EVALUATION OF RECHARGE BEHAVIOUR THROUH DIFFERENT WATER BALANCE APPROACHES IN CANAL COMMAND

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ABSTRACT: *The knowledge of groundwater resources is essential for proper planning and management of an irrigated area. This requires recharge estimation through reliable and easy method. Thus, an attempt was made to evaluate different approaches used for recharge estimation viz. Inflow and out flow approach, change in watertable depth approach and a computer model (Surfer) approach. The results from three approaches indicate that ground water was recharged in November, December and February and discharged in months of January and March of Rabi season. The difference in values of recharge based different approaches, depending upon the nature of method was observed with similar trend throughout season. Volume of water through canal water supplies to the fields was 22.44 against 17.71 million* m^3 *of the crop demand plus ETa of non cultivated area was the considerable margin to increase the recharge in the area. To keep the water balance at required level, adverse impacts of inflow factors (excess irrigation, seepage losses from irrigation and drainage system) have to be minimized to reduce 26% extra water to be recharged. Evaluation of three approaches indicated that the watertable fluctuation method is easy and reliable method for monitoring the water balance as well as the recharge behavior in the canal command.*

Key Words: Water table, Recharge, Crop demand, Rabi season, SURFER, Seepage losses

INTRODUCTION

The ever increasing population, urbanization and rapid industrial development as well as increase in the production of food and fiber crops have compelled to explore the potential of freshwater resources with considerable saving to cop the demand of water in various parts of the world. In view of increasing demand of water for various purposes like agricultural, domestic and industrial etc., a greater emphasis is being laid for a planned and optimal utilization of water resources. The water resources of the basins remain almost constant while the demand for water continues to increase [1]. A great deal of land in Pakistan is affected by salinity and water logging due to continuous irrigation in the absence of drainage. The problem is wide spread particularly in Sindh where about 33% of the total cultivated area had a water table depth of 0-1.524 m in 1964 and that rose 74% in 1982[2]. Due to this trend, many of the projects were launched to install drainage tubewells to lower down the water table in Pakistan

The quantification of groundwater resources is an important issue in socio- economic development and irrigation water management on the priority. Therefore the estimation of groundwater recharge is a prime prerequisite for an efficient management of water resources particularly in semiarid parts and where there is overexploitation.

For managing the judicious use of fresh surface water resources as well as safe groundwater exploitation, water balance techniques have been used to quantify the exact estimates of recharge and discharges in any canal command. Through water balance approach it may be possible to have a quantitative evaluation regarding dynamic behavior of recharge to the groundwater and monitoring its adverse effects.

Water cycle stages within the selected regions or canal commands can be estimated through water balance approach but it presents higher spatial variability. The water balance consists to quantify the components of the control system in a predetermined volume control, based on the principle of conservation of mass and energy exchange of the systems involved in time and space [3]. The conservation of mass for certain volume control means that the rate of variation mass stored is the same as the difference between the sum of the amounts of water entering and leaving in a given time interval .The watershed, when used as control volume, is the key element in the analysis of the hydrological cycle. Water balance approach was being extensively used for variety of hydrological components such as actual regional evapotranspiration [4] and water harvesting quantities [5].A theme issue published by the International Association of Hydro-geologists, entitled Groundwater Recharge [6], provides extensive reviews of various aspects of groundwater recharge; some of the contributions of specific relevance to the current study are referred to present a valuable review of the wide range of alternative methods which can be used to quantify recharge. [7;8] considers the potential for using remote sensing to obtain information about soil moisture which can be used to refine soil moisture balance models. [9] provides an overview of the limitations of some traditional groundwater modeling approaches for estimating recharge and highlights the errors which can occur when recharge is represented by specifying groundwater heads.

In this paper, an attempt has been made to describe and utilize the methodologies to understand and evaluate the various recharge and discharge components of ground water balance in the secondary canal command through different approaches. This might help in deciding the most reliable and easy approach to monitor the efficiency of surface water use and groundwater balance for safe groundwater exploitation in central part of Sindh province, Pakistan

MATERIAL AND METHODS

Study area

The study was conducted in the command area of Heran distributary in Left Bank Outfall Drain (LBOD) Stage-1 area in Sindh, Pakistan. The selected command area covers the culturable area of 6239 hectares.

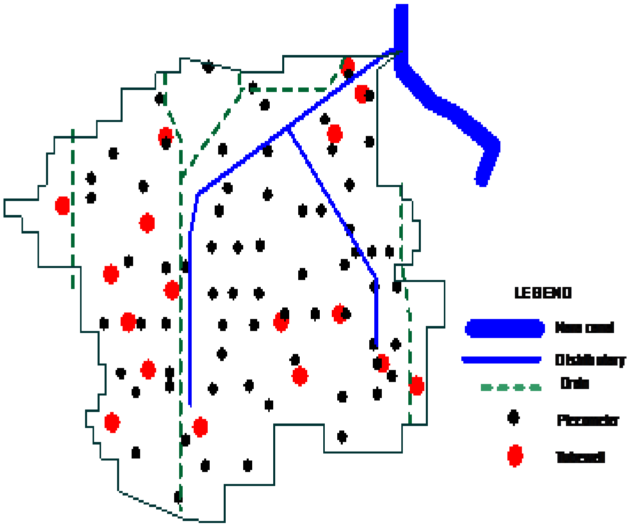

Figure 1. Layout Plan of the command area of Heran Distributary

The drainage system in the command area consists of Surface drains (Horizontal drainage) and saline and scavenger tubewells (vertical drainage). The area is serviced by 5 surface drains, 14 saline tubewells, 3 scavenger tubewells and 86 piezometers for watertable depth monitoring (installed under the IWMI's project). The detail of all features is shown in Figure 1.

Water balance approaches used

1st Approach (inflow outflow factor method)

This approach consists the measurement of inflow and outflow factors (the volume of water entering and leaving the area). The main concept of this approach is given in Figure 2. The factors shown in the figure have been individually calculated. For Evapotranspiration factor (ETa) CropWat software was used. Other factors are based on the regular measurements/ observations and monitoring of different components of irrigation and drainage system for one crop season.

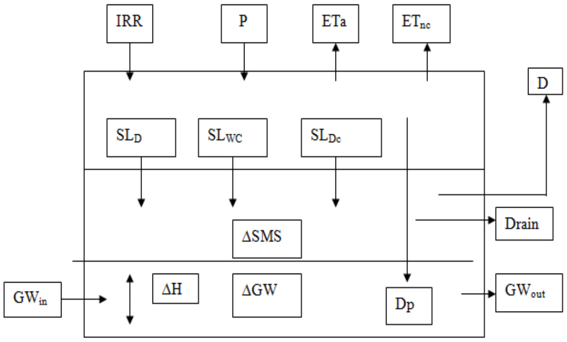

Figure 2. Concept of inflow and outflow factors

IRR = Effective irrigation from canal
P = Precipitation
SL_D = Seepage losses from distributary
SL_{wc} = Seepage losses from watercourses
SL_{DC} = Seepage losses from disposal channels
ET_A = Evapotranspiration from crops
Et_{nc} = Evaporation from non cultivated area
D = Effective drainage through tubewells
Drain = Contribution of drains through lateral flow
σH = Change in Watertable depth
σSMS = Change in soil Moisture Storage
GW_{in} = Ground water inflow
GW_{out} = Ground water outflow

According to the hydrologic cycle explained Figure 2, following basic relation was used for calculating net recharge (R_{NET}) to the ground water.

$$\sum Inflow - \sum outflow + \Delta Storage = 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (i)$$

Where

$$\sum Inflow = IRR + P + SLD + SLWC + SLDC$$

$$\sum Outflow = ETA + ET_{nc} + D + DRAIN$$

$$(IRR+P+SL_D+SL_{WC}+SL_{DC})-(ET_A+Et_{nc}+D+Drain)+\sigma\,(SMS+GW_{TOT}) = 0 \ldots\ldots\ .(ii)$$

$$-\sigma GW_{TOT}=IRR+P+SL_D+SL_{WC}+SL_{DC}-ET_A-Et_{nc}-D-Drain+\sigma SMS \ldots\ldots\ldots\ldots\ldots (iii)$$

σSMS was taken as common because in entire hydrological cycle the moisture exists in the soil as constant due to rotational irrigation water supplies to the fields (warabundi system). Therefore the change in soil moisture is taken as common and σSMS=0

The change in Ground water Storage is equal to the net recharge to the groundwater

$-\sigma$ GWTOT= R_{NET}

-ve sign indicates change in groundwater as discharge

The magnitude of water by seepage losses in the system is included in irrigation supplies by the irrigation system; therefore the equation reduces as under

$$R_{NET} = IRR + P + SL_{DC} - ET_A - Et_{nc} - D - Drain \ldots\ldots (iv)$$

2nd approach (Watertable fluctuation method)

This method is based on the change in watertable depth in the command area. The effective change in watertable depth is multiplied with the gross command area and specific yield of the soil [10]. This approach was also checked with Net recharge calculated by SURFER

3rd Approach (Use of SURFER software)

Surfer is computer software developed for a grid based contouring and three dimensional surface plotting graphics runs under the Windows-System. Surfer interpolates irregularly spaced XYZ data on to a regularly spaced grid. The grid files are used to produce contour maps and Surface plots. Volume below a surface or between two surfaces can be calculated with this software. In this study volume between monthly plotted surfaces were calculated.

DATA COLLECTION

Watertable data

Watertable data was collected from the 65 piezometers installed in the command area fortnightly. The frequency was kept very narrow to know the change in depth within one season(Nov to March) in relation to the recharge and drainage in the area. The data of water table was put in to excel spread sheet for analysis. The data was designed Surface mapping and contouring) in software SURFER.

Tubewell Operation Data

Operational hours were recorded through control panel equipped at each tubewell fortnightly to determine the volume of water discharged. The hours running reading was subtracted from previous reading to calculate net hours the tubewell operated. The volume of water drained through tubewells was calculated as under.

$$V_{TW} = O_h \times Q \times 3600$$

Where

V_{TW} = Volume of water drained by tubewells (m^3)

O_h = Operational hours

Q = Discharge of tubewell in m^3/sec

Discharge of Tubewells

Broad crested) weir at head of the disposal channels was used for discharge measurement.

Measurement of Inflow factors

Irrigation (IRR)

The volume of water that enters in the command area through irrigation supplies was quantified by using following relation.

$$IRR = Q_{distry} \times T$$

Q_{distry}= Discharge of distributary head regulator in [cumec].

T = Actual time of distributary operation in one month.

Precipitation (P)

During study period (Nov to March in 2013), the effective precipitation was taken in to account that contributed to the soil in the command area.

Seepage losses from disposal channels (SL_{DC})

The disposal channels are shallow channels conveying drainage effluent from tubewell to the drain. Seepage losses from these channels were measured through inflow-outflow test on two disposal channels.

Measurement outflow factors

Actual evapotranspiration (ET_A)

It was calculated by using CropWat (8.1). The meteorological data of 15 years was obtained from the Meteorological Station DRIP (Drainage and Reclamation Institute of Pakistan) at Tandojam.

Evaporation from un-cropped Land (ET_{nc})

Evapotranspiration from non cultivated (barren and fallow land) was calculated by following relation

$$E_{f+b} = E_0 \times C \times A_{f+b} \times T$$

Where

E_o =Normal surface water evaporation (pan evaporation).

C =It is the relationship of loss from the ground water surface with depth as fraction of Eo. This value is related to the soil characteristics (As the area under study lies in the Lower Indus Project (LIP) area, so the characteristics of the LIP, Alipur silty clay loam were used).

A_{f+b} =Fallow and barren area in the distributary command

T = time of one month.

Effective volume drained from Tubewells (D)

For calculating the monthly volume of pumped water from the command area was calculated by following relation.

$$D = V_{TW} \times F_{DC}$$

D = Effective volume of water drained by tubewell (monthly)

V_{TW} = volume of water drained by tubewell (monthly)

F_{DC} = Drainage Efficiency Factor for disposal channel

Base flow drainage (Drain)

This factor consists of amount of water seeping from agricultural lands into the drains and excess irrigation water diverted by water users in to drains. To obtain this, discharge measurement was taken at source and disposal points of the drain in the command area. By subtracting inflow from outflow of the drain, water contributed by drain is obtained, but this contribution also consists of water drained through tubewells in to the same drain, therefore, effective volume of water to be contributed by tubewells (D) was subtracted from the entire contribution by drains to estimate the contribution of the drains as base flow.

$$Surface\ drains\ volume = Outflow - Inflow$$

Effective base flow & excess irrigation water Contribution = Drain contribution-Effective drainage by tubewell

$$Drain = Surface\ drains\ volume - D \ (m^3)$$

RESULTS AND DISCUSSION

Water Balance

1st approach

The results of inflow outflow factors are given in Table 1for each month. The net recharge in the groundwater shows that water from the command area is recharged in the month of November, December and February, where as it is discharged in the months of January and March. The main reason for water to be recharged in these months could be the excess supply of irrigation water to the fields beyond the crop water requirement. This could be the due to excess losses from the irrigation system as well as losses in the fields during water application. The Table 1 shows the higher recharge of 1.47 million m^3 to the ground water in month of November because of higher supply of irrigation water to the lands, less evaporation rate, low evapotranspiration from crops and probably less drainage through tubewells. In this month very few tubewells were operating and lands were being irrigated for wheat sowing also seepage losses from distributary and watercourses were observed maximum.

In month of December, the recharge to the ground water declines to 1.07 x 10^6 m^3. It was due to less supply if irrigation water at head regulator in this month as compared to the month of November and operation of more tubewells. In month of January figure was changing its inverse trend showing that 3.45 million m^3 water was discharging from the ground instead of recharging. The main reason behind this change was closure of distributary in this month for annual maintenance; the distributary has operated only for 6 days. The supply at head regulator was 1.16 million m^3 only so no more amount of water recharged. The volume drained through tubewells was significantly higher as 0.63 million m^3 in this month. Still water did not recharge through inflow factors but there were outflow factors in action i.e. evapotranspiration, evaporation from bare and non cultivated land and drainage network. Again in the month of February water recharged to the ground water because supply of irrigation water started after the closure period. The recharging amount of water in this month was somewhat lower than the other recharging months as the supply at head was lower 4.93 million m^3 as compared to other recharging months and on other side outflow factors had significant values to discharge. The month of March showed the discharge of 0.74 million m^3 to ground due to rise in temperature and evapotranspiration rate. The rising evaporation rate reduces the recharge to maintain ground water balance but at the cost of serious soil salinisation (WAPDA, 1990). Also the volume drained by tubewells is 0.57 million m^3 as compared to previous month.

2^{nd} Approach (Watertable fluctuation method)

Watertable fluctuation in the study area depends on various irrigation and drainage factors. The Figure 3 shows the average watertable fluctuation in each month. The average seasonal watertable fluctuation was between 0.73 m to 1.16 m with an average value of 0.92 m in Rabi. Depth wise classification express that 37 % command area comes under 0.61 to 0.92 m, 30% under 0.92 m to1.22 m and 12% under 1.22 to 1.52 m. Irrigation water supply in command area was observed an influential factor responsible to raise watertable level. The net recharge under this method was calculated by using the monthly net change in watertable depth and specific yield. The calculation of net recharge on the basis of watertable change depicts almost same trend or pattern of net recharge but there is difference in values. The pattern of net recharge or discharge by both approaches is same up to the month of March.

Table 1.Net recharge on the basis of Inflow and outflow factors for water balance

Inflows (10^6 m^3)	Nov	Dec	Jan	Feb	Mar
IRR	6.27	5.71	1.16	4.93	4.26
P	0	0	0.06	0.13	0
SL_{DC}	0.01	0.02	0.04	0.02	0.03
Sum Inflows	**6.28**	**5.73**	**1.26**	**5.08**	**4.29**
Outflows (10^6 m^3)					
ET_A	3.51	3.06	3.07	2.8	3.42
Et_{nc}	0.43	0.37	0.38	0.38	0.45
D	0.12	0.42	0.63	0.42	0.57
Drain	0.75	0.8	0.63	0.67	0.59
Sum outflows	**4.81**	**4.65**	**4.71**	**4.27**	**5.03**
Net Recharge (Inflow -Outflow)	**1.47**	**1.08**	**-3.45**	**0.81**	**-0.74**

Table 2. Net recharge to the groundwater calculated through watertable change method

Month	Change in WTD	Specific Yield of soil (10%)	GCA (ha)	Volume (ha.m)	Net Recharge (m.m^3)
Nov-99	0.10	0.1	7000	72.35	0.72
Dec-99	0.12	0.1	7000	80.88	0.81
Jan-00	-0.37	0.1	7000	-257.38	-2.57
Feb-00	0.18	0.1	7000	127.62	1.28
Mar-00	-0.25	0.1	7000	-175.64	-1.76

Table 3. Calculation of Net recharge by SURFER

Lower Surface	Upper Surface	Trapezoidal Rule	Simpson's Rule	Simpson's 3/8 Rule	Average volume 10^6 m^3	Average volume Difference[Sy=10%]
Nov	Nov	7.12	7.14	7.12	7.13	0.71
Dec	Dec	7.84	7.82	7.87	7.84	0.78
Jan	Jan	-23.22	-23.20	-23.30	-23.24	-2.32
Feb	Feb	11.41	11.42	11.44	11.42	1.14
Mar	Mar	-15.94	-15.93	-15.97	-15.95	-1.59
Sum						-1.28

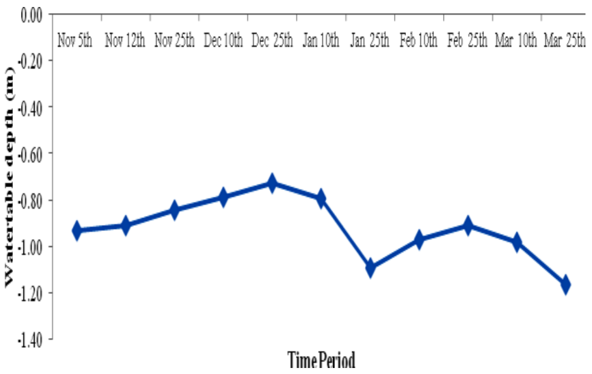

Figure 3. Water table fluctuation in Rabi season

There could be error in net recharge for the month of March by 1st approach because a breach occurred in this month which was not measured. The breach water from the distributary diverted in to the drain MBD directly as the drain in the tail of distributary concise with distributary. Water supply at head regulator was taken in to account but the amount of water diverted to the drain has not taken in to account which is obviously not contributed or recharged to the groundwater. On the basis of this valid reason it could be said that water is actually discharged from the ground and should have shown higher discharge value rather than actual it has shown. The net recharge by water table fluctuation method is shown in Table 2.

Water balance by SURFER (3rd Approach)

From watertable change (σH) in each month, volume between the surface plots of consequence months was calculated by SURFER. It plots the surface of each month according to the interpolated grid system of watertable and then calculates the difference between two surfaces (plotted as 3 dimensions). SURFER calculates volume by three different methods as trapezoidal rule, Simpson rule and Simpson 3/8 rule. For this calculation average of three methods have been taken, the volume calculated by this method was multiplied with specific yield assumed for the soil. The volume calculated from the SURFER is depicted in Table 3, which closely relates with the volume calculated by watertable fluctuation method, because the value of change in watertable depth was used under this approach. The SURFER method has in turn validated the calculation as demonstrated under 2nd approach.

Comparison among three approaches

The difference between the values of net recharges of 1st and other two approaches is about 51%, 27%, 32% 29% and 52% in the months of November, December, January February and march respectively. Whereas the difference between 2nd and 3rd approach is very minimum or negligible. The reason behind the almost similar recharge values by later two methods is use of values of water table depth change. The software approach has in turn validated the net recharge by 2nd approach. From Figure 3 it is clear that the trend of change in recharge is same in three approaches except the difference in values. 1st approach was based on the measurements of the irrigation and drainage components where as other two approaches is based on the assumed specific yield.

Recharge by 1st approach has shown higher value than other approaches in months of November and December and also the higher discharge in January and again lower recharge and discharge in February and March. The trend of recharge calculated by 1st approach over other two approaches is not parallel. There could be two reasons that are the error in measurements of inflow and out flow factors in February and March and second that assumed value of specific yield of the soil. Any way both are reliable and leave a room to extend the research in the same context.

DISCUSSION

Due to difficult measurements of factors related to weather, hydrology and hydrogeology or in other words recharge and discharge factors, the monitoring of groundwater recharge by water table fluctuation is quite easy as compared to precise measurement of inflow outflow factors as demonstrated by [1]. There is no direct method currently to be used for estimation of groundwater balance and difference between different approaches have higher variability except the use of water table fluctuation method and it is also verified by the present study as well as stated by different researches like [11; 5;12].

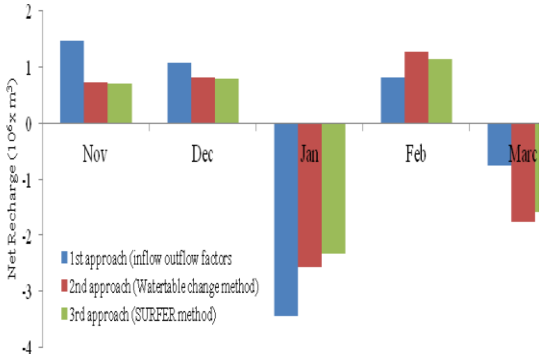

Figure 4: Comparison of net recharges calculated through different approaches

The estimation of water resources in terms of surface as well as groundwater is extensively being determined through water balance techniques by [5] such as water balance study using the Thornthwaite and Mather (TM) [13] models with the help of remote sensing and GIS for determining the moisture deficit and moisture surplus for an entire watershed.

This study reveals that the evaluation of water balance techniques as its own importance in connection with the facilities available to monitor certain factors that help in quantifying the recharge and discharge within the canal command. The watertable level fluctuation method has its own advantage of simplicity, easy method and reliable results.

CONCLUSION

Ground water was recharged in November, December and February and discharged in months of January and March of Rabi season. There is differences in values of recharge between approach-1 and other two approaches (watertable change and Surfer) depending upon the nature of method, but the trend of changing is same in every month. This methodology supports the validity of approaches. The supply of water for irrigation to crops was more as compared to the crops demand created significant imbalance between recharge and discharge. The supply must be managed with optimization of drainage system. The monitoring of water balance or recharge behavior in the canal command area can be well demonstrated by watertable fluctuation method as it is very easy and convenient.

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