CASE STUDY CS (AR) 164

SEASONAL GROUNDWATER BALANCE STUDY IN PURI DISTRICT, ORISSA
(PART-II)

आपो हिष्ठा मयोभुवः

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PREFACE

Agriculture continues to be the dominant sector of Indian economy. For augmenting the agriculture production to a new high under the Special Food Grain Production Programme, the Planning Commission in the Govt.of India envisaged installation of about 6 lakhs shallow tubewells and dugwells annually in 88 selected districts of six States. Whereas, there is always the need for detailed assessment of available groundwater potential in each area for precise planning and impact assessment of the proposed development to protect ecology and regime, it was not possible to conduct such detailed studies in each of the 88 districts due to various constraints. So, a total of 6 representative basins/districts were selected for detailed studies of which, the Puri district in Orissa was entrusted to National Institute of Hydrology for conducting the groundwater balance and the groundwater model studies. The lumped model groundwater balance study will provide the groundwater potential of the area and the model study will indicate the effect of the proposed development on the groundwater regime on a long term basis.

The present volume deals with groundwater balance study in Puri district. The study is presented in two parts. While the Part-I report of the study pertains to the collection and processing of the data, the present report forming Part-II deals with the methodologies adopted for quantification of water balance components and their quantification. The seasonal groundwater balance for the Puri district is prepared and presented in the present report.

The present study is taken up under the annual work programme of the Deltaic Regional Centre of the Institute.The study has been conducted by Sh J V Tyagi, Scientist'C'. The technical assistance during the course of data collection and analysis was provided by Sh S M Saheb, SRA, Sh T Thomas, SRA and Sh U V N Rao, RA. The overall guidance for conducting the study was provided by Dr. P V Seethapathi, Scientist'F'.

(S M Seth)

DIRECTOR

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ABSTRACT

Water balance techniques have been extensively used to make quantitative estimates of water resources and the impact of man's activities on the hydrologic cycle. With water balance approach, it is possible to evaluate quantitatively individual contribution of sources of water in the system, over different time periods, and to establish the degree of variation in water regime due to changes in the components of the system.

The water balance study (lumped model) has been undertaken for the groundwater system of Puri district in Orissa. The study is carried out on seasonal basis i.e. for monsoon(Jun-Oct) and non-monsoon(Nov-May) seasons for a period of 5 years (1978-79 to 1982-83). The groundwater balance during monsoon season yields an estimate of rainfall recharge and that during non-monsoon season determines the degree of accuracy with which the components of water balance equation have been estimated.

Based on the available information, the water balance components for the study area were identified and each component except the rainfall recharge has been estimated independently by analysing the basic data. The methodologies adopted for estimation of these components have been discussed. The recharge from rainfall has been evaluated during the monsoon season as a residual term in the groundwater balance equation. During non-monsoon seasons, the unaccounted water has also been computed which is found to be within reasonable limits. Based on the annual recharge , the groundwater potential of the study area is also estimated.

1.0 INTRODUCTION

1.1 General

Groundwater is an important source of water supply throughout our country. Though, the groundwater resource of the country is limited, its use in irrigation, industries, municipalities and rural homes continues to increase. A greater emphasis, therefore, needs to be laid on the resource utilization studies and proper planning for the safe development and management of this vital resource. Based on the norms recommended by the "Groundwater Estimation Committee,March 1984", the total replenishable groundwater resources of the country have been estimated as 45.22 mham, out of which 6.94 mham have been kept for drinking, industrial and other committed uses and the remaining 38.28 mham of utilizable groundwater resources are meant for irrigation purpose. The present draft is 10.65 mham, leaving a balance of 27.63 mham of groundwater resources available for exploitation.

Thus, when seen for the country as a whole there is considerable groundwater still required to be developed. However, when viewed from micro level angle, there are pockets where intensive development has led to rather critical situations and manifestation of problems like declining groundwater levels, shortage in supply, ingress of sea water in the coastal areas etc. On the other hand, in many major canal command areas, the water table is progressively rising because of excessive seepage from surface irrigation and poor subsurface drainage leading to the creation of water-logging and salinity problems. Therefore, there is need for planned integrated development of surface and groundwater resources and their scientific management.

While planning for the development and management of a groundwater basin, it is to be ensured that a balance exists between the recharge to and discharge from the basin and the groundwater levels fluctuate within a particular range over the monsoon and non-monsoon seasons. This is best achieved by conducting the groundwater balance of the basin. The water balance of a groundwater basin establishes that all waters entering the basin during any given period of time must either go into storage within its boundaries, be consumed or flow out during that period.

The groundwater balance study serves as a means of solution to various important theoritical and practical hydrological problems. It enables a quantitative assessment of groundwater available for development. Knowledge of water balance also assists prediction of the consequences of artificial changes in the regime of groundwater basin. In coastal areas where sea water intrusion is a common problem, the quantity of fresh water storage in the basin aquifers can be assessed by accomplishing the groundwater balance. With water balance data, it is possible to compare individual sources of water in a system over different periods of time and to establish the degree of their effect on variations in the water regime. Further, the initial analysis used to compute individual water balance components and the coordination of the components in the hydrologic balance equation make it possible to identify deficiencies in the distribution of observational stations and discover systematic errors of measurements. Finally, water balance study enables evalution of one unknown component of water balance from all other known components. Thus, for proper assessment of potential, present use and additional exploitability of groundwater resource at optimal level, a groundwater balance study is necessary.

1.2 Statement of the Problem

Agriculture continues to be the dominant sector of Indian economy. With a view to augmenting the agriculture production under the Special Food Grain Production Programme, the Planning Commission envisaged installation of about 6 lakhs shallow tubewells/dugwells annually in 88 selected districts of six states. Apparently, the areas so selected have abundant groundwater resource and a first approximation study justifies the proposed quantum of groundwater withdrawal. However, intensive pumpage in localized pockets may create depression that will, not only affect the micro-environment, but may also limit the efficient functioning of the existing and proposed groundwater abstraction structures by way of well interference and lowering of water table. The purpose of installation of these structures will be defeated if excessive lowering of water table either renders them functionless or induces sub-optimality in their efficient functioning. Such a massive concentration of groundwater structures in selected locations must, therefore be supported by a detailed micro-level assessment of the various components of water balance in the concerned regions.

Though, there is always the need for detailed assessment of available groundwater potential in each area for precise planning and impact assessment of the proposed development to protect ecology and regime, it was not possible to take up such detailed studies in each of the 88 detailed districts selected for intensive groundwater development due to various constraints. So, a total of six representative basins/districts for different categories were selected and it was decided to carry out the groundwater balance and groundwater model studies for each of these selected areas. The lumped model groundwater balance study will provide an estimate of the available groundwater that can be safely withdrawn. Besides, it will also bring out the interrelated effect of stressing a particular component on the other constituents of the hydrologic cycle of the region. Coupled with this, a groundwater model study will indicate the effect of the proposed development on the groundwater regime on a long term basis. The model study will also be useful for attempting simulation of alternative policies for a safe abstraction in future.

Of the six representative areas selected for detailed studies, the Puri district of Orissa was entrusted by the Planning Commission to the National Institute of Hydrology, Roorkee for conducting the groundwater balance and model studies. Accordingly, these studies have been taken up in Puri district of Orissa. The studies have been divided in two volumes, 1) the groundwater balance study and 2) the groundwater model study. The present volume deals with the groundwater balance study (lumped model) in Puri district of Orissa.

1.3 Presentation of the Study

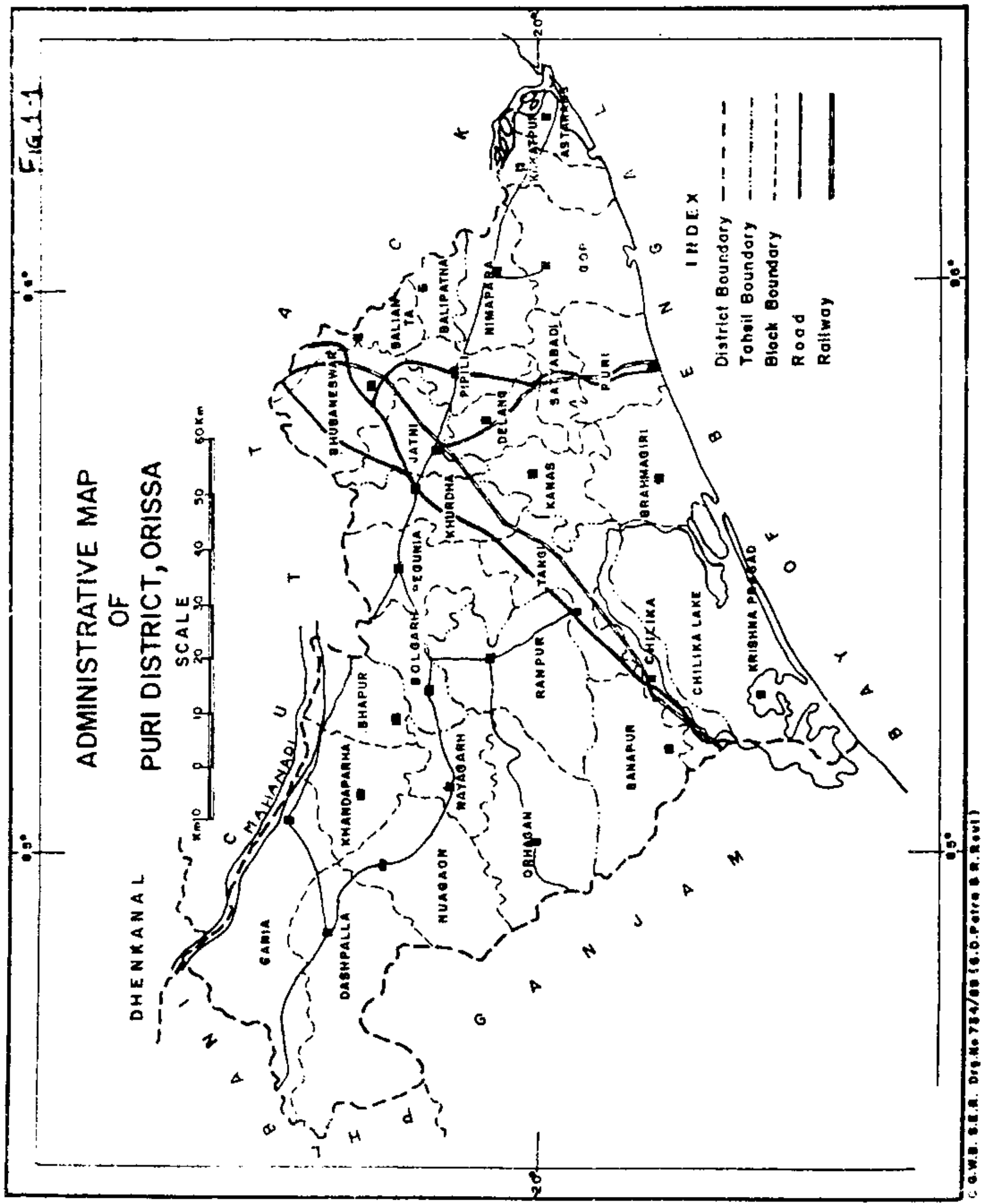
The water balance analysis of a groundwater basin involves a variety of data on various aspects. Therefore keeping in view the huge data requirement, the present study on groundwater balance has been divided in two parts. The first part pertains to the collection and processing of data and the report titled 'Groundwater Balance Study in Puri District of Orissa, Part-I (Processing and Analysis of Data)' has already been brought out (NIH Report No. CS(AR)-127). The report broadly dealt with the general description of the study area, data requirement, collection and processing of various types of data and the identification of various components of water balance in the Puri district. The present report forming Part-II of the study deals with the methodologies adopted for the quantification of various groundwater balance components and their quantification. In view of non availability of long term data, the study has been carried out for 5 years i.e. from 1978-79 to 1982-83 and the seasonal groundwater balance (for monsoon & non-monsoon seasons) is presented in the report.

1.4 Study Area

The study has been taken up in Puri district of Orissa. The district of Puri having a total geographical area of about 10,182 sq.km. forms a part of Mahanadi delta and largely comes under coastal alluvial tract of Orissa. The saline water occurs atop the fresh water along the coast. The study area is shown in Figure-1.1

The detailed description of the study area and necessary maps showing different features are presented in the part-1 report of the study .

Fig.1.1


ADMINISTRATIVE MAP
OF
PURI DISTRICT, ORISSA
SCALE
Km 10 0 10 20 30 40 50 60 Km
INDEX
District Boundary
Tahsil Boundary
Block Boundary
Road
Railway
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CUTTACK
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MAHANADI
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BHAPUR
NUAGAON
NAYAGARH
ODAGAN
BOLGARH
BEGUNIA
RANPUR
KHURDHA
TANGI
CHILIKA
CHILIKA LAKE
BANAPUR
KRISHNA PRASAD
BHUBANESWAR
JATNI
BALIANTA
BALIPATNA
PIPILI
DELANG
KANAS
BRAHMAGIRI
SATYABADI
PURI
NIMAPARA
GOP
KAKATPUR
ASTARANG
85°
86°
20°
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1.5 Availability and collection of Data

The data requirement for the study was identified and various Dept./Organisations in Orissa state were contacted for collection of the required data. The data as available with them were collected and after preliminary processing were presented in the Part-1 of the study reports. The various dept./organisations who provided the data are also acknowledged in the report. Therefore, the NIH report No.CS(AR)-127 may be referred to for the data used in the present study.

2.0. ANALYSIS AND METHODOLOGY

2.1. General

The study of water balance is defined as the systematic presentation of data on the supply and use of water within a geographic region for a specific period. The basic concept of groundwater balance is

Inflow to the groundwater basin (I) - Outflow from the groundwater basin (O) = Change in groundwater storage (ΔS)

Depending on geographic and hydrologic features of the basin, the items of inflow and outflow can include a number of components. So as a first step, the various components of inflow and outflow which play a significant role in water balance analysis of the study area were identified using the available data and physiographic and hydrologic characteristics of the Puri district. The inflow and outflow components thus identified, were coordinated in the hydrologic balance or groundwater balance equation as presented below.

$$Ri + Rc + Rr + Si = Tp + Et + Og + Se + \Delta S$$

Where,

Ri = recharge from rainfall

Rc = recharge from canal seepage

Rr = recharge due to deep percolation from field irrigation or returnflow (Rr=Rrs+Rrg)

Rrs = recharge from surface water irrigation

Rrg = recharge from groundwater irrigation

Si = influent seepage from rivers

Tp = withdrawal from ground water

Et = evapotranspiration losses (Etf+Etw)

Etf = evapotranspiration losses from forested or deep rooted tree areas

Etw = evapotranspiration losses from water-logged or shallow water table areas

Og = subsurface outflow from the basin

Se = effluent seepage to rivers

ΔS = change in ground water storage (positive for increase and negative for decrease)

The various components of inputs and outputs used in ground water balance equation have been discussed in part-I report of the study. The above expression considers only one aquifer system and thus does not account for the interflows between the aquifers in a multi-aquifer system. In Puri district, the confined aquifers also occur throughout the coastal saline tract and in patches in the sub coastal tract but the piezometric level data for these aquifers are not available. Though, the entire coastal saline tract of about 543 sq.km. has been excluded from the study area as the groundwater in top aquifers is generally saline and the tract is considered unsuitable for installation of shallow tube wells, but the interaction between confined and unconfined aquifers which occur rather in a small area in sub coastal tract could not be accounted for in the present study due to want of piezometric level data. However, if sufficient data related to water table and piezometric head fluctuations and conductivity of intervening layers are available, the additional terms for these interflows can be included in the equation.

Theoritically, the hydrologic equation must balance but it rarely happens in practice as there are always some inaccuracies in the estimation of various components, even if they are computed independently, and also some components may not be considered in the water balance analysis. The amount of unbalance or unaccounted water (η) can be evaluated as a residual term in the water balance equation. A low value of unbalance indicates a fair degree of accuracy in water balance analysis.

In the present study, the water year extending from 1st June to 31st May has been adopted and the groundwater balance has been carried out on seasonal basis i.e. for monsoon (Jun-Oct) and non-monsoon (Nov-May) seasons. The various water balance components except rainfall recharge have been estimated independently. The rainfall recharge has been computed during monsoon seasons using the water balance approach. The amount of unaccounted water has been computed during non-monsoon seasons using the estimated values of all the components of water balance.

2.2 Analysis of Groundwater Balance Components and Methodology Adopted for Their Estimation

2.2.1 Draft from Ground Water (Tp) :

Draft is the amount of water lifted from the aquifer by means of various groundwater structures and devices, e.g. tubewells, dug wells, rahat or any other means. The draft from these individual sources may vary widely depending upon the yield, type of source, depth of water table, type of water use etc. Thus, a suitable methodology is required to estimate the ground water draft.

The draft is generally estimated by multiplying the average number of working hours with the average draft per hour and the number of wells in the particular category. The sum of groundwater draft calculated for each category of sources will give the total draft. The average unit draft for above calculation is determined by conducting pumping tests on wells. Where wells are energised, the average unit draft per unit of electricity or fuel consumed can be determined for different ranges in depth to water levels. By noting the depth to water levels at each distribution point and multiplying the average draft value with the number of units of electricity or diesel consumed, the draft at each point can be computed for every month. Where wells are used for irrigation, agriculture statistics can be used for computation of groundwater draft for irrigation.

In the study area of Puri district, different types of groundwater structures such as dug wells, filter point tube wells and shallow tube wells are being used for irrigation purpose. The data on number of different types of structures and their average unit seasonal draft (i.e. for monsoon and non-monsoon seasons) were provided by the G W S & I, OLIC, Bhubaneswar. Using this data the groundwater draft for monsoon and non-monsoon seasons has been calculated by multiplying the number of structures with their unit seasonal draft.

2.2.2 Effluent and Influent Seepage (Se and Si):

The interaction between a river and the aquifer may be of two types. Depending upon the gradient, either aquifer may be contributing to the river flow (effluent) or river may be recharging the aquifer (influent). since the river stages and the groundwater levels keep on changing with time and space, the river may behave as influent or effluent. The direction of flow is governed by the position of water table in respect to the river stage and the amount of flow depends upon the both hydraulic gradient as well as the transmissivity of the aquifer system.

The effluent or influent flows are generally estimated using the following groundwater flow equation.

$$Q = T*I*L$$

where, Q = rate of flow, m**3/day

T = Transmissivity of the aquifer, m**2/day

I = Hydraulic gradient (the ratio of difference between the river stage at the point where the normal from the observation well meets river and the water level in the observation well to normal distance between the points under reference)

L = Length of the river reach, meters

For the purpose of estimating the effluent and influent seepage in the present study, the various rivers/streams have been divided in two categories, i) rivers originating from the study area and ii) rivers coming from outside and flowing through study area. The data on river stages for these rivers are not available. However, the data on average discharges during rainy, winter and summer seasons for the eight rivers originating from the study area as provided by GWS&I,OLIC,Bhubaneswar for one year are available. Using the average discharges, the average effluent seepage during monsoon and non-monsoons seasons for these rivers have, therefore, been estimated by assuming the following contribution from the groundwater reservoir to the river flow.

i) 40% of the river flow during rainy season

ii) 90% of the river flow during winter season

iii) 100% of the river flow during summer season.

In the second category of rivers, i.e rivers coming from outside, the river Kuakhai takes off from the Mahanadi river outside the study area and after entering the Puri district bifurcates into three namely, Daya river, Bhargavi river and Kushabhadra river. These rivers are perennial in nature and drain to the Bay of Bengal. On both sides of these rivers, the irrigation canals of Mahanadi delta stage II project exist all along the entire length of the rivers. These canals run for about 10 months in a year. Because of the seepage from these canals, the groundwater table below and around these canals remain high. Since these three water bodies i.e the river and the canals on both sides are not located much apart, the groundwater table throughout the cross section of these water bodies remain very high and it is assumed that there is no significamt hydraulic gradient developed in water table in the zone of influence of these water bodies to cause any effluent or influent seepage to or from the river during lean discharge periods. So during non-monsoon seasons, the seepage from canals only has been taken as recharge to the groundwater reservoir and interaction between rivers and aquifers has been neglected. However, in monsoon seasons, these rivers carry heavy floods and contribute to the basin aquifers. So in addition to the canal seepage the influent seepage from these rivers has also been considered and estimated during monsoon seasons. The influent seepage from each of the three major rivers, i.e Daya, Bhargavi and Khusbhadra rivers have been estimated during monsoon seasons using the following groundwater flow equation.

$$Q = T*I*L$$

In absence of the data on river stages, the average hydraulic gradient (I) in respect of different rivers were computed by taking the slope of the water table normal to the water table contours by using the water table contour maps as drawn for pre and post monsoon periods for the study area.

2.2.3 Evapotranspiration from Groundwater Reservoir (Et)

The amount of water that is directly extracted from the groundwater reservoir and lost to the atmosphere through evaporation and transpiration from plants needs to be computed for preparing the groundwater balance. The evapotranspiration losses from the groundwater reservoir may be of two types, i) in a water-logged tract due to rise in water table (Etw) and ii) in a forested or other deep rooted trees area which has the roots extending to the water table or upto capillary zone (Etf). The evaporation losses from groundwater reservoir may also take place through the surface of lakes and marshes fed by groundwater. The evaporation losses from these water bodies will be at potential rate which can be estimated by multiplying the pan evaporation value by the pan coefficient. However, the study area does not have any surface water structure fed by groundwater and the evapotranspiration losses from groundwater are estimated for shallow water table areas and deep rooted tree areas only.

i) Shallow Water Table Areas (Etw) :

The areas where the water table is within 1.5m from the ground surface have been considered as areas of discharge. In view of the proximity of the water table to the ground surface, the evapotranspiration from these areas have been considered at potential rate. For estimation of these evapotranspiration losses, the depth to water level contours were drawn and areas having water table within 1.5m were identified. The total amount of water extracted through evapotranspiration was estimated by multiplying the area with the average rate of potential evapotranspiration.

(ii) Deep rooted Tree Areas (Etf) :

For deep rooted trees which have direct access .to the groundwater, the evapotranspiration has been considered at potential rate. The evapotranspiration losses for such areas, therefore, have also been estimated by multiplying the area under these trees with the average values of potential evapotranspiration.

2.2.4 Sub-surface Outflow (Og)

For the estimation of sub-surface flow of groundwater from or to the study basin, contour maps of the phreatic surface and the piezometric surfaces of the deeper aquifers, if they exist, have to be prepared based on the phreatic and piezometric level data of wells located both within and outside the section delimiting the basin outlet. The flow into the region or out of the region is mainly governed by the hydraulic gradient and transmissivity of the aquifer.

In the present study, it is observed that there is no groundwater inflow to the study area from the adjacent basins. However, the groundwater outflow from the study area takes place to, i) the Chilika lake and ii) the saline tract along the coast (an area of about 543 sq.km which has been excluded from the study owing to the occurrance of the saline water in upper aquifers and therefere considered unsuitable for installation of shallow tube wells). For the purpose of estimation of subsurface outflows to these areas, the length of the section across which flow takes place was divided into a number of small reaches and computations made for each segment. The total outflow to each of the two areas were then computed by adding the outflow through each segment. The following equation has been used to determine the subsurface outflows.

$$Q = T*I*L$$

The hydraulic gradient for different reaches was determined by taking the slope of the water table normal to the water table contours and the average value of coefficient of transmissivity for the aquifers was provided by the GWS&I,OLIC,Bhubaneswar. The length of the section, across which flow occurs, was determined from the contour maps, the length being measured parallel to the contours. The subsurface outflows have been estimated for unconfined aquifers only. Though, the confined aquifers also occur in the coastal saline tract and the sub-surface flows might take place in these aquifers but in absence of the piezometric level data, the flows through these aquifers could not be accounted for in the present study.

2.2.5 Recharge from Canal Seepage (Rc):

The seepage water from canals after percolating deep joins the groundwater table and form a significant component in the groundwater balance studies. The recharge through seepage from canal depends on the infiltration capacity of the canal bed and sides, subsurface lithology, extent of wetted area, physical and chemical properties of water and relative position of bed with respect to the water table. There are several methods to estimate the seepage losses from canals. The indirect method include the assessment of the factors affecting the canal seepage. In direct methods, the inflow-outflow method and the Ponding method are most commonly used. The inflow-outflow method consists of measuring the water that flows into and out of the section of irrigation canal being studied. The difference between the quantities of water flowing into and out of the canal reach is attributed to seepage. The evaporation and precipitation being comparatively small can be neglected. In Ponding method, the rate of drop in a pool formed in the canal reach is measured. To maintain the constant water level in the pond, water is added to the canal. The accurately measured volume of added water is considered equal to the total losses and the lapsed time establishes the rate of loss. Besides the above methods, a number of investigation have been carried out elsewhere to study the seepage losses from canals. The Groundwater Estimation Committee (1983) has recommended the following norms :

(i) for unlined canals in normal type of soil with some clay content alongwith sand-15 to 20 ham/day/10**6 Sqm of wetted area of canal or 6 to 8 cusec/10**6 sq.ft of wetted area of canal or 1.8 to 2.5 cumec/10**6 sqm. of wetted area.

(ii) for unlined canals in sandy soils- 25 to 30 ham/day/10**6 sqm of wetted area, or 10 to 12 cusec/10**6 sq.ft of wetted area or 3 to 3.5 cumec/10**6 sq.m of wetted areas.

(iii) for lined canals, the seepage losses may be taken as 20% of the above values.

As discussed in Part-I report of the study (CS(AR)-127), the major canal network in the Puri district consists of a Puri main canal which takes off from the Mundali Weir (Mahanadi delta stage-II project), 6 branch canals namely, Daya west branch, Gop branch, Sakhigopal branch, Kanas branch, Chandanpur branch and Nimapara branch canals, and a number of distributories taking off from these branch canals. In addition to this, the canals of 4 medium irrigation projects and a number of minor irrigation projects also exist in the study area. As regards the data availablity for seepage loss estimation, the discharge data are available only for Puri main canal, while the information on the length of various canals, their average wetted perimeter and the average number of running days is available in respect of all the projects. Therefore, in absence of the complete canal discharge data, the Ground Water Estimation Committee (1983) norms have been used for estimation of seepage losses from the canals in study area.

2.2.6 Recharge From Field Irrigation (Rr) :

The irrigation water applied to the fields is partly lost by crops for meeting their consumptive use requirements and the balance infiltrates to recharge the groundwater storage. For irrigation of dry crops, the irrigation water applied is much less as the soil is required to be saturated for short periods, with the result that the greater part of the water applied is abstracted from the soil and lost to the atmosphere through evapotranspiration leaving only a small fraction, if any, to recharge the ground water. However, in the study area, paddy being the major crop in both the seasons, the amount of infiltration becomes significant in view of continuous submergence of soil for long durations. The amount of recharge from applied irrigation water, derived both from ground water and surface water sources, therefore, needs to be estimated for evaluating the groundwater balance.

For correct assessment of this quantity, studies are required to be taken up in the study area on experimental plots under different crops. However, the results of similar studies conducted elsewhere indicate that the return flow from irrigation by surface water sources varies from 25 to 50% of the water delivered at the outlet and that from irrigation by groundwater sources varies from 20 to 40%. Groundwater Estimation Committee has also recommended the values of return seepage from irrigation fields in the same range. In the present study, The G W Estimation Committee (1983) norms are adopted and the return flow from fields have been estimated as under.

1. Irrigation by surface water sources

(a) 40% of water delivered at the outlet in case of paddy irrigation.

(b) 35% of water delivered at the outlet in case of other crops.

2. Irrigation by groundwater sources

(a) 30% of the groundwater draft (the G W Estimation Committee recommended the return flow as 35% of the water delivered at the outlet in case of paddy irrigation. However, in absence of discharge data at outlet, the return flow is taken as 30% of the groundwater draft).

In all the above cases, return seepage figures include losess in field channels also hence these losess are not accounted for separately. The canal discharge data at outlet as required to estimate the return flow are not directly available. Therefore using the available statistics on cropwise area irrigated and the average water requirements of these crops during different seasons, the total quantity of irrigation water which is supposed to be applied to these crops was computed for monsoon and non-monsoon seasons of each year of the study period. The amount of irrigation water thus computed has been used for estimation of return flow from surface irrigation.

2.2.7 Change in Groundwater Storage (Δ S)

The groundwater storage responds to two factors, namely recharge and discharge. Where recharge exceeds discharge, groundwater storage increases and on the other hand, groundwater storage experiences decrease in its volume when the discharge exceeds recharge. The change in groundwater storage is exhibited by the changes in water table levels in the aquifers. The water table levels are observed through a network of observation wells spread over the area. Since a major portion of recharge takes place from the percolation of rain water, the groundwater levels are highest immediately after monsoon in the month of October and lowest before the onset of monsoon or in other words at the end of non-monsoon season. For preparing seasonal ground water balance, the net change in storage volume during monsoon (June to October) and non-monsoon seasons (November to May) are worked out. The increase in groundwater storage which is common phenomena in monsoon season is represented by a + ve sign and the decrease during non-monsoon season by -ve sign. For estimating the change in storage, the pre monsoon (June) and post monsoon (October) groundwater level contours were drawn by using the monthly water table observations for the study area. Then, with the help of planimeter the areas between two successive contours were measured and the average position of water table during pre monsoon and postmonsoon seasons calculated by using the following equation :

$$P = \frac{A_1(P_1+P_2) + A_2(P_2+P_3) + A_3(P_3+P_4) + \dots\dots\dots + A_n(P_{n-1} + P_n)}{2(A_1+A_2+A_3+\dots\dots\dots+A_n)}$$

where,

P is average position of water table,

P_1, P_2, P_3 are the values of successive contours and

A_1, A_2, A_3 are the areas enclosed by two successive contours.

The difference between average water table positions during premonsoon and postmonsoon season gives the average change in water table position during monsoon season while the difference between water tables of post monsoon and pre monsoon of next year gives the average change during non monsoon season. Once the above excercise was done for all the years, the change in groundwater storage (ΔS)during monsoon and non monsoon seasons were calculated as below:

Change in groundwater storage = Average change in water table *
Total study area * Specific yield (Sy)

The specific yield as used in above relationship may be computed from pumping tests. In absence of pumping test results, the following values of specific yield for different types of geological formations in the zone of water level fluctuations may be adopted.

1. Sandy alluvial area ----- 12 to 18%
2. Valley fills ----- 10 to 14%
3. Silty/clayey alluvial area ----- 5 to 12%
4. Granites ----- 2-4%
5. Basalts ----- 1 to 3%
6. Laterite ----- 2-4%
7. Sandstone ----- 1 to 8 %
8. Limestone ----- 3%

(Source: Groundwater Estimation Methodology , 1984)

Since the study area consists of three different geological formations i.e sedimentary, crystalline and alluvium, the average values of specific yield for these formations have been taken as 5%, 3% and 12.5% respectively for the analysis of change in groundwater storage.

2.2.8 Recharge from Rainfall (Ri):

Recharge from rainfall is the most important parameter among a variety of inputs used in the groundwater balance equation. A part of rainwater infiltrates into the soil and after filling the soil moisture deficiency percolates down reaching the water table. The water reaching the water table is known as the recharge from rainfall to the aquifer. This recharge which is a fraction of total rainfall depends upon several factors such as soil characteristics, topography, vegetal cover, land use, soil moisture conditions, depth to water table, intenstiy, duration and seasonal distribution of rainfall and other meteorological factors. Recharge from rainfall, therefore, varies in space and time. There are different approaches for estimation of rainfall recharge. Various types of emperical relationships established over the years between recharge and rainfall for different regions can be used to estimate the recharge. The Groundwater Estimation Committee has also recommended a range of recharge values for different types of geological formations. However, the water balance approach for estimation of rainfall recharge gives fairly better results provided a very extensive and accurate hydrological and meteorological data are available and all other components of water balance equation are estimated independently with suitable methodologies

In the present study, the rainfall recharge is calculated using the water balance approach. In this approach, all the components of water balance equation other than the rainfall recharge, are estimated using the relevant hydrological and meteorological information. Since almost all the rainfall recharge takes place during monsoon season with little or no recharge in non- monsoon, the recharge has been calculated for monsoon season by substituting the estimates of other components in water balance equation. The mean areal rainfall over the basin for monsoon season was computed using Thiessen Polygon method and thus the recharge coefficients i.e. recharge per unit rainfall have also been calculated.

3.0 ESTIMATION OF GROUNDWATER BALANCE COMPONENTS

3.1 General

The total geographical area of Puri district is 10,182 sq.kms. of which about 992 sq.kms. is covered under Chilika lake. In an area of about 543 sq.kms. along the coast, the groundwater in upper aquifers is generally saline and the tract is considered unsuitable for agriculture and also for installation of shallow tube wells. This coastal saline tract has, therefore, been excluded from the study area and the groundwater balance is conducted for a net area of 8,647 sq.kms. The various groundwater balance components which need to be considered in the study area have been analyzed and alongwith the methodology adopted for their estimation presented in chapter-2 of this report. The study has been carried out on seasonal basis for 5 years i.e.from 1978-79 to 1982-83. Except rainfall recharge, all other components of groundwater balance equation have been estimated independently by analyzing the available data. The rainfall recharge during monsoon seasons has been estimated using water balance approach to arrive at the overall groundwater balance. The estimation of various components are presented in the following paragraphs.

3.2 Draft from groundwater (Tp)

Various types of groundwater structures are in use for irrigation purpose in the study area. These include dugwells with tenda, dugwells with pumpset, filter point tubewells, shallow tubewells and medium deep tubewells. The data on yearwise number of these structures and their seasonal draft are presented in Part-I report (CS-(AR)-127). Using the available data, the total ground water draft in monsoon and non-monsoon seasons of different years of study period have been estimated and are given in Table 3.1.

Table 3.1 : Seasonal Draft from Groundwater Reservoir

S.No.	Year	Draft (MCM)	
		Monsoon	Non-Monsoon
1.	1978-79	19.92	41.12
2.	1979-80	21.00	43.26
3.	1980-81	22.14	45.50
4.	1981-82	23.41	48.00
5.	1982-83	24.70	50.55

3.3 Effluent and Influent Seepage (Se & Si)

For the purpose of estimating effluent and influent seepage, the rivers of the study area have been divided in two categories- i) rivers originating from the study area and ii) rivers coming from outside and flowing through the study area. As per the analysis carried out in para 2.2.2, the effluent seepage to the rivers originating from the study area is estimated during monsoon and non-monsoon seasons while for the rivers coming from outside the study area, it is the influent seepage which is calculated during monsoon seasons only and no interaction is considered during non-monsoon seasons. The river stage data for these rivers are not available. However, the average discharges during rainy, winter and summer seasons at the lower reaches of all the eight major rivers in first category are available. With this data, the effluent seepage during monsoon and non-monsoon seasons have been estimated by adopting the methodology as described in chapter 2. Since the average river discharges were available only for one year, the same have been assumed for other years also. The influent seepage during monsoon seasons for other category of rivers have been estimated by using the gradient of water table(slope of the water table taken normal to the water table contours) and transmissivity of the aquifer system. The value of coefficient of transmissivity, as provided by G W S & I, OLIC, Bhubaneswar, was taken as 5050 sq.m/day. The effluent and Influent seepage as estimated in respect of both categories of rivers are presented in Tables 3.2 and 3.3.

Table 3.2 : Effluent Seepage to Rivers Originating from the Study Area.

S.No.	Year	Effluent Seepage (MCM)	
		Monsoon	Non-Monsoon
1.	1978-79	100.86	219.30
2.	1979-80	100.86	219.30
3.	1980-81	100.86	219.30
4.	1981-82	100.86	219.30
5.	1982-83	100.86	219.30

Table 3.3 Influent Seepage from rivers coming from outside the Study Area

S.No.	Year	Influent Seepage (MCM)	
		Monsoon	Non-Monsoon
1.	1978-79	182.86	--
2.	1979-80	345.35	--
3.	1980-81	236.20	--
4.	1981-82	112.55	--
5.	1982-83	110.50	--

3.4 Evapotranspiration from Groundwater Reservoir (Et)

As mentioned in para 2.2.3, the evapotranspiration losses from groundwater reservoir have been estimated for (a) shallow water table areas and (b) deep rooted tree areas.

For estimation of evapotranspiration from shallow water table areas, depth to water table contours were drawn and areas with depth to water table below ground level less than 1.5m identified. The seasonal evapotranspiration losses were then calculated by multiplying the area with the average potential evapotranspiration rates as applicable to the study area. Similarly, the evapotranspiration losses through deep rooted trees were also calculated by multiplying the area under such trees with the average potential evapotranspiration rates. The evapotranspiration losses as estimated for monsoon and non-monsoon seasons of study period are presented in Table 3.4.

Table 3.4 Evapotranspiration Losses from Shallow Water Table Areas and Deep Rooted Tree Areas

S.No.	Year	Evapotranspiration losses (MCM)	
		Monsoon	Non-Monsoon
1.	1978-79	675.16	1896.31
2.	1979-80	91.23	936.78
3.	1980-81	377.68	863.11
4.	1981-82	752.08	755.48
5.	1982-83	998.29	847.10

3.5 Subsurface Outflow (Og)

The subsurface outflows from the study area take place to (a) Chilika lake and (b) the coastal saline tract. For the purpose of computation of outflows in each case, the boundary across which flow takes place was divided into small segments. The average gradient of water table for each segment was determined from contour maps by taking the slope of water table normal to the contours and the length of segment was measured parallel to contours. The pre and post-monsoon water table contour maps for one year i.e. 1982 are presented in Fig.3.1 & 3.2. The average value of coefficient of transmissivity was provided by GWS & I, OLIC, Bhubaneswar as 5050 sq.m/day. The outflows through each segment were then calculated by using the following relationship.

$$\Delta Q = T * I * \Delta L$$

To get the total discharge passing across the study area boundaries, the discharge values for each segment were summed up as below.

$$Q = \Sigma T * I * \Delta L$$

The estimated seasonal outflows from the study area to the Chilika lake and the coastal saline tract are presented in Table 3.5 & Table 3.6 respectively. From these tables, it is observed that the outflows during non-monsoon season are generally more than those during monsoon season. It is mainly because of the fact that the non-monsoon season extends over a longer period of seven months as compared to five months of monsoon season. Secondly, the water table gradient developed during the non-monsoon seasons of 1978-79 to 1980-81 are steeper than those during monsoon seasons and hence caused more outflows during non-monsoon seasons of these years.

Table 3.5 Subsurface outflows to Chilika Lake

S.No.	Year	Subsurface Outflows (MCM)	
		Monsoon	Non-Monsoon
1.	1978-79	97.28	155.17
2.	1979-80	45.51	105.73
3.	1980-81	55.21	113.28
4.	1981-82	102.11	106.07
5.	1982-83	126.29	122.79

Table 3.6 Subsurface outflows to coastal saline tract

S.No.	Year	Subsurface Outflows (MCM)	
		Monsoon	Non-Monsoon
1.	1978-79	25.48	35.32
2.	1979-80	16.55	31.20
3.	1980-81	18.83	33.60
4.	1981-82	28.35	23.20
5.	1982-83	29.15	22.35

3.6 Recharge from Canal Seepage (Rc)

The study area is mainly served by the Puri main canal, its branches and distributaries. Besides, the canals of four other medium projects and a number of minor irrigation projects also exist in the study area. As mentioned in para 2.2.5, the discharge data for these canals are not available and hence the Groundwater Estimation Committee (1983) norms have been adopted for estimation of seepage losses from these canals. The data on canal lengths, their average wetted perimeter and average number of running days are available for all the canals under different projects. Using these available data, the seepage losses from these canals have been computed by taking a seepage rate of

FIG. 3·1

PREMONSOON GROUNDWATER TABLE CONTOUR MAP
(JUNE - 1982)

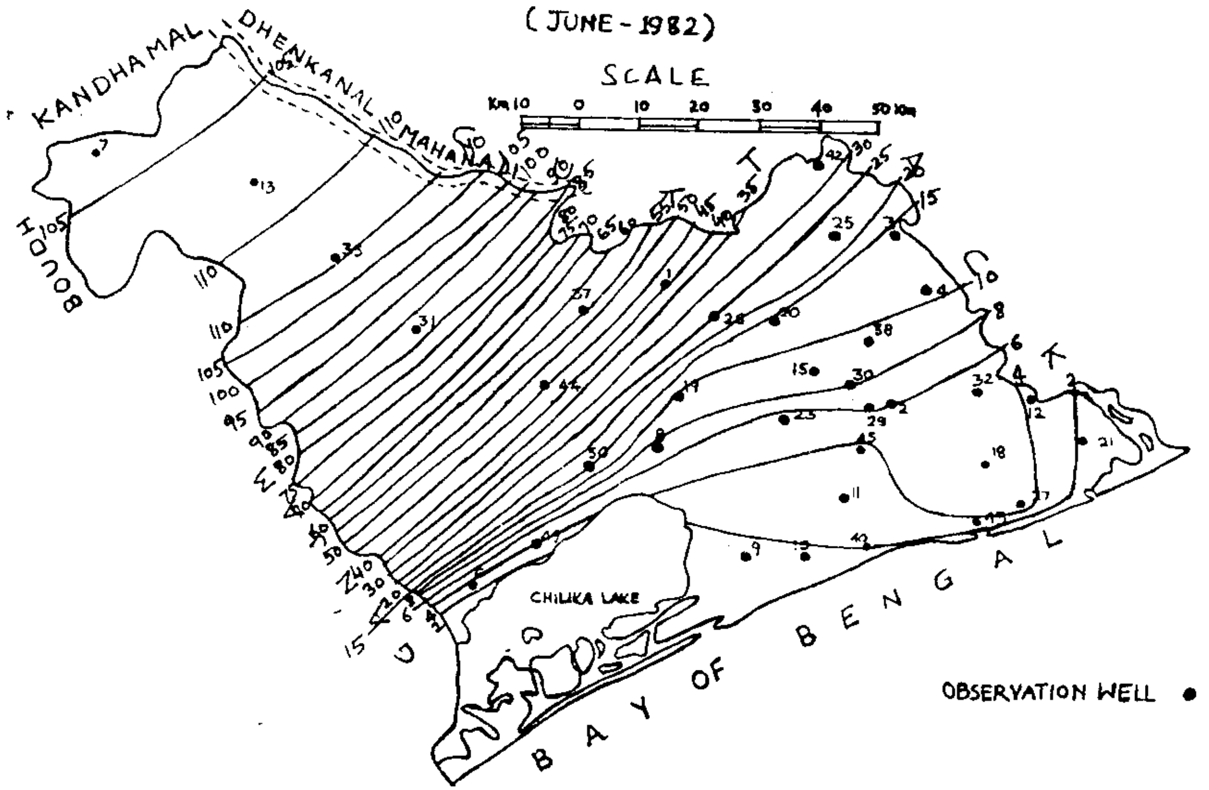
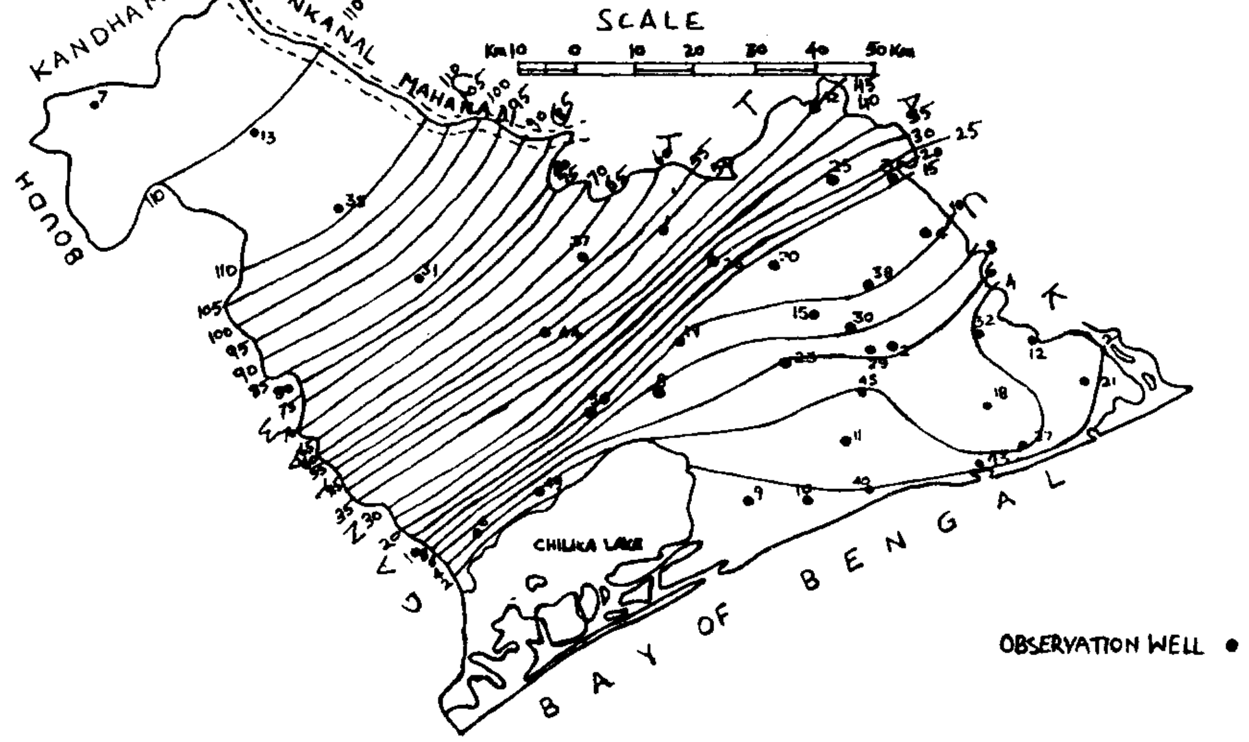


FIG. 3.2

POSTMONSOON GROUNDWATER TABLE CONTOUR MAP
(NOV-1982)



15 ham/day/10**6sq.m of wetted area which is recommended by Groundwater Estimation committee for unlined canals in normal type of soil with some clay content alongwith sand. Since there is no major change in length of canals over the study period, the seepage losses also remain same during different years of study. The estimates of seasonal recharge due to canal seepage are presented in Table 3.7

Table 3.7 Seepage losses in Canal System

S.No.	Year	Canal Seepage (MCM)	
		Monsoon	Non-Monsoon
1.	1978-79	125.64	199.00
2.	1979-80	125.64	199.00
3.	1980-81	125.64	199.90
4.	1981-82	125.64	199.00
5.	1982-83	125.64	199.00

3.7 Recharge from Field Irrigation (Ri)

The recharge from field irrigation or the return flows have been calculated both from surface water irrigation as well as groundwater irrigation separately. In the case of surface water irrigation, the canal discharges at outlets are not available. The quantity of irrigation water which is supposed to be applied to the fields through canals has, therefore, been estimated by using the statistics on cropwise area irrigated and the average water requirements of these crops during different crop seasons. In the case of groundwater irrigation, the groundwater draft for agriculture purpose during monsoon and non-monsoon seasons have already been estimated vide para 3.2. With these estimated quantities of irrigation water, the seasonal return flows from surface water irrigation and groundwater irrigation have been computed by adopting the G W Estimation Committee norms as explained in para 2.2.6. The seasonal estimates of return flows are given in Table 3.8.

Table 3.8 Recharge from Field Irrigation (Rr)

S.No.	Year	Recharge (MCM)			
		Canal Irrigation		Groundwater Irrigation	
		Monsoon	Non-monsoon	Monsoon	Non-monsoon
1.	1978-79	247.00	164.00	6.00	12.33
2.	1979-80	250.00	165.00	6.30	12.98
3.	1980-81	251.00	165.00	6.64	13.65
4.	1981-82	252.00	166.00	7.00	14.41
5.	1982-83	257.00	168.00	7.40	15.17

3.8 Change in Groundwater Storage (ΔS)

For the purpose of estimating the change in groundwater storage, the groundwater table contours were drawn for the study area for June (pre monsoon) and October (post monsoon) of each year of the study. With the help of these contour maps, the average changes in water table positions during monsoon (Jun-Oct) and non-monsoon(Nov-May) seasons were worked out as per the methodology explained in para 2.2.7. Finally, the change in groundwater storage during monsoon and non-monsoon seasons were calculated by multiplying the average change in water table position with the area and the corresponding specific yield. The seasonal change in groundwater storage as estimated for different years of study are presented in Table 3.9. The -ve sign used with the figures during non-monsoon seasons indicates the decrease in groundwater storage.

Table 3.9 Change in Groundwater Storage

S.No.	Year	Change in groundwater storage (MCM)	
		Monsoon	Non-Monsoon
1.	1978-79	787.26	-1951.99
2.	1979-80	1509.83	-922.07
3.	1980-81	1401.98	-943.65
4.	1981-82	603.93	-738.73
5.	1982-83	264.21	-911.28

3.9 Recharge from Rainfall (Ri)

The monthly rainfall for 29 raingauge stations in the study area were collected and analyzed for monthly mean areal rainfall over the study area using the Thiessen Polygon approach. These were presented in Part-I report of the study. With the help of these monthly mean areal rainfall, the seasonal rainfall values are computed for the study period as given in Table 3.10.

Table 3.10 Mean seasonal Rainfall over the Study Area
(Study Area = 8647 sq.kms.)

S.No.	Year	Mean seasonal rainfall (mm)		Mean seasonal rainfall (MCM)	
		Monsoon	Non-monsoon	Monsoon	Non-monsoon
1.	1978-79	1002.70	80.60	8670.20	696.92
2.	1979-80	919.70	63.30	7952.58	547.32
3.	1980-81	1297.20	193.70	11216.75	1674.90
4.	1981-82	998.30	185.30	8632.19	1602.26
5.	1982-83	906.90	211.50	7841.23	1828.83

The recharge from rainfall has been estimated using water balance approach and therefore further discussion on rainfall recharge is presented in chapter 4 alongwith the groundwater balance.

4.0 Groundwater Balance

The groundwater balance of Puri district has been carried out seasonwise for monsoon (Jun-Oct) and non-monsoon (Nov-May) seasons of 5 years i.e. from 1978-79 to 1982-83. The all other components of groundwater balance equation except rainfall recharge were estimated independently by analyzing the basic data and presented in chapter-3. As it is very difficult to obtain the value of recharge from rainfall by computation, the same has been evaluated as a residual term in the water balance equation during monsoon seasons since a major portion of rainfall recharge takes place during this period only. The groundwater balance during non-momsoon seasons provides the estimates of unaccounted water which determine the degree of accuracy with which the various components of groundwater balance equation have been estimated. The seasonal groundwater balance for the study area is presented in Table 4.1.

The rainfall recharge during monsoon seasons of the study period as obtained by substituting the estimates of all other components in the water balance equation are presented in Table 4.1. The recharge from rainfall varies from 1043 MCM to 1357 MCM for rainfall amounts of 7841 MCM(907mm) to 11217 MCM(1297mm) respectively. A graph is drawn between seasonal rainfall (monsoon) and the recharge due to rainfall in monsoon season and is presented in Figure 4.1. From the graph, it is observed that as the rainfall increases, the quantity of recharge also increases but the increase is not linearly proportional. However, for rainfall values between 7800 MCM to 9000 MCM, the recharge is

Table 4.1 Seasonal Groundwater Balance of Puri District in Orissa
(All quantities are in MCM)

Components	1978-79		1979-80		1980-81		1981-82		1982-83		
	M	NM	M	NM	M	NM	M	NM	M	NM	Remarks
1.Draft from Groundwater	19.92	41.12	21.00	43.26	22.14	45.50	23.41	48.00	24.70	50.55	1.Total area of Puri = 10182 sq.km
2.Evapotranspiration through deep rooted trees & shallow water table areas	675.16	1896.31	91.23	936.78	377.68	863.11	752.08	755.48	998.29	847.10	2.Area under Chilika lake = 992 sq.km
3.Effluent seepage to rivers	100.86	219.30	100.86	219.30	100.86	219.30	100.86	219.30	100.86	219.30	3.Area under saline tract = 543.13 sq.km 4.Area taken up for water balance = 8646.87 sq.km
4.Subsurface flow to Chilika lake	97.28	155.17	45.51	105.73	55.21	113.28	102.11	106.07	126.29	122.79	
5.Subsurface flow to saline tract	25.48	35.32	16.55	31.20	18.83	33.60	28.35	23.20	29.15	22.35	
6.Recharge from canal seepage	125.64	199.00	125.64	199.00	125.64	199.00	125.64	199.00	125.64	199.00	
7.Influent seepage from rivers	182.86	--	345.35	--	236.20	--	112.55	--	110.50	--	
8.Recharge from return flow											
a)Canal Irrigation	247.00	164.00	250.00	165.00	251.00	165.00	252.00	166.00	257.00	168.00	
b)Well Irrigation	6.00	12.33	6.30	12.98	6.64	13.65	7.00	14.41	7.40	15.17	
9.Change in ground water storage	787.26	-1951.99	1509.83	-922.07	1401.98	-943.65	603.93	-738.73	264.21	-911.28	
10.Recharge from rainfall (Ri=9-6-7-8+1+2+3+4+5)	1144.46	--	1057.69	--	1357.22	--	1113.55	--	1042.96	--	
11.Rainfall (P)	8670.20	696.92	7952.58	547.32	11216.75	1674.90	8632.19	1602.26	7841.23	1828.83	
12.Recharge coeff -icient (Ri/P)	0.132	--	0.133	--	0.121	--	0.129	--	0.133	--	
13.Unaccounted water (Non Monsoon) =[10+6+7+8-(1+2+3+4+5)-(9)]	--	-19.90	--	-37.22	--	46.51	--	-33.91	--	31.36	

Fig. 4·1

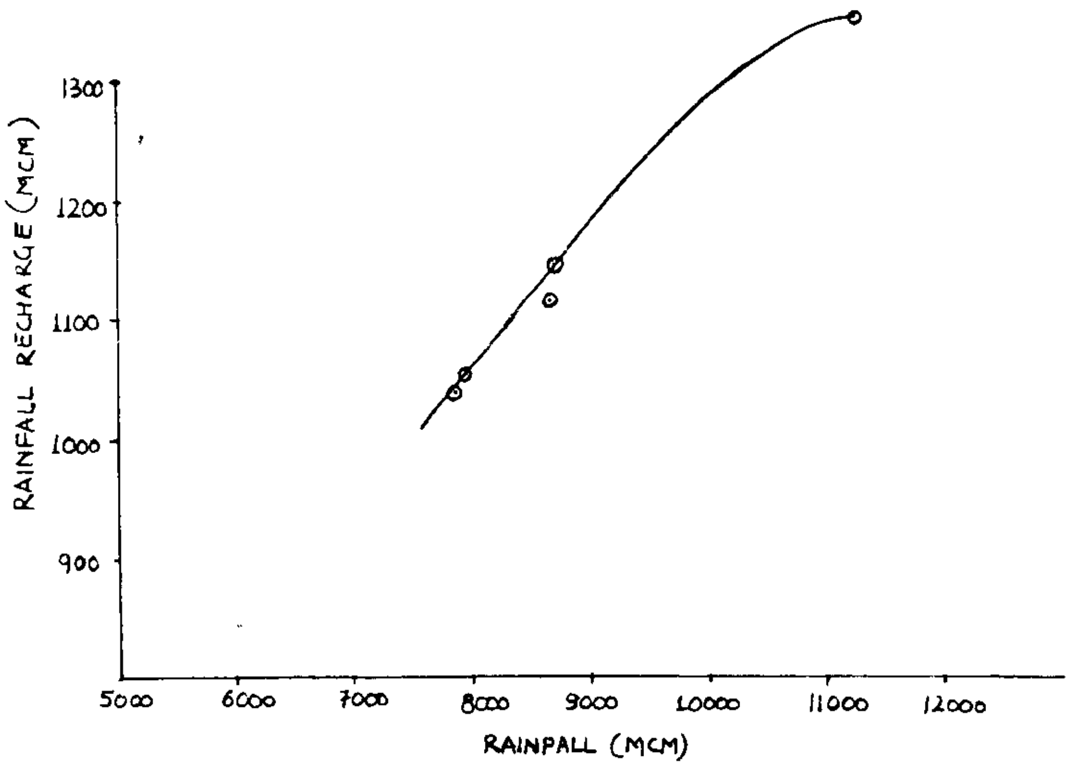


FIG: 4·1 VARIATION OF RAINFALL RECHARGE WITH RAINFALL more or less linearly proportional to the rainfall. Based on the monsoon season rainfall, the recharge coefficients (the ratio of recharge to rainfall) are also calculated and are presented in Table 4.1. The recharge coefficients for the study area during monsoon seasons of 1978-79 to 1982-83 are found to vary from 0.121 to 0.133. From the plot between recharge coefficients and monsoon rainfall as given in Figure 4.2, it is observed that the recharge coefficient increases with the rainfall and a maximum recharge coefficient of 0.14 is obtained for a rainfall of about 8200 MCM (950mm). Beyond the rainfall value of 8200 MCM, the recharge coefficient starts decreasing. The recharge coefficient Vs rainfall curve can be extended to get the minimum effective rainfall which produces the recharge. This extended portion can be used for estimating the recharge from lesser amount of rainfall during non-monsoon seasons. In the present study, the maximum rainfall during non-monsoon season of 1982-83 is 1829 MCM and is less than the effective rainfall. Hence, no recharge from rainfall is considered during non-monsoon seasons of the study period.

For non-monsoon seasons, unaccounted water has been computed as (Inflow - Outflow - Change in groundwater storage). The amount of unaccounted water varies from 19.90 MCM to 46.51 MCM, the highest being in the year 1980-81. From the groundwater balance chart, it is observed that during the non-monsoon season of 1980-81, the total outflow from the groundwater basin and the change in groundwater storage are 1274.79 MCM and 943.65 MCM respectively. The unaccounted water of 46.51 MCM, if expressed in

FIG. 4.2

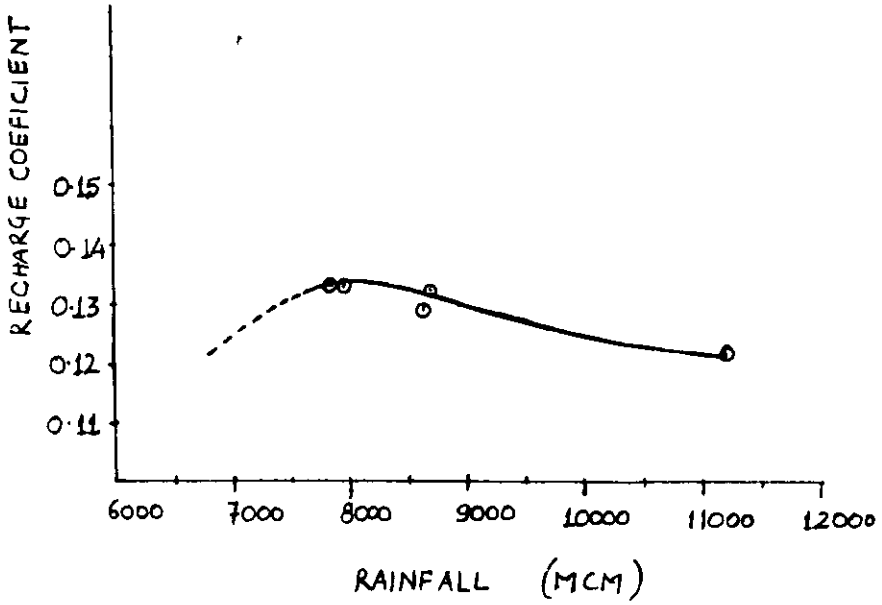


FIG: 4.2 VARIATION OF RECHARGE COEFICIENT WITH RAINFALL terms of percentage of these quantities, works out to 3.64% and 4.9% respectively and is less than 5% in both the cases. Keeping in view the large study area (8647 sq.km), this amount of unaccounted water seems to be quite reasonable and within limits. Therefore, overall groundwater balance can be considered to be in order although individual components may have some errors.

The above groundwater balance analysis enables to determine the dynamic component of the groundwater reserve of the area. From the Table 4.2, it is observed that the total annual recharge during the study period varies from 1925.65 MCM to 2354.35 MCM. The baseflow in rivers is a regenerated groundwater resource and is sometimes committed for lift irrigation schemes and other uses. It is, therefore, recommended that 15% of the total groundwater resources be kept for drinking and industrial purposes for committed baseflow and to account for the unrecoverable losses. The remaining 85% subject to the stipulation specified can be utilised for irrigation purposes.

Table 4.2 Annual Recharge to the Groundwater Reservoir

S.No.	Year	Seasonal Recharge (MCM) (6+7+8+10) of Table 4.1		Total Annual Recharge (MCM)
		Monsoon	Non-monsoon	
(i)	(ii)	(iii)	(iv)	(v=iii+iv)
1.	1978-79	1705.96	375.33	2081.29
2.	1979-80	1784.98	376.98	2161.96
3.	1980-81	1976.70	377.65	2354.35
4.	1981-82	1610.74	379.41	1990.15
5.	1982-83	1543.50	382.17	1925.65

5.0 CONCLUSIONS

The seasonal groundwater balance for monsoon and non-monsoon seasons for a period of 5 years i.e. from 1978-79 to 1982-83 has been conducted for an area of 8647 sq.kms. of Puri district. Based on the available information on physical and hydrological characteristics of the study area, the water balance components were identified and each component except the rainfall recharge has been computed independently. The recharge from rainfall during monsoon seasons has been evaluated as a residual term in the groundwater balance equation. The recharge coefficients are also computed during monsoon seasons of the study period and it is observed that the recharge coefficient increases with the increase in rainfall and a maximum recharge coefficient of 0.14 is obtained for a rainfall of 8200 MCM. The recharge coefficient starts decreasing for rainfall of more than 8200 MCM.

During non-monsoon seasons of the study period, the unaccounted water has been found to be less than 47 MCM. Also during different years, the percentage of unaccounted water with respect to the total seasonal outflow and also to the seasonal change in groundwater storage in respective years comes to less than 5%. Keeping in view the large study area, this unaccounted water is considered within limits which further indicates a reasonable degree of accuracy in quantification of the various components. Therefore,, the overall water balance is considered to be in order. Based on the annual recharge, the groundwater potential of the study area is also estimated.

The water balance approach is found to be a viable method of establishing the rainfall recharge coefficients and for evaluating the methods adopted for the quantification of recharge and discharge from other sources. The results of the groundwater balance will be utilised for mathematical modelling of the aquifer system so as to predict the behaviour of the groundwater system under alternative policies of the groundwater development.

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