainfall periods, and depth-to-water table. These conditions further impose a limit on threshold value of rainfall required to affect ground water recharge.

The natural recharge to the aquifer in a groundwater basin from precipitation is computed by various methods. Some of the methods in vogue in India are :

I. Empirical methods

II. Hydrologic budgeting methods

III. Ground water level fluctuations.

The above three methods are discussed in details in next chapters.

EMPIRICAL METHODS FOR RECHARGE ESTIMATION

Based on the studies undertaken by different scientists and organisation regarding correlation of ground water level fluctuation and rainfall, some empirical relationships have been worked out for computation of natural recharge to ground water from rainfall. Some of the these empirical relationships for different hydrogeological situations in India are described hereunder.

i) Chaturvedi formula

Based on the water level fluctuations and rainfall amounts, Chaturvedi (1943) derived an empirical relationship to arrive at the amount of rainfall that penetrates into the ground, when rainfall exceeds 15 inches (38 cms) :

$$R_p = 2\ (P - 15)^{0.4} \qquad \ldots (1)$$

By further work, the formula was modified as :

$$R_p = 1.35\ (P - 14)^{0.5} \qquad \ldots (2)$$

Where,

R_p = ground water recharge in inches, and
P = annual rainfall in inches.

Subsequently, Sehgal (1973) developed a formula commonly called 'Amritsar Formula' using regression analysis for certain interstream alluvial tracts in Punjab. With the same notations as above, the formula given below was found to hold good with actual observations, for rainfalls between 58 and 71 cm.

$$R_p = 2.5\ (P - 16)^{0.5} \qquad \ldots (3)$$

The Chaturvedi formula has been widely used for preliminary estimations of groundwater recharge due to rainfall infiltration.

ii) Empirical relationship evolved by Uttar Pradesh Irrigation Research Institute (UPIRI).

On the basis of a study conducted by U.P. Irrigation Research Institute in Western Uttar Pradesh (Sharma et. al., 1977), the rainfall infiltration, R_p is given by

$$R_p = 3.74\ (P - 38)^{0.4} \qquad \ldots (4)$$

in which P is the annual rainfall in centimeters. Groundwater recharge from rainfall was also studied by Datta et. al., (1973) by tracing movement of layer of moisture tagged with tritiated water. As a result of this study, the following relationship between recharge R_p, annual rainfall, P and the average clay content of the top soil, C has been given

$$R_p = 0.4\ Pe^{0.046C} \qquad \dots (5)$$

iii) Studies in Vedavati River Basin Project, Karnataka, India by Central Ground Water Board.

Under the Project studies, the continuous monitoring of Ground Water levels in upper and lower reaches and central part of basin underlain by hard work formations was done to determine rainfall infiltration. The total rainfall affecting the rise in ground water levels was correlated with increment to ground water body utilising a uniform factor 0.025 which is average specific yield of the aquifers in the basin. The following relationship was worked out between rainfall (R) and percolation (P) based on statistical analysis :

$$P = 0.26\ (R-23) \qquad \dots (6)$$

P and R are expressed in millimeters. The threshold value of rainfall to result in significant rise of ground water level is 23 mm. The correlation coefficient between P and R is highly significant and has a value of 0.96.

HYDROLOGIC BUDGETING METHODS FOR RECHARGE ESTIMATION

In this method it is presumed that rainfall in excess of evapotransipiration losses is utilised in bringing the soil moisture upto its field capacity and the rest is available for ground water recharge and runoff. The hydrological budget technique is a statement of accounting for the water gains and losses for selected periods in an area. The equation of the hydrologic cycle is the budge balance, which can be expressed as follows :

$$P+I = R + ET + \Delta\ SW + \Delta\ SM + \Delta\ GW \qquad \ldots (7)$$

P = rainfall;
I = applied irrigation water
R = is runoff;
ET = evapotransipiration;
Δ SW = change in surface water storage;
Δ SM = change in soil moisture; &
Δ GW = change in ground water storage.

Further, $\Delta\ GW = \Delta\ H.\ yg$

Where

Δ H = change in ground water stage
yg = specific yield.

The complex sum of the revised equation P-R-Δ SW-ET-Δ SM, is equal to Δ H.yg which is equivalent to ground water recharge.

CASE STUDIES

A. Ghaggar Project

The estimation of ground water recharge was done by using hydrologic budget technique and also by adopting soil moisture budget technique in Ghaggar Project covering semi arid areas of parts of Haryana and Punjab States of India under UNDP assisted Phase III Project. These data were used to compare with the estimations arrived at by hydrogeological studies of changes in ground water storage. These case studies are described hereunder.

i) Estimation of recharge by Analysis of hydrometereological data.

The Ghaggar River Basin covers an area of some 42,200 Km^2 extending over parts of several States in north-western India; Haryana, Himachal Pradesh, Punjab, Rajasthan and Union Territory of Chandigarh. The Ghaggar river basin is part of the large Indo-Gangetic Qauternary basin and consists of alluvial deposits. The area is also fed by surface water irrigation system through a canal network.

For water-balance studies, the Project area was divided into ten zones; the nine canal command areas plus the one rain-fed zone in the north-eastern part of the Project area, where there was no canal irrigation.

Water-balance studies were done separately for each zone for each of the two crop season-Kharif (June to October) and Rabi (November to May) for the two years 1976-1977 and 1977-1978.

Using monthly rainfall data from the 114 existing stations and 19 project stations, total rainfall data for Kharif and Rabi seasons were worked out for both years. Isohyetal maps of the project areas were prepared for each season and average rainfall converted into volume of water received for each zone.

Rainfall during the November-to-May period amounts to barely 20 percent of the annual total and hence is not sufficient to raise the soil moisture to field capacity. Loss from actual evaporation plus soil moisture retention was therefore limited to rainfall in this period for all zones.

Rainfall was above normal in both 1976-1977 and 1977-1978 by about 30 percent and 20 percent, respectively, 1976 and 1977 departures from normal annual rainfall were worked out for all water balance zones; in 1976, all zones received more rainfall than in 1977; moreover, ground-water recharge in 1976 was greater than in 1977 in all the water balance zones as given in the Table 1.

ii) Estimation of Recharge from Rainfall by Soil Moisture Budget Technique

The technique of soil moisture budget was applied at 25 selected stations representing all water balance zone and climatic zones of the Project area. The findings of this technique in different climatic zones were as follows :

a) Arid Zones :

(i) There is no contribution to ground water in the arid zone from the mean seasonal areal rainfall of 190 mm.

(ii) If the areal rainfall during a given year is as much as one and half times of the mean seasonal rainfall, there is no contribution to the ground water recharge.

(iii) If the seasonal areal rainfall in a given year is of the order of double the mean seasonal rainfall, rainfall will contribute positively to ground water recharge.

Table - 1 Ground Water Recharge and Departure from Normal Rainfall in Water Balance Zones, 1976 and 1977.

	1976		1977	
Water balance zone (s)	**Groundwater Recharge (mm)**	**Rainfall Departure (% above normal)**	**Groundwater Recharge (mm)**	**Rainfall Departure (% above normal).**
1.	40.8	45.0	20.9	26.5
2.	70.8	33.8	69.6	29.0
2A.	193.7	59.0	124.5	47.6
3.	106.0	24.1	59.6	16.5
4.	37.6	14.3	42.0	7.5
5.	10.5.0	12.5	43.8	8.3
6, 7.	72.9	29.2	40.7	17.5
8.	114.8	59.0	90.2	47.6
9, 9A.	113.2	59.0	95.8	47.6
10.	87.6	10.7	51.1	8.9

(iv) Hence, direct recharge from rainfall in the arid zone is possible only in wet years (double or more than double the mean seasonal rainfall). In 1976 the seasonal rainfall received in the zone was 441.7 mm, which accounted for a recharge of 34.0 mm, or about 7.6 per cent. In 1977 the recharge from rainfall was nil although the year's recorded rainfall was about 43 per cent above mean seasonal rainfall.

b) Semi-arid zone :

(i) The long-term mean seasonal areal rainfall in the semi-arid zone, 312 mm, does not contribute to ground-water recharge. Only in wet years, with above-normal rainfall, does rainfall contribute to recharge.

(ii) Rainfall contributes to ground-water recharge only in those years when seasonal rainfall is more than 10 percent above the mean, i.e. 340 mm or higher.

(iii) In 1977, the areal seasonal rainfall was 456.6 mm, or about 116.6 mm above threshold value (340 mm), recharge was 13.8 mm, which was 12 percent of the amount in excess of the threshold value. In 1976, the areal seasonal rainfall was 548.0 mm, or about 208 mm above the threshold value; accounted for a recharge of 85.1 mm, which was 41 per cent of the amount in excess of threshold value.

c) Sub-humid zone

(i) The areal seasonal rainfall in 1976 and 1977was 35 per cent and 46 per cent, respectively, above mean areal seasonal rainfall. The recharge contribution from rainfall was about 24 per cent of seasonal rainfall in each year :

(ii) Every year in which rainfall is equal to or greater than the mean seasonal rainfall, groundwater recharge takes place.

d) Humid zone

(i) The humid zone contributes highly significant runoff, of the order of 50 per cent of total rainfall received.

(ii) In 1976 and 1977 the areal seasonal rainfall was about 24 percent and 18 percent, respectively above mean seasonal rainfall, contributing 16 percent and 15 percent respectively, to groundwater recharge. In this zone, ground-water recharge occurs almost every year. Recharge from rainfall is about 15 percent in a normal rainfall year; if rainfall is more than 25 percent above mean seasonal rainfall in a year, the percentage contribution to recharge would also be greater than 15 percent.

B. Sikar Luni and Bikaner Basins :

A project entitiled "Ground Water Surveys in Rajasthan and Gujarat" was taken up by the Central Ground Water Board with UNDP assistance. The Rajasthan Project area is located in the semi arid to arid western part of State of Rajasthan and covers about 42000 Km^2. The area is divided into three ground water basins-the Sikar, the Bikaner and the Luni basins. The area is underlain by aeolian deposits, semi consolidated and consolidated formations. The ground water occurs under phreatic as well as confined conditions.

Soil moisture balance computations were made in semi-arid zones with an areal extent of 14,464 Km^2 in the Sikar basin and 26,398 Km^2 in the Bikaner and Luni basins of Rajasthan to obtain groundwater replenishment.

In the absence of any notable surface runoff in the Rajasthan project area, it was assumed that the computed total runoff, or "Water surplus" represents ground-water recharge.

Considering a root zone approximately 2 metres deep, the maximum available soil moisture, or soil moisture storage capacity, was estimated at 100 m for the eastern part of the project area. North of the project area, falling in surface water irrigation project (Rajasthan Canal Project) the available soil moisture is between 9.4 and 12 per cent. Accordingly a value of 150 mm for the maximum water-holding capacity in the Bikaner area was used.

The estimated annual water surplus for soil moisture of 150 or 100 mm was computed for 11 stations for the years 1971, 1972 and 1973 to show the areal variation which has been depicted in the Table -2. As could be expected, the areal variation is very large. This is explained by the very local nature of thunderstorms in this area. In 1973 for example, most of the annual water surplus at Nagaur (27°12', 73°45'), which was about 280 mm, was carried by a single storm in August. At the same time the annual water surplus at Didwana (27°24', 74°34'), which was not hit by any cloudburst was probably zero.

During the three project years 1971-1973 the average annual water surplus was about 40 mm on an average for the Sikar basin, assuming 100 mm available soil moisture, that is, somewhat higher than the long-term mean of about 33 mm (average of water surplus for Didwana and Jhunjhunu). For the western part of the project area, if 150 mm available soil moisture is assumed, water surplus for the three years is about 32 mm.

Table-2 : Estimated Water Surplus for 11 Stations During the Period 1971-1973 (in millimeters).

Area	Station	1971		1972		1973	
		Annual rain-fall	Water sur-plus	Annual rain-fall	Water sur-plus	Annual rain-fall	Water sur-plus
Sikar baisn & Luni Basin 1/	Churu	298	0	191	0	304	11
	Didwana	402	4	160	0	334	0
	Jhunjhunu	535	15	234	10	379	5
	Parabatsar	857	391	239	20	453	68
	Ratnagarh	438	36	146	0	406	26
	Sikar	575	12	160	22	447	49
	Sujangarh	472	89	159	0	540	112
	Average	510	78	184	7.5	409	39
Bikaner Basin 2/	Bikaner	211	0	207	0	209	0
	Didwana	402	0	160	0	334	0
	Dungargarh	231	0	247	0	344	8
	Nagaur	467	98	331	0	731	277
	Average	328	24	236	0	404	71

1/ Soil moisture storage capacity 100 mm.
2/ Soil moisture storage capacity 200 mm.

Acutally, these computations of recharge by soil moisture budget technique are valid only when the moisture surplus percolates quickly to the water table. If infiltration capacity is lower than rainfall intensity, part of the water remains on the soil and evaporates directly. If the percolation rate in the subsurface is slowed by compact materials or clay beds, evaporation can also take place during the dry season throguh roots of scattered trees which penetrate deeply in the soil.

It is, therefore quite essential to monitor the ground water levels to observe the effect of moisture surplus on ground water regime and as such the soil moisture budget technique needs to checked with actual ground water regime responses.

GROUND WATER LEVEL FLUCTUATION METHOD FOR RECHARGE ESTIMATION

In this method, use is made of the data on seasonal variation of ground water level, rainfall, applied irrigation water etc. This method is generally not applicable to confined aquifers. It covers recharge only at the soil surface. When the recharge is seasonal, the ground water level may fluctuate in a sine curve pattern with varying amplitudes; by plotting the annual rise for corresponding to annual rainfall 'P' an average relationship is derived which gives a limiting value of rainfall (threshold value) below which there is no recharge. This amount of rainfall is completely lost in ET and surface runoff. The recharge in any particular year is the difference between the observed annual rainfall and the total losses. There are several variants of this method which have been utiilised by different workers. The rise and fall of water table over an area is a measure of change in ground water storage which is computed as a product of specific yield, the average rise in level and the area over which the change occurs.

The ground water recharge or change in storage can be expressed by following relationship.

$$R = \Delta h.Sy. \quad \ldots (9)$$

where

R = Ground water recharge
Δh = Change in water level due to rainfall.
Sy = Specific yield of the formation in the zone of fluctuation.

This method of computation of component of rainfall recharge utilising ground water level fluctuation and specific yield is widely used in India. The ground water level fluctuation is a true reflection of the input to and output from the ground water regime and is utilised in computations of ground water resources all over India.

The ground water levels are being monitored by different organisations in India varying from two to four times in a year based on the rainfall pattern. The frequency of measurement is more in areas where the intensity of ground water development is high or where some specific problems as regards quality of ground water etc. are encountered.

Estimation of specific yield of the different types of aquifers is quite essential for precision in computation of recharge. The estimation of specific yield are normally done by laboratory methods, field saturation and drainage methods, moisture equivalent methods, pumping test methods, etc.. Of these the pumping test methods utilising standard equilibrium and non equilibrium equations of ground water are most important and reliable. Considerable work has been done in India as regards this and specific yield values for different hydrogeological formations have been computed.

Besides, the above commonly used methodologies, the estimation of natural ground water recharge is also being done by other methods namely, analysis of base flow hydrograph, hydrochemical methods, tracer techniques, mathematical and other modelling techniques etc. In detailed project studies undertaken time to time, various methodologies are used for ground water recharge estimation and results compared with real field situations to judge the authenticity of computations.

Estimation of ground water recharge and extent of its utilisation in various parts of the country for speedy ground water development, was, by and large based on different empirical methods adopted from time to time. During the last decade, significant steps were taken when extensive and intensive scientific studies through multi-disciplinary ground water projects were undertaken by the Central Ground Water Board (CGWB) and State Ground Water Organisations to evaluate the ground water resources available for development. These studies yielded valuable data from the varied hydrogeological situations of India and concerted efforts were made to rationalise the recharge estimation methodology all over the country. In the year 1982 Govt. of India constituted a committee "Ground Water Estimation Committee" (GEC) with the members drawn from various organisations engaged in hydrogeological studies and ground water development. This Committee, after reviewing the data collected by central and state agencies, research organisations, universities etc. recommended the norms for ground water resources estimation, in the year, 1984.

The Committee recommended that the ground water recharge should be estimated based on the ground water fluctuation method. However, in areas where ground water level monitoring is not adequate in space and time, norm of rainfall infiltration may be adopted. The rainfall infiltration contributing to ground water recharge are evolved based on the studies undertaken in various ground water projects in India. The norms for recharge from rainfall under various hydrogeological situations are recommended in Table 3.

The normal rainfall figures are taken from India Meteorological Department which is main agency for collection and presentation of rainfall data. The ranges of rainfall infiltration factor are recommended as a guideline and need to adopted based on applicability of these to prevalent hydrogeological situation.

Table - 3 Rainfall Infiltration Factor in Different Hydrogeological Situations.

Hydrogeological Situation			Rainfall infiltration factor
1.	**Alluvial areas**		
	a.	Sandy. Areas	20 to 25 percent of normal rainfall.
	b.	Areas with higher clay content.	10 to 20 percent of normal rainfall.
2.	**Semi consolidated sandstones.** Friable and highly porous.		10 to 15 percent of normal rainfall.
3.	**Hard rock areas**		
	a.	Granitic terrain	
	i)	Weathered and fractured.	10 to 15 percent of normal rainfall.
	ii)	Un-weathered	5 to 10 percent of normal rainfall.
	b)	Basaltic terrain	
	i)	Vesicular and jointed basalt.	10 to 15 percent of normal rainfall.
	ii)	Weathered basalt.	4 to 10 percent of normal rainfall.
	c)	Phyllites, limestones, sandstones, quartzites shales etc,	3 to 10 percent of normal rainfall.

NORMS FOR ESTIMATION OF GROUND WATER RECHARGE

Based on the analysis of well hydrograph, the water level fluctuation and specific yield approach is recommended for recharge estimation.

a) Ground Water Level Fluctuations.

Generally a well hydrograph follows a definite trend like stream hydrograph with a peak followed by a recession limb. The recession limb in a post-recharge period is charcterised by two distinct slopes-one a steep one (from August to October/ November) and other a gentler one (from October/November to June). The steeper limb signifies the quick dissipation of a major part of recharge during the later part of recharge period itself. This recession of water table is very sluggish in alluvial areas compared to hard rock areas wherein a substantial recession occurs within one or one and half month after the peak water level is achieved. Due to less demand and adequate soil moisture in later half or recharge period and under prevailing agricultural practice in India the fast receding limb of hydrograph is not considered for computation of utilisable recharge. The utilisable recharge is estimated based on pre-recharge (pre-monsoon-April-May) to post recharge (Post-monsoon-November) water level fluctuation for the areas receiving South-West monsoon. For the areas receiving North-East-monsoon similar approach for taking pre monsoon (November) and post monsoon (March) water level fluctuation can be adopted.

The monitoring of water level network stations needs be adequate in space and time to smoothen the inconsistencies in observations which may arise due to varied hydrogeological situations and other factors.

b) Specific Yield

The specific yield of the geological formation in the zone of water level fluctuation may be computed from pumping tests for utilising these in recharge estimation: As a guide following values computed in different studies are recommended :

1.	Sandy alluvial area	12 to 18 percent.
2.	Valley fills	10 to 14 percent.
3.	Silty/clayey alluvial area	5 to 12 percent.
4.	Granites	2 to 4 percent.
5.	Basalts	1 to 3 percent.
6.	Laterite	2 to 4 percent.
7.	Weathered phyllites, shales, schist & associated rocks.	1 to 3 percent.
8.	Sandstone	1 to 8 percent.
9.	Limestone	3 percent.
10.	Highly Karstified limestone	7 percent.

C. Normalisation of Rainfall Recharge.

The water table fluctuation in an aquifer corresponds to the rainfall of the year of observation. The rainfall recharge estimation should be corrected to the long term normal rainfall for the area as given by India Meteorological Department.

For calculation of the annual recharge during monsoon the formula indicated below may be adopted.

$$\text{Monsoon Recharge} = (\Delta S + DW - Rs - Rigw - Ris) \times \frac{\text{Normal monsoon RF}}{\text{Annual monsoon RF}_1} + Rs + Ris \qquad \text{... (10)}$$

where

ΔS = Change in groundwater storage volume during pre and post-monsoon period, (April/May to November)_, (million cubic metre or mcm).

DW = Gross groundwater draft during monsoon (million Cubic metre).

Rs = Recharge from canal seepage during monsoon (mcm).

Rigw = Recharge from recycled water from groundwater irrigation during monsoon (mcm).

Ris = Recharge from recycled water from surface water irrigation during monsoon (mcm).

RF = Rainfall (metre).

To eliminate the effects of drought or surplus rainfall years, the recharge during monsoon is estimated as above for a period of 3 to 5 years and an average figure is taken for long term recharge. Recharge from winter rainfall may also be estimated on the same lines.

Besides natural ground water recharge estimation, recharge due to seepage from surface water canals, return seepage from irrigation fields, seepage from tanks and lakes, contribution from inflluent seepage, potential recharge in waterlogged and flood prone areas, and computation of ground water resources in confined aquifers is also taken into consideration.

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