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CURRENT STATUS OF METHODOLOGY FOR GROUND WATER ASSESSMENT IN THE COUNTRY IN DIFFERENT REGION

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PREFACE

Ground water potential can be classified as static and dynamic. The static ground water potential can be defined as the amount of ground water available in the permeable portion of the the aquifer below the zone of water level fluctuation. The dynamic resource can be defined as the amount of ground water available in the zone of water level fluctuation. The usable ground water resource is essentially a dynamic resource which is recharged annually or periodically by rainfall, irrigation return flows, canal seepage, and influent seepage etc.

The present study aims at collecting information from Central Ground Water Board and State Ground Water Organisations, about the methods that are being followed for ground water resources evaluation and reviewing them. The information has been collected from Central Ground Water Board, New Delhi; National Bank for Agriculture Rural Development; Ground Water Department, Government of Andhra Pradesh; Department of Mines and Geology ,Government of Karnataka; Ground Water Survey Circle, Water Resources Department, Bhopal, Madhya Pradesh; Groundwater Survey and Development Agency, Pune, Maharastra; Orissa Lift Irrigation Corporation Limited, Bhubaneswar, Orissa; Ground Water Department, Jodhpur, Government of Rajasthan; Public Works Department, Groundwater, Madras, Tamilnadu. It has been reported that the ground water estimation methodology recommended by Ground Water Estimation Committee is being used by most of the organisations.

The present review on current status of methodology for ground water assessment in the country in different regions has been carried out by Dr. G. C. Mishra Scientist 'F' as a part of the work programme of Ground Water Assessment Division .

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SUMMARY

Ground water potential can be classified as static and dynamic. The static ground water potential can be defined as the amount of ground water available in the permeable portion of the the aquifer below the zone of water level fluctuation. The dynamic resource can be defined as the amount of ground water available in the zone of water level fluctuation. The usable ground water resource is essentially a dynamic resource which is recharged annually or periodically by rainfall, irrigation return flows, canal seepage, and influent seepage etc.

The groundwater resources need to be evaluated using groundwater balance equation containing all recharge and discharge components including the sub basin inflow and outflow. The static storage in a ground water basin should be assessed in order to use part of it during drought period. Ground water from the static storage should be used after evaluating its economic value.

The ground water estimation methodology recommended by the Ground Water Estimation Committee is being currently used in different regions of the country. The component of water balance which need further research are:(i) recharge due to rainfall and irrigation return flow in hard rock region, (ii) recharge from tanks, (iii) evaportranspiration losses from shallow water table (iv) influent and effluent seepage, (v) seepage from canals in hard rock region and (vi) computation of seepage from canals in shallow water table aquifer. The dynamic nature of ground water needs to be considered while evaluating the ground water potential.

INTRODUCTION

Ground water regime is a dynamic system in which water is absorbed at the land surface and eventually recycled back to the surface. The ground water movement occurs through the porous unconsolidated sediments and through interconnected openings in the rocks that mantle the earth. The occurrence and movement of ground water depend on the geohydrological characteristics of the sub surface formations. These natural deposits vary greatly in their lithology, texture and structure and differ in respect of their hydrological characteristics. The frame work in which ground water occurs is as varied as those rocks and as intricate as their deformation, which has progressed through geologic time. The possible combinations of variety and intricacy are virtually infinite. It has been, therefore, experienced that ground water investigations at a given site almost always exhibit a certain uniqueness (Brown et al,1972).

For estimating regional ground water potential it has been recommended that the general manner in which the regime functions must be identified. The potential for recharge to the ground water regime in an area depends on the amount and pattern of annual precipitation in relation to the potential evaporation in the area and to the occurrence of any surface or sub surface inflow from adjacent areas. Most of this potential recharge is commonly intercepted by the soil veneer and eventually returned to the atmosphere through processes of evapotranspiration or dissipated through surface run-off. The amount that actually contributes to ground water recharge varies seasonally and from year to year. It is generally difficult to quantify the recharge from various sources. Similarly, ground water discharge may be difficult to quantify because of temporal variations, especially if it occurs at a number of scattered locations, either at the land surface in the form of springs, gaining streams, lakes, ponds, marshes or growths of phreatophytes, or at depth through permeable formations (Brown et al,1972).

The relationship between recharge and discharge under natural conditions is often obscured and not readily apparent from field observations. However, useful guide-lines that are generally applicable to specific problem areas have been provided on the the basis of practical experience gathered through field study of ground water regimes in a variety of natural environments. These guide-lines have been summarized as follows (Brown et al):

i) In relatively undeveloped areas long-term average discharge from a ground water reservoir can be presumed to be in equilibrium with long-term average recharge. Therefore, a large volume of ground water discharge at the land surface is a proof of high recharge to the system.

ii) The potential for recharge in an area as determined by observing precipitation, should not be confused with actual recharge. The two are related only in that actual recharge cannot exceed the potential for recharge. Thus, desert areas characteristically receive low recharge because of low potential for recharge, but humid areas do not necessarily receive high recharge unless rocks underlying the land surface are highly permeable and water level is not close to the ground surface.

iii) Surface water discharge represents both run-off and ground water discharge. The latter can be approximately equated with the low-flow natural discharge less inflow of streams not originating in the area.

iv) A ground water reservoir tends to fill at least to the level of the lowest outlet regardless of aquifer characteristics.

Usually, this level corresponds to the lowest point at which an aquifer is exposed at the land surface in a ground water basin. The occurrence of discharge at such a location is good evidence of saturation below that level. The absence of any discharge at such a location indicates sub surface drainage, in which case observation well data are needed to determine the local level of saturation.

v) Withdrawal of water from a ground water reservoir through development (usually construction of wells) will reduce ground water discharge by a corresponding amount. Withdrawal in excess of recharge removes water from storage resulting in decline of water table .

India is a vast country having diversified geological setting and hydrometerological conditions. Physiographically India may be divided into five distinct and well defined parts, viz.,(i) the Himalayas; (ii) the Indo Gangetic Plains; (iii) the Thar or Rajasthan Desert; (iv) the Southern Plateau; and (v) the Coastal Belts (Framji et al,1982). The country covers an area of 3,287,780 km^2 of which two third is occupied by hard rock. The replenishable ground water resource of India is about 452 cubic km. and nearly 50% of this is in the Peninsular India. There is also great variation in precipitation, evaporation and evapotranspiration and temperature in different parts of the country. The country may be divided into seven agroclimatic zones. These varied conditions in physiography and climate necessitate specific regional estimation of the ground water recharge and discharge components.

In 1972 guide lines for an approximate evaluation of ground water potential was circulated by the Ministry of Agriculture, Government of India, to all the State Governments and the related financial institutions. These guide lines are discussed below.

REVIEW

(i) Norms for approximate Evaluation of Ground Water Potential:

1. Ground water Recharge from Rainfall

(a) For alluvial areas it has been suggested to compute the recharge due to rainfall by the Chaturvedi(1973) formula

$$R_p = 2.0\ (R-15)^{2/5}$$

where

R_p = recharge in inches

R = rainfall in inches.

In metric system the Chaturvedi formula is given by (vide Karanth,1987):

$$R_p = 13.93\ (R-381)^{2/5}$$

where R_p = recharge in mm, and R = rainfall in mm.

It may be noted that there is a lower limit of the rainfall below which the recharge due to rainfall is zero. The percentage of rainfall recharged commences from zero at R=15 inches and increases with rainfall. The percentage recharge, $(R_p/R)100$, is maximum at R=25 inches, the maximum percentage being 20.09 % of the rainfall. Beyond R=25 inches, the percentage of rainfall getting recharged decreases with increasing rainfall. The decrease in percentage may arise in areas of high rainfall and shallow water table position. The formula contains the potential term responsible for recharge. The lower limit of rainfall in the formula may account for the soil moisture deficit, the interception losses and potential evaporation. These factors are being site specific, one generalised formula may not be applicable to all the alluvial areas. More ever the maximum percentage of rainfall getting recharged at 25 inches of rainfall independent of prevailing hydrological and geological conditions in an area is not realistic. However Chaturvedi's empirical formula which has been derived based on water level fluctuation and rainfall amounts in Ganga-Yamuna doabs is applicable to this region. Tritium tracer studies on ground water recharge in the alluvial deposits of Indo-Gangetic plains of Western U.P.,Punjab and Haryana show that the recharges due to rainfall in these areas are 22%, 18% and 17% of the rainfalls respectively (Goel et al.,1975). The corresponding rainfall values in Western U.P., Punjab, and Haryana are 990, 460 and 470 mm respectively. The recharges for these rainfall values computed by Chaturvedi formula are 18.3% , 17.4% , 17.8% respectively.

The rainfall recharge values have been estimated by tritium method in the alluvium in Gujurat state. It has been reported that the percentage of rainfall recharge at two sites in Ahmedabad ,and at another three sites, one site each in Varahi, Kapandvanj and Kalol, are 7.0, 5.5, 3.3, 13.0 and 6.7 respectively. At Ahmedabad the rainfall has been reported to be 600mm and by Chaturvedi formula the percentage of rainfall recharge is 20.0% . At Kapadvanj the annual rainfall is 1210mm and the percentage of rainfall recharge computed by Chaturvedi formula is 16.9. This indicates that Caturvedi formula will not be applicable to the alluvium in Gujarat state.

(b) In hard rock area it has been suggested that the recharge due to rainfall can be taken up to 7.5 percent of the rainfall. This suggestion gives the upper limit of recharge due to rain fall. It is worth looking into the water balance study conducted by Sutcliffe, Agrawal, and Tuckler (1981) in Betwa basin. The Betwa, a tributary of Jamna, drains from the Decan Plateau. The basin is saucer-shaped, with sandstone hills around and clays under lain by Decan trap basalt in the lower ground towards the centre. The mean annual rainfall over the period 1926-1975 is 1138 mm and the mean runoff is 351mm. The soil moisture recharge over the basin is about 175mm and the ground water recharge in an average year is 50mm. According to the norm the maximum ground water recharge will be 85 mm which is too higher than the actual. The net mean rainfall is 583mm and the ground water recharge is about 8.6% of the net mean annual rainfall or 4.4% of the mean annual rainfall. The net rainfall has been deduced by subtracting monthly potential evaporation from the monthly basin rainfall.

The rainfall recharge has been estimated by Athavale et al. (1978) in the Granite and Gondwana sand stone region. The estimated recharge values at two sites in granite region are 8.3 and 6.1 % of the annual rainfall. At two sites in Gondwana sand stone the rainfall recharges are 15.5 and 5.4% . The average rainfall recharge in Maner basin in Andhra Pradesh works out to be 7.57 % of the annual rainfall. Thus the recommended rainfall recharge is appropriate for some hard rock region.

Besides geological conditions the climatological conditions would control the recharge due to rainfall. The following percentages of rainfall recharge to various aquifers in Rajasthan have been reported (UNDP,1976).

Table 1: % of Rainfall Recharged to Ground Water in Rajasthan

Basin	Aquifer	Annual Rainfall (mm)	% Recharge
Sikar	Quaternary aeolian sand	409	8.0
Bikaner & Luni	Palana	409	3.0
Bikaner	Nagpur sandstone	404	1.7
Bikaner	Nagpur limestone	404	2.0
Bikaner	Basement crystalline	404	1.5

(c) In project areas where authentic data are available about the rise of water table, it has been suggested that the rainfall contribution to ground water recharge may be calculated as a second check by multiplying rise of the water table with estimated average value of specific yield and making adjustments for the withdrawals of ground water if any during the monsoon season and also for the seepage during the period from canals and other surface sources which may exist in the area. The water balance approach norm suggested by the Ministry of Agriculture is appropriate. The average specific yield in the zone of fluctuation should be determined from a water balance study for the non monsoon period and using this specific yield the recharge due to rainfall should be determined using the water balance components for the monsoon period.

The values of specific yield in the zone of fluctuation of water table in different parts of the basin can be computed using the graph of particle size and specific yield presented by Johnson (1967). The graph is given in Figure 1.

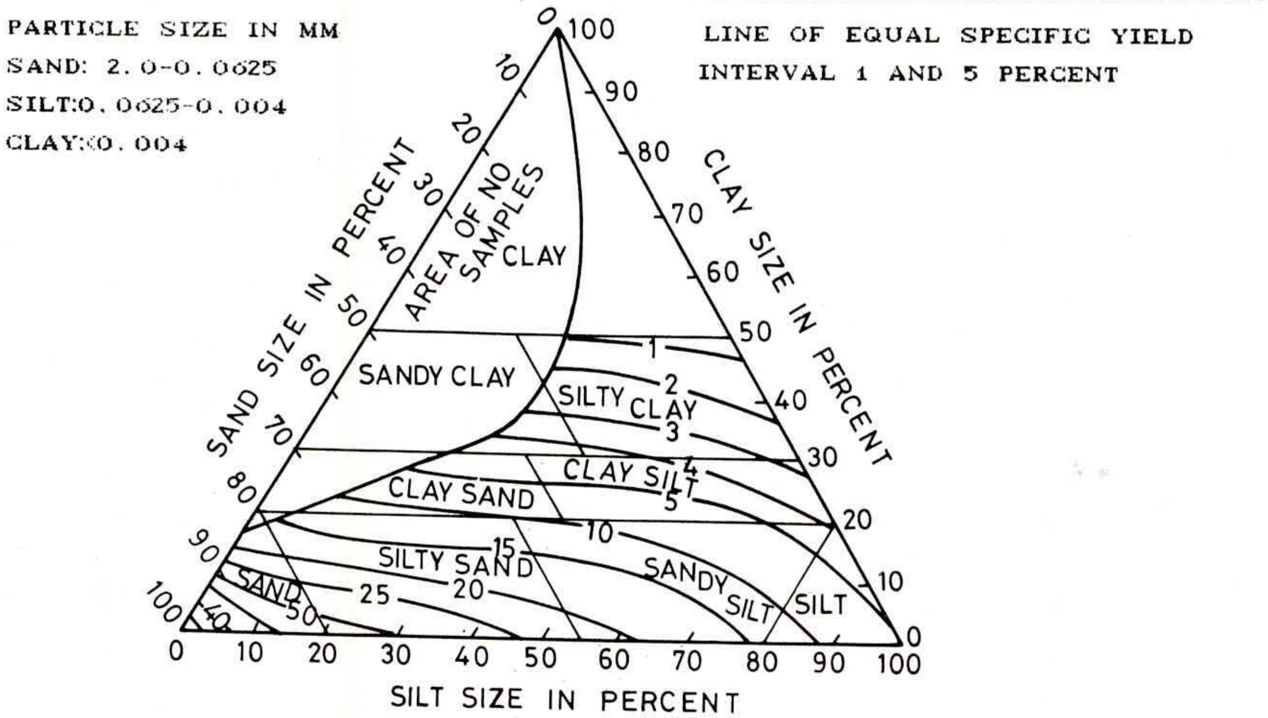

FIG.1- SOIL CLASSIFICATION TRIANGLE SHOWING RELATION BETWEEN PARTICLE SIZE AND SPECIFIC YIELD (JOHNSON, 1967)

An alternate approach which has been suggested and applied by Sutcliffe can be applied to ascertain the recharge due to rainfall. The monsoon climate in different river basins in India provides a large seasonal water surplus of rainfall over evaporation, which either runs off or recharges the sub surface reservoirs. By measuring or estimating the rainfall, the evaporation and the runoff, it is possible to make an estimate of the total recharge. It is necessary to distinguish between the soil moisture reservoir which is the zone from the ground surface to the bottom of the root zone, and the groundwater reservoir which drains below this. The soil moisture is available for evaporation during the dry season while the second drains beyond the reach of roots and eventually contributes either to deep storage or to maintain the base flow or dry season component of river discharge. Under natural conditions the soil moisture replenishment eventually evaporates, while the ground water recharge does not. The annual water balance of a basin may be simplified by considering the seasonal cycle as a single period of water surplus during the monsoon and a single period of deficit during the reminder of the water year. During the monsoon period, monthly rainfall is greater than the potential evaporation where as during the the rest of the water year the potential evaporation in most time exceeds rainfall. The early part of monsoon is the period of soil moisture recharge and the remaining period of monsoon is the period of water surplus. The water surplus includes ground water recharge as well as surface runoff. After the end of monsoon begins the period of soil moisture utilisation followed by a period of water deficit. The soil moisture recharge will be reasonably constant from year to year in the absence of land use changes and it can be considered as a first charge on the net rainfall, the surplus of rainfall over evaporation. With the assumptions that soil moisture recharge is a fixed charge on the net rainfall and the water surplus is always divided in the same proportion between runoff and ground water recharge, it is possible to draw a straight line graph of measured runoff versus seasonal net rainfall. The soil moisture recharge is the intercept on the horizontal axis. It is the net rainfall required before any runoff occurs. The ground water recharge is the divergence between the 45^0 line and the net rainfall runoff points. The method suggested by Sutcliffe et al requires the annual stream flow, seasonal rainfall and potential evaporation data for several years for prediction of rainfall recharge. The method therefore can not be applied readily unless the required data are available. Other than rainfall the ground water is also recharged from other sources for which the following norms have been laid down.

2. Ground Water Recharge from Other Sources:

(a) Seepage from canals:

It has been recommended that seepage loss from canal should be considered as 1.8 to 2.5 cumec/10^6 sq metre of the wetted area.

The seepage losses have been recommended neglecting the importance of the type of soil or the hydraulic conductivity of the soil in which the canal runs and the water table position in the vicinity of the canal. Seepage loss from canals which run in hard rock region has not been recommended. Also seepage losses from lined canals have not been recommended.

As reported by the Indian Standard (IS:9452 part 1-1980) the loss of water by seepage from unlined canals in India varies from 0.3 to 7.0 $m^3/s\ /10^6 m^2$ depending on the permeability of soil through which the canal passes, location of water table, distance of drainage, bed width, side slope, and depth of water in the canal.

Estimation of seepage losses from Ganga Canal near Roorkee using radio isotopes by Krishnamurthy and Rao(1969) reveals that Ganga Canal with its silty clay bank and water logged condition in the vicinity looses 0.35 $m^3/s/10^6 m^2$ as seepage loss. Seepage loss computed by ponding method from Salawa distributary, which is a distributary of Upper Ganga Canal and runs in Meerut District, has been found to vary from 1.69 $m^3/s/10^6\ m^2$ at the head reach to 0.97 $m^3/s/10^6\ m^2$ at the tail end (Singh,1983). The seepage loss computed in Dabthua distributary which runs in Meerut district is found to vary from 1.65 $m^3/s/10^6\ m^2$ at the head reach to 1.296 $m^3/s/10^6\ m^2$ at the tail reach (Singh, 1983). The seepage loss from Sarda Sahayak Feeder Channel computed by analytical method has been reported to be $5.658 m^3/s/10^6\ m^2$ (Technical Memorandum no 44, 1973).

Seepage loss from Lower Bhawani distributary which runs in a hard rock region has been reported to be 16 to 20 % of the canal discharge(Raju et al.,1980). The subsoil is comprised of weathered and semi weathered gneiss and charnockite overlain by a two meter thick black calcareous soil. Seepage loss from canals in Vedavati basin has been reported to be 9 to 10 % of the water conveyed in the canal (Karanth,1978).

The seepage loss from a ridge canal when the water table is at large depth can be computed either using Vedernikov formula or using Kozeny formula. According to Vedernikov (vide Harr, 1962) the seepage per unit length of the canal is given by

$$q=k(B+AH)$$

in which B = the width of the canal at the water surface; H = the maximum depth of water in the canal; and A = a parameter which has been derived rigorously for a trapezoidal straight canal in a homogeneous isotropic porous medium of infinite depth with the assumption that the water table lies at large depth below the canal bed. The water table can be considered to be at large depth if it lies below the canal bed at a depth more than 1.5 B. The value of the parameter A for a given canal cross section can be obtained using the graph given in Fig.2. According to Kozney formula the value of the parameter A is equal to two.

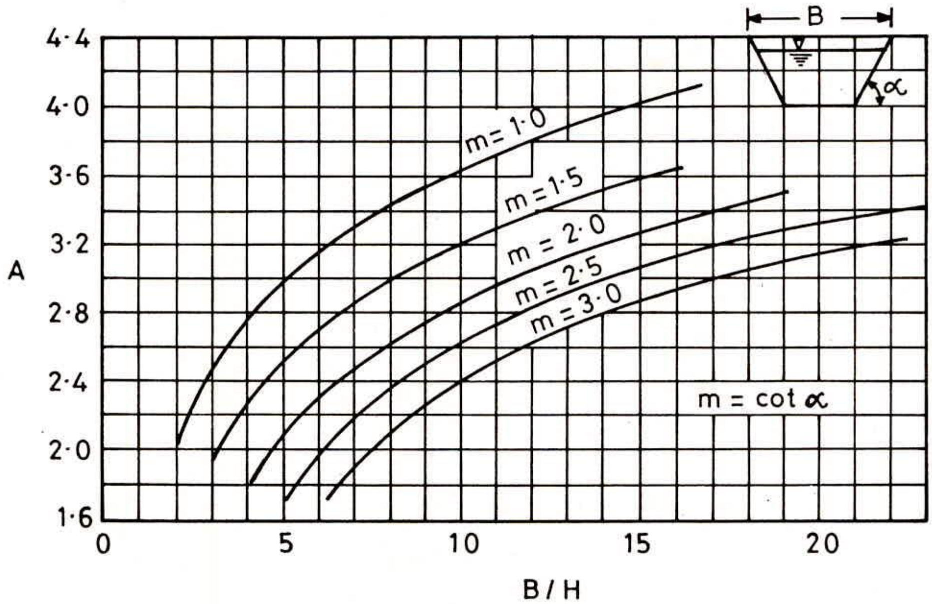

FIG.2- VEDERNIKOV'S PARAMETER A

The crux of computation of seepage depends on correct assessment of the hydraulic conductivity k. Knowing the percentage of sand silt and clay the hydraulic conductivity of undisturbed soil can be approximately known using Johnson's chart given in Fig.3.

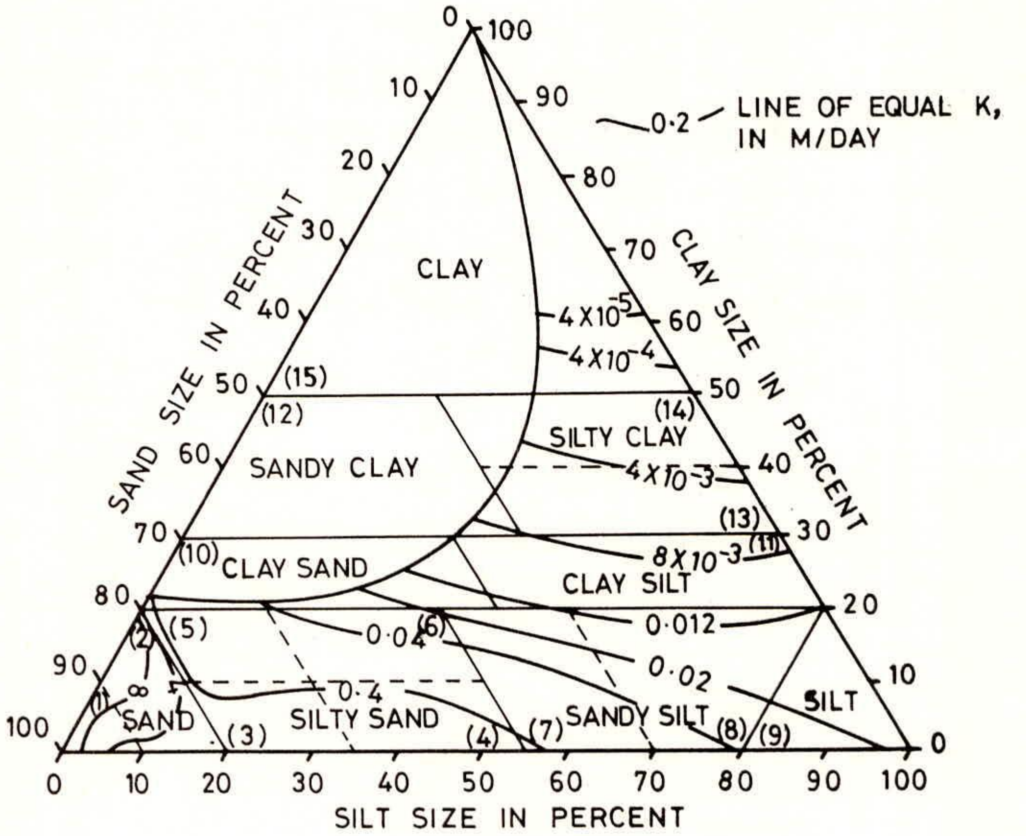

FIG.3- RELATION OF HYDRAULIC CONDUCTIVITY TO SAND SILT AND CLAY PERCENTAGES(JOHNSON, 1963)

Let us compute the seepage loss from a canal for various type of soils using Vederinkov's approach and the hydraulic conductivities values given by Johnson. Let the canal have the following dimension:

Bed width = 51.45m;

Water depth, H = 3.355m;

Side slope = 1.5:1 ; m = cotα = 1.5;

Wetted surface area of unit length of canal= 57.5 m^2;

The width of the canal at the water surface, B =61.5m;

For m=1.5, and B/H = 18.3,the parameter A=3.7.

The seepage losses for different type of soil are presented below.

Table 2 Seepage losses from a canal corresponding to different type of soils computed using Vederinkov's approach and Kozney approach

Soil type	Range of hydraulic conductivity (m/day)	Range of seepage loss (cumec/10^6 m^2)	
		Vederinkov's approach	Kozney approach
Sand	8.0 to 4.0	119 - 59.5	109.8 - 54.9
Silty sand	4 to 0.04	59.5 - 0.59	54.9 - 0.549
Sandy silt	0.4 to 0.012	5.95 - 0.1785	5.49- 0.1647
Clay silt	0.012to 0.008	0.1785 - 0.119	0.1647-0.1098
Silty clay	0.008 to 0.004	0.119 - 0.059	0.1098-0.0549

It will be appropriate to compute seepage losses using the Vederinkov parameter A and the hydraulic conductivity given by Johnson.

Transmission loss of $0.60 m^3/s/10^6 m^2$ of wetted perimeter of lined canal is generally assumed (IS:10430-1982).

(b) Recharge from Storage Tanks:

The norm for recharge from storage tanks has been laid down as 5 percent of the storage in the tanks.

A study on recharge from 12 percolation tanks in Ahmednagar by Kittu, Mehta and Jain (1990) shows that the recharge varies from 36.0% to 76.7% of the storage in tanks. The average recharge is found to be 50.90% of the storage in the tanks. Thus the recharge values recommended in the norm is very much less than the actual.

(c) Return flow:

It has been recommended that the return flow from irrigation is 20 percent of the estimated average total water applied; higher figures for paddy areas should be considered.

In irrigation practices certain portion of the applied water, over and above the consumptive use, infiltrates into the ground to reach either an aquifer as deep percolation or to a nearby stream as inter flow. This contributory repleshiment from irrigation is referred to as irrigation return flow.

Return flow from irrigation has been studied both experimentally and analytically by Harley(1968). It has been found that the loss can be of the order of 32% of the water supplied including precipitation.

Irrigation return flow from paddy field in Parkal experimental basin in Andhra Pradesh has been conducted by Karanth (1978). Drum culture method has been used to estimate the return flow. The water-balance equation that has been applied to a closed paddy field under continuous submergence condition is:

$$P+W_a = CU+I$$

where

P=precipitation accumulated during the period of observation,

W_a= water applied,

CU= consumptive use, and

I= infiltration.

As reported the infiltration percentage varies from 16 to 82 percentage of the water available.

Thus the irrigation return flow suggested in the norm is much less than the actual that may occur.

The above mentioned norms were used for computation of ground water resources on block wise basis all over country. The above methodology of ground water resource evaluation has also been utilised for availing institutional finance.

(ii) Over Exploitation Committee Norms for Groundwater Resources Evaluation

A high level committee known as "Groundwater Over Exploitation Committee" was constituted to refine the then existing norms for ground water assessment which were evolved in the year 1972. The committee gave its recommendation in 1979 after detailed study and discussion with various State Groundwater Organisations.

The Groundwater Over Exploitation Committee has recommended the following norms for ground water resources evaluation.

(A) Recharge from Rainfall:

(i) In Sandy areas: 20 to 25 percent of normal rainfall;

(ii) In areas with large clay content: 15 to 20 percent of normal rainfall;

(iii) In hard rock areas: 10 to 15 percent of normal rainfall.

If on the basis of field studies the State Ground water Organisation finds that the percentage of rainfall infiltration is less than the above figures in either alluvial or hard rock areas then the actually observed value of percentage infiltration should be adopted.

On the basis of the finding of the studies conducted by Athavale et al. (1978) in the Granite and Gondwana sand stone region, and studies conducted by Sutcliffe, Agrawal, and Tuckler (1981) in Betwa basin, it is seen that the recharge due to rain fall recommended by Over Exploitation Committee for hard rock areas is on a higher side.

(B) Recharge due to Seepage from Canals

(i) For canals in normal type of soils which have some clay content along with sand: 1.8 to 2.5 cumec/10^6 sq m of the wetted area.

(ii) For canals in sandy soils 3 to 3.5 cumec/10^6 sq m of the wetted area.

The above norms thus take into consideration the type of soil in which the canals run while computing seepage. However the actual seepage will also be controlled by the water table position and will be much less than the recommended values as indicated by the study conducted by Krishnamurthy and Rao(1969). It may be seen that the seepage losses from canals in hard rock areas have not been recommended by the committee.

(C) Return Seepage from Irrigation Fields

(i) Irrigation by Major Irrigation Sources (Gravity Canals):

35 % of the water delivered at the outlet for application in the field.

(ii) 40 % of the water delivered at the outlet for paddy irrigation only.

(iii) Irrigation by All Minor Irrigation Sources (Tube wells, Lift Canals etc.):

30 percent of the water delivered at outlet.

In all the above cases the return seepage figures include losses in field channels for which no separate estimate need be made.

It may be noted that the irrigation return flows will depend on the soil type, irrigation practice and type of crop. Therefore, irrigation return flows are site specific and it will vary from one region to another.

(D) Seepage from Tanks

44 to 60 cm per year over the total water spread. The losses should be taken into account depending upon the agro-climatic conditions in the area.

(E) It has been mentioned that while estimating the gross recharge the amount of seepage from other sources like the influent seepage and seepage from ponds and lakes for which no norms have been prescribed should also be accounted for. In case of stage of development the additional recharge expected from the surface water projects to be commissioned during the period should also be added.

(F) Net Recoverable Recharge

From the gross recharge calculated by summing up all the input components, the net recoverable recharge may be taken as 70 percent of the gross recharge.

In case some of the State Ground Water Organisations feel that the percentage of net recoverable recharge may be different from the above, they should carry out detailed field studies to revise the above values in specific areas.

(G) Water Level Fluctuation Approach

It has been recommended that the areas where sufficient data are available and in all cases where the stage of ground water development in a block/taluk is over 60 percent of the recoverable recharge the ground water should be evaluated by the water table fluctuation and specific yield approach. The fluctuation of water table should be taken as the difference between the lowest pre-monsoon and the highest post-monsoon water levels in an observation well. Inconsistencies in observations should be smoothed out making use of contours of water level fluctuation in an area. It has been suggested that ground water contours of adjoining divisions should be put on one map to check their continuity on a regional/basin basis.

The change in groundwater storage in a basin during a certain time period can be computed from the water table fluctuation exhibited in the basin during the time period. The simplest way to show water-table fluctuations is to show water-table position at two or more different times on separate maps. This is an effective method, particularly when the maps can be shown on the same page or sheet. A second method is to show contours of the water table at two or more different times by different line patterns, or by lines of different colour, on the same map. The extent of the fluctuations can be shown by isolines derived from two or more sets of water-table elevations. Such maps are particularly useful in areas where lowering of water table is excessive or is considered to be potentially so. Using the elevation, the change in water level can be determined by subtracting the water level at each data point at the end of the time period from the water level at the beginning of the time period. The resultant changes in water table position can then be contoured. The change in storage in a groundwater basin, ΔS, during a time period Δt can be computed using the relation

$$\Delta S = \sum_{i=1}^{N} s_{yi} \Delta h_i \, A_i$$

in which s_{yi} = specific yield of the aquifer in the area A_i; Δh_i = water level change in the i^{th} observation well; A_i = the area of i^{th} polygon which is the weightage of water level observation in the i^{th} observation well; N = total number of observation wells. Water level changes are weighted by drawing a Thiessen polygon around each observation well.

For assessing ground water potential by water table fluctuation approach, data recorded at a number of observation wells have to be used. However the committee has not specified the norm for the minimum number of observation wells required for assessing ground water potential by water table fluctuation approach.

The following specification may serve as a rough guide (IILRI,1974):

Table 2: Rough Guide for Required Number of Observacion Well

Size of the area in hectare	Number of observation points	Number of observation points per hectare
100	20	20
1000	40	4
10,000	100	1
100,000	300	0.3

As suggested by the Over Exploitation Committee the specific yield values for different types of geological formations in the zones of fluctuations of water table may be adopted as below:

(a) Sandy Alluvial areas	12 to 18 percent
(b) Silty Alluvial areas	6 to 12 percent
(c) Granites	3 to 4 percent
(d) Basalt	2 to 3 percent

Based on extensive compilation Johnson (1967) has specified specific yields of various textural classes of sedimentary materials as follows:

Type of sedimentary material	Specific yield (%)
Clay	2
Silt	8
Sandy clay	7
Fine sand	21
Medium sand	26
Coarse sand	27
Gravelly sand	25
Fine gravel	25
Medium gravel	23
Coarse gravel	22

It has been recommended that the gross recharge evaluated by the water table fluctuation method corresponding to the rainfall in the year of observation or corresponding to the average rainfall should be proportionately corrected to Normal Rainfall as given by the India Meteorological Department in the area on the basis of linear proportionality. If, the recharge calculated on the basis of the water table fluctuation approach widely exceeds (more than 10 percent) the value estimated on the basis of the penetration norms, the matter should be reviewed.

While estimating ground water availability by the water level fluctuation and specific yield approach the conceptual input and out put components should not be lost sight of.

The rise in water table in an area as reflected in the water levels between the pre-monsoon and post-monsoon period includes all components of recharge during the monsoon period including return seepage from the ground water pumped during monsoon period and used for irrigation purposes during the period. However, the component of ground water pumpage during monsoon period that does not go as return seepage to recharge the ground water reservoir is not accounted for in the observed water level fluctuation even though it has come out from the ground water reservoir. This should, therefore, be separately added as a component of recharge during the monsoon/kharif period presuming that 30 percent goes as return seepage during the period.

It would be desirable to first evaluate the figure of mean gross yearly recharge and mean gross yearly extraction before estimating the net water balance available for future development.

The concept of Net Water Balance has been introduced by the World Bank for clearance of minor irrigation works. This implies that:

(a) Future works should be cleared against Net Water Balance available for development.

(b) The unit draft of each category of work should first be estimated as gross draft based upon field survey. Thereafter, the future number of works that can be cleared against the available net water balance should be based upon their net draft as 70 percent of the gross draft. For example, if X is the net water balance in an area and Y is the gross draft of a particular type of pumpage work, then the total number of works that can be cleared against X are X / (0.7Y).

(c) Stage of Ground Water Development: Stage of Ground Water Development is taken as the ratio of the net draft to the net recoverable recharge; or Stage of Ground Water Development = (Net yearly draft) ÷ (Net yearly recharge)

The Ground Water Over Exploitation Committee has recommended the norms for evaluation of ground water resources depending upon levels of ground water development. For white areas ground water assessment was to be based on estimated norms of various recharge parameters. For grey areas seasonal fluctuation approach was to be insisted upon but for Dark area, however, methodology was not presented as such but micro-level analysis was to be insisted upon.

Groundwater, which is a renewable resource, is temporarily depleted when aquifers are over pumped. Aquifer storage is commonly described as temporary or permanent. The former refers to water stored between the highest and lowest levels of the water table and thus subject to seasonal drainage, which, averaged over a long period, itself provides a measure of the average recharge. However, below the minimum level of the water table in major aquifers lies a great volume of saturated soil that provides permanent storage available to wells of adequate depth but which can not be drained naturally. A good management practice during drought period demands adequate information on how much water is in dynamic storage and how much in static storage and how these volumes vary with time.

The maximum mining yield could be arrived at maximizing the objective function (Domenico, 1972)

$$\text{Max } \{V = \int_0^{t'} e^{-\lambda t}\, b(t)\, [X(t) + r(t)]dt + \int_{t'}^{\infty} [b(t')r(t')e^{-\lambda t}]\, dt\}$$

with respect to X(t), t', in which b(t) is the time dependent net benefit for unit pumped water, X(t) is the withdrawal from the storage, r(t) is recoverable replenishment during the mining period, r(t') is the recoverable replenishment after mining ceases, and t' is the time at which mining should stop and $e^{-\lambda t}$ is the present worth factor.

For evaluation of the time dependent benefit b(t), it is required to know the drawdown at well points to ascertain the pumping cost. The recharge rate r(t) can be determined by solving the ground water flow problem numerically for nonhomogeneous aquifers and by analytically for homogeneous aquifers.

Differentiating the objective function with respect to t' and equating to zero, Domenico has arrived at the following equation:

$$\frac{dV(t')}{dt'} = b(t')[X(t') + r(t')]e^{-\lambda t'} + \frac{db(t')}{dt'}\, r(t')\, \frac{e^{-\lambda t'}}{\lambda} + b(t')\, \frac{dr(t')}{dt'}\, \frac{e^{-\lambda t}}{\lambda} - b(t')\, r(t')e^{-\lambda t'} = 0$$

or $$b(t')\, X(t') + \frac{db(t')}{dt'}\, \frac{r(t')}{\lambda} + \frac{b(t')}{\lambda}\, \frac{dr(t')}{dt'} = 0$$

The second term of the above equation is negative as the benefit decreases with time due to increase in pumping cost. Solving the equation for t' would determine the mining volume .

Let the net benefit be given by (Morel -Seytoux,1978):

$$b(t)=b_0-Cs$$

in which s= drawdown , C= cost of pumping per unit lift per quantity of water. Considering the aquifer as a unit cell the draw down, s, at any time t has been expressed as

$$s= \left[\int_0^t X(\tau)d\tau \right]/\phi = W/\phi$$

in which ϕ = specific yield, W = the volume of water withdrawn in excess of natural recharge per unit area. If W_m is the volume of water mined till the time of exhaustion t', the corresponding benefit at the time of exhaustion is

$$b(t')=b_0-CW_m/\phi$$

Let the recharge rate be independent of withdrawal and hence be independent of time. Therefore, $\frac{dr(t')}{dt'}$ =0. Incorporating these

$$(b_0-CW_m/\phi\ )X(t') + \frac{r(t')}{\lambda} \{-C\ X(t')/\phi\} =0$$

Hence,

$$W_m= \phi b_0/C -r/\lambda.$$

CONCLUSION

The components of water balance which need further research are: i) Recharge due to rainfall, ii) Irrigation return flow, iii) Recharge from tanks iv) Recharge from influent streams, v) Capillary lift and evaporation losses, vi) Ground water draft in different agroclimatic conditions, vii) Static and dynamic components of groundwater potential, and viii) Assessment of potential indicating its quality and depth of occurrence.

The groundwater resources need to be evaluated using groundwater balance equation containing all recharge and discharge components including the sub basin inflow and outflow. The static storage in a ground water basin should be assessed in order to use part of it during drought period and it should be used considering the economics of its exploitation.

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