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WATER BALANCE STUDY OF SEMI-ARID REGION – A CASE STUDY

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ABSTRACT
Rational estimation of groundwater potential of any region is one of the major influential factors towards increasing the cultivable land area in that region. Groundwater is pumped out regularly to supplement the available surface water resources in fulfilling the water demands of the region. Increase in population and more demand of water for irrigation purposes and domestic uses will cause the digging up of greater number of tube wells to meet the increasing water demand, thus, the water table will fall at a faster rate resulting in increased cost of pumping. The concept of Water Balance helps in studying the behaviour and hydrological characteristics of a catchment area. Thus, Precipitation and Evapotranspiration are major sources of input and output of water respectively. The development, planning and operation of water resources project are dependent upon the availability of water in the required quantity. The present study is based upon the available data on Agra district of Uttar Pradesh to manage the sustainable development of the available water resources to meet the demand. Thus, in order to estimate the safe draft of groundwater, location of new wells and to suggest other economical sources of water this study was carried out. In areas where unfavourable geological conditions exist, rainwater harvesting has proven to be a very effective and promising solution to the problem of groundwater recharge.

KEYWORDS: Evapotranspiration, Precipitation, Rainwater Harvesting and Water Balance.

INTRODUCTION
The estimation of Water Balance is necessary to manage water supply and predict where there may be water shortages. The development, planning and operation of water resources project are dependent upon the availability of water in the required quantity. From the ground water table observations of District Agra (having Latitude 26°-45' and 27°-25' North and Longitude 77°-26' and 78°-51') for the period in 70's and even recently it has been observed that the water table in this region has fallen considerably, which indicates that recharge is less than the water being pumped[1]. Due to increase in population, agriculture and industrial demand, more number of wells as well as canal irrigation systems will be required to meet the water demand. Thus, in case of wells the cost of pumping of water increases, therefore it becomes necessary to conduct water balance study.
Water balance is a useful tool to understand the hydrologic behaviour of a study area. It also enables one to get an assessment of the quality of the data and detect discrepancies. It can be carried out in a small area of a few square meters to a large contingent of millions of square kilometres. The time of analysis can vary from a second to a year or more. When analysing the water balance data, one must carefully ensure the right order of the magnitudes of the different terms and also the right proportion of their relative magnitudes. A comparison with the data of hydro-meteorologically similar areas will indicate whether there is any discrepancy in some terms or not [1].

The water balance of an irrigated area is the quantitative representation of the change in groundwater and surface resources due to natural and artificial factors (Man's economic activities). The factors affecting the water balance of an irrigated area are as follows:

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- Moisture Evaporation & Transpiration
- Water Condensation in soil and on the surface
- Surface Runoff
- Sub-surface Runoff

Precipitation (P) and Potential Evapotranspiration (PET) are not independent of each other. Thus, in the study of water balance if P < PET (absence of runoff and the period will be called deficit period) and if P > PET (runoff will be there and the period will be called surplus period).

STUDY AREA

The Agra district is a border district of Uttar Pradesh. It has common boundaries with Rajasthan along west and some part of the south and with Madhya Pradesh along the remaining southern portion. It is located between Latitude 26°-45' and 27°-25' North and Longitude 77°-26' and 78°-51'.

The district Agra experiences moderate type of subtropical monsoon climate. The temperature rises up to 44°C in the summer and falls down up to 2°C in winter season. The normal annual rainfall of district Agra is 651.11mm.

The canal network in Agra consists of branch canals, distributaries and minor canals having length of 127km, 245km and 355km respectively. The Groundwater in Agra is used by means of state tube wells, private tube wells, pumping sets, wells with Persian wheels and from wells using other means [1].

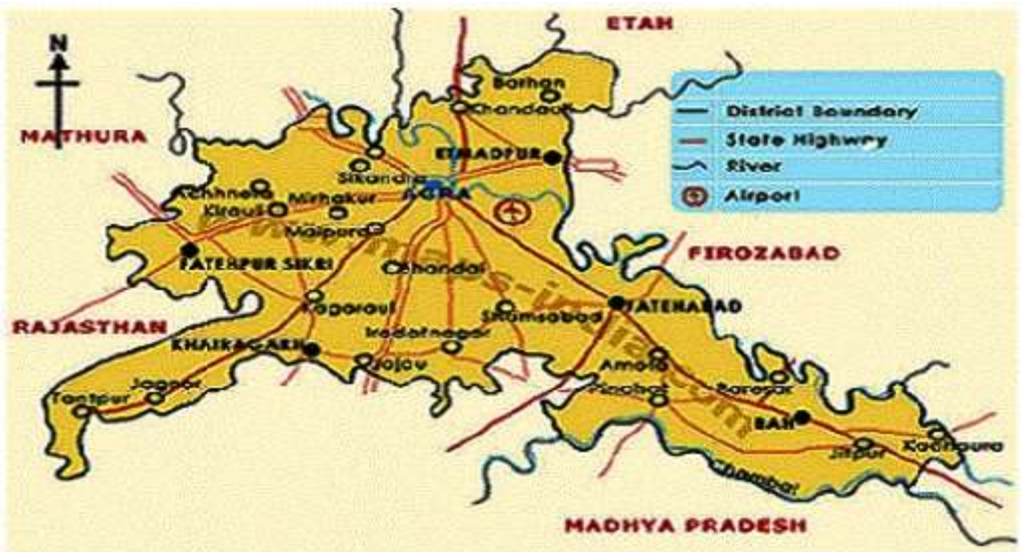

Figure 1: Map of Agra

METHODOLOGY AND ANALYSIS

To study the water balance of an irrigated area, special experimental plots are considered with comparatively similar natural conditions. The area of these plots may vary from a few hectares to some hundred hectares depending upon the complexity of the geology and hydrology of the irrigated area. The boundaries of the plots are generally irrigation channels. After studying the geology and hydrology of the balance plots, a network of observation wells is made in it to study the regime of the ground water. In addition, special experimental balance plots are made for the study of evaporation, percolation, transpiration and other factors.

The water balance equation [2] is composed of change of water resources on the earth's surface (lakes, irrigation network), in the soil of the zone of aerationand in the zone of free groundwater. It may be expressed as follows:

$$\pm D_1 \pm D_2 + \mu\,(\Delta H/\Delta t) = P + C - E + (A_1 - A_2/F) + (Q_1 - Q_2/F) + (I_{irr} - I_{ret}/F)$$

Where,

± D_1= Change of water resources on

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the surface
$\pm D_2$= Change of water resources in soil grounds of the Zone of aeration
μ ($\Delta H/\Delta t$) = Change in Groundwater level
P=Atmospheric Precipitation
C=Condensation
E=Evaporation
($A_1 – A_2/F$)=Surface Runoff
($Q_1– Q_2/F$)= Subsurface Runoff
($I_{irr} – I_{ret}/F$) = Irrigation Runoff

Therefore, in the study of Water Balance of district Agra, the various components of the Balance Equation used are as follows:

3.1.1 Recharge of Groundwater by Rainfall: Recharge depths were found out from the difference of groundwater levels just before and after the monsoon in a year for each block for the period 1971 to 1975. These recharge depths were modified by the ratio of average rainfall to normal rainfall for each block. Average values of recharge depths of the various hydrograph stations were plotted to get the contours of recharge depth. The area between contours was multiplied by the average recharge depth and the specific yield to get the groundwater recharge by rainfall for each block. Thus, recharge by rainfall values ranges from 9 to 35 million cubic meters of various blocks of district Agra.

3.1.2 Recharge of Groundwater by Seepage from Canals: For various types of canals, the lengths were multiplied by the seepage rate per unit length to get the total seepage from canals [4]. Eighty percent of total seepage water was taken as the groundwater recharge from canals, because 17 to 20 percent of seepage water is lost by adsorption and evaporation [5]. Thus, recharge by seepage from canals values ranges from 1 to 19 million cubic meters of various blocks of district Agra.

3.1.3 Recharge of Groundwater by Field Irrigation: The water depth available for field irrigation is 0.45m. Twenty two percent of this value gives the groundwater recharge depth, because it has been studied that 75 to 80 percent of water applied is lost by adsorption, evaporation and Evapotranspiration [5]. Irrigated area multiplied by recharge depth gives the groundwater recharge. Thus, recharge by field irrigation values ranges from 3 to 16 million cubic meters of various blocks of district Agra.

3.1.4 Drought: For each type of minor irrigation works, the draft was calculated by multiplying the number of minor irrigation work with the drafting capacity. Thus, the annual drought values range for various years are as follows:

- For the year 1974, the value ranges from 6 to 57 million cubic meters.
- For the year 1975, the value ranges from 7 to 65 million cubic meters.
- For the year 1976, the value ranges from 22 to 65 million cubic meters.
- For the year 1977, the value ranges from 13 to 64 million cubic meters.

The total drought was found out by summing up the drafts for various types of minor irrigation works.

3.1.5 Groundwater Depletion: The groundwater level at each hydrograph station was calculated by subtracting the maximum depth to groundwater from the groundwater level for the year 1975 to 1977. The changes in groundwater levels were calculated for the various hydrograph stations and contours of groundwater level change were drawn. Groundwater depletion was calculated by multiplying the area between contours by the average change in groundwater level.

Further change in the water resources, i.e., $\pm D_1$ and $\pm D_2$ is assumed to be negligible, since the water storage remains practically constant during the period of study. The period of study Δt was taken as 1971 to 1977. Vapour condensation data was not available and thus C was assumed as negligible. Recharge from canals and irrigation fields have been directly used and thus there is no need of using evaporation and Evapotranspiration losses[3]. Recharge from canals has been used for the surface runoff values ($A_1 – A_2/F$). Groundwater inflow and outflow were assumed to be same and thus the value of underground runoff ($Q_1 – Q_2/F$) is taken as zero. Recharge from irrigation fields has been taken for the irrigation runoff value ($I_{irr} – I_{ret}/F$).

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Table 1: Total Recharge and Drought Values for the Various Blocks of District Agra (1974-1977)

Blocks	Annual Recharge (10^6M^3)				Annual Drought (10^6M^3)				Average Annual Drought (D) x 10^6M^3	Water Balance = R-D x10^6M^3	Annual ground water depletion calculated x 10^6M^3
	Recharge by rainfall	Recharge by canals	Recharge by field irrigation	Total Recharge (R)	For year 197 4	For year 1975	For year 1976	For year 1977			
Akola	15.59	7.71	7.25	30.55	30.87	36.06	39.60	39.91	36.61	-6.06	+0.54
Barauli-Ahir	27.23	8.29	14.13	49.45	56.42	64.29	64.19	61.89	61.69	-12.24	-9.80
Bichpuri	19.98	6.18	10.50	36.66	33.14	37.62	41.23	36.79	37.19	-0.53	-0.68
Bah	21.89	-	3.97	25.86	38.18	39.57	39.01	41.22	39.49	-13.63	-13.65
Jitpur Kalan	34.47	-	6.77	41.24	34.78	33.88	34.02	36.37	34.76	+6.48	-11.31
Pinhat	22.36	-	11.25	33.61	32.20	33.50	31.91	31.44	32.26	+1.35	-6.07
Itmadpur	15.21	2.91	13.38	31.50	27.24	32.86	34.90	37.60	33.15	-1.65	-4.76
Khandauli	18.31	1.47	9.23	29.01	22.70	49.47	27.32	28.51	32.00	-2.99	-3.18
Tundla	21.06	3.36	12.14	36.56	41.70	46.68	45.72	34.78	42.22	-5/66	-3.22
Fatehabad	26.43	13.38	8.20	48.01	36.34	43.14	59.59	63.97	50.76	-2.75	-15.42
Shamsabad	20.63	7.97	12.79	41.39	39.34	48.26	54.96	62.92	51.37	-9.98	-5.96
Firozabad	27.07	2.14	11.41	40.62	47.59	44.81	55.69	59.15	51.18	-11.19	+2.20
Kotla	24.32	1.98	13.75	40.05	47.43	52.30	55.85	59.73	53.82	-13.77	-6.72
Jagnair	9.10	-	4.22	13.32	6.12	7.95	22.21	13.48	12.44	+0.88	+15.67
Khairagarh	11.25	13.50	14.00	38.75	17.47	21.27	24.26	31.65	23.66	+15.09	+2.09
Saiyan	13.21	15.74	7.72	36.67	26.59	30.13	33.30	19.68	27.42	+9.25	+4.60
Kiraoli	23.87	18.21	16.00	58.08	37.55	37.36	60.24	58.60	48.43	+9.65	+4.17
Fatehpur	16.77	14.27	6.25	36.29	25.21	28.69	36.04	37.68	31.90	+4.39	+13.23
				667.62					700.98	-33.36	-38.27

Table 2: Total Recharge and Drought Values for the District Agra (2007-2010)

District	Annual Recharge (10^6M^3)				Annual Drought (10^6M^3)				Average Annual Drought (D) x 10^6M^3	Water Balance = R-D x10^6M^3	Annual ground water depletion calculated x 10^6M^3
	Recharge by rainfall	Recharge by canals	Recharge by field irrigation	Total Recharge (R)	For year 2007	For year 2008	For year 2009	For year 2010			
Agra	25.6	15.61	19.26	60.5	63.25	72.4	80.01	79.51	73.79	-13.3	-4.03

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RESULT AND DISCUSSION:

Table 3: Results of water balance study for various blocks (1974-1977)

Blocks	Annual total recharge by rainfall, canals and field irrigation (10^6M^3)	Average Annual Drought x 10^6M^3	Recharge-Drought x10^6M^3	Annual ground water depletion calculated from contours x 10^6M^3	Inference
Akola	30.55	36.61	-6.06	+0.54	Ground water enters into this block from the adjoining block kiraoli, which is confirmed by the slope of ground water contours.
Barauli-Ahir	49.45	61.69	-12.24	-9.80	Ground water enters into this block from the adjoining block Bichpuri and Khandauli, which is confirmed by the slope of ground water contours.
Bichpuri	36.66	37.19	-0.53	-0.68	Ground water enters into this block from the adjoining block Barauli-Ahir, which is confirmed by the slope of ground water contours.
Bah	25.86	39.49	-13.63	-13.65	No change in ground water runoff.
Jitpur Kalan	41.24	34.76	+6.48	-11.31	Ground water is going out to the adjoining District Gwalior.
Pinhat	33.61	32.26	+1.35	-6.07	Ground water is going out to the adjoining District Gwalior.
Itmadpur	31.50	33.15	-1.65	-4.76	Ground water enters into this block from the adjoining block Tundla, which is confirmed by the slope of ground water contours.
Khandauli	29.01	32.00	-2.99	-3.18	Ground water enters into this block from the adjoining block Barauli-Ahir, which is confirmed by the slope of ground water contours.
Tundla	36.56	42.22	-5/66	-3.22	Ground water enters into this block from the adjoining block Itmadpur, which is confirmed by the slope of ground water contours.
Fatehabad	48.01	50.76	-2.75	-15.42	Ground water enters into this block from the adjoining block Shamsabad and Firozabad, which is confirmed by the slope of ground water contours.
Shamsabad	41.39	51.37	-9.98	-5.96	Ground water enters into this block from the adjoining block Fatehabad and Saiyan, which is confirmed by the slope of ground water contours.
Firozabad	40.62	51.18	-11.19	+2.20	Ground water enters into this block from the adjoining block Fatehabad, which is confirmed by the slope of ground water contours.
Kotla	40.05	53.82	-13.77	-6.72	Ground water enters into this block from the adjoining block Btah, which is confirmed by the slope of ground water contours.

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Jagnair	13.32	12.44	+0.88	+15.67	Ground water enters into this block from the adjoining district.
Khairagarh	38.75	23.66	+15.09	+2.09	Ground water enters into this block from the adjoining block Fatehpur Sikri and district Dholpur, which is confirmed by the slope of ground water contours.
Saiyan	36.67	27.42	+9.25	+4.60	Ground water enters into this block from the adjoining block Shamsabad, which is confirmed by the slope of groundwater contours.
Kiraoli	58.08	48.43	+9.65	+4.17	Ground water enters into this block from the adjoining block Akola, which is confirmed by the slope of ground water contours.
Fatehpur	36.29	31.90	+4.39	+13.23	Ground water enters into this block from the adjoining block Khairagarh, which is confirmed by the slope of ground water contours.
	667.62	700.98	-33.36	-38.27	Ground water is going out from the district Agra to joining districts

Table 4: Result of water balance study for District Agra (2007-2010)

District	Annual total recharge by rainfall, canals and field irrigation (10^6M^3)	Average Annual Drought x 10^6M^3	Recharge-Drought x10^6M^3	Annual ground water depletion calculated from contours x 10^6M^3	Inference
Agra	60.5	73.79	-13.3	-4.03	Ground water is going out from the district Agra to joining districts

Therefore the irrigation water in this region is available either from canals or tube wells. Pumping of water from the groundwater resources can be modified and water can also be used from the major rivers like Yamuna, Gambhir and Chambal in the blocks Bah, Barauli-Ahir, Tundla, Firozabad and Fatehbad.

The old wells which have been dried up due to fall of the water table in blocks of Bah, Akola, Firozabad, Itmadpur and Kotla, can be used as recharge wells. The recharge water from these wells can be taken directly from the rivers Yamuna and Khari. Increased pumping can also induce recharge from the rivers.

The construction of new wells can be carried out in the blocks Pinhat and Jitpur Kalan. A number of minor irrigation works can also be increased in the blocks Khairagarh, Saiyan and in Jagnair. Some new minor irrigation works can be provided in the blocks Kiraoli and Fatehpur Sikri. The water from the new minor irrigation works can be used in the adjoining blocks, because the slope of the ground is favourable for this purpose.

The water, which is going out of the region to the adjoining district, can be checked and utilized by increasing the number of minor irrigation works in block Khairagarh and this water can also be used in the adjoining block Akola.

CONCLUSION

The entire irrigation requirement of the district Agra is met with the water pumped out from the groundwater storage and canals. The Groundwater recharge is due to seepage from canals, infiltration from irrigation fields and recharge by rainfall. But due to the insufficient recharge or over usage, it has been found that there is a continuous fall in water table thereby causing depletion of Groundwater resources as mentioned in Table.

Some remedial measures can be undertaken to prevent this depletion of the natural groundwater table. The number of minor irrigation works can be increased in the region where the recharge of Groundwater is more than the Draft. This excess water of one region can be used in the adjoining blocks for use with the help of gravity flow through open drains because of the favourable topography of the ground. The dried up wells can be used as recharge wells, recharged through the waters of the river Yamuna and Khari which may thus help conserve the ground water resources in the region. At present the groundwater resources are the most exploited for the purpose of irrigation which can be partly met with the pumped waters from the rivers like Yamuna, Gambhir and Chambal. All these solutions may thus help solve the problems of the shortage of groundwater in the study region.

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