e ISSN-0976-7223 | Visit Us - www.researchjournal.co.in DOI : 10.15740/HAS/IJAE/7.2/334-339

RESEARCH PAPER | International Journal of Agricultural Engineering | Volume 7 | Issue 2 | October, 2014 | 334–339

Water balance study in an agricultural watershed for evaluating ground water potential at Sindewahi

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Received : 13.03.2014; **Revised :** 01.08.2014; **Accepted :** 15.08.2014

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ABSTRACT : Water balance study on Zonal Agricultural Research Station, Sindewahi, Distt.Chandrpur was conducted on 9 open wells during the rainfall 2005-06. During the year total rainfall received was only 1422 mm. The study indicated that the availability of total water balance during the year was about 964.94 mm (67.84 %) of the total rainfall. Out of the total rainfall 8per cent was surface runoff, about 18.67 per cent ground water recharge (Yg) and 37 per cent soil moisture storage. Maximum (75.45 ha-m) ground water storage was observed in the month of September followed by 63.45 ha-m in the month August and minimum (16.50 ha-m) in the month of June. The monthly ground water fluctuations were determined by considering the month of May as the driest season. The average ground water level was found higher 455 cm in the month of September and maximum seasonal fluctuation of ground water level was observed in well No. 2 *i.e.* 612 cm. The study indicated the annual status of ground water potential.

KEY WORDS : Precipitation, Water balance, Ground water potential, Specific gravity yield, Seasonal fluctuation

HOW TO CITE THIS PAPER : Mhaske, Ashok R., Ubarhande, V.P. and Taley, S.M. (2014). Water balance study in an agricultural watershed for evaluating ground water potential at Sindewahi. *Internat. J. Agric. Engg.*, **7**(2): 334-339.

In India at present more than 90 per cent of the total water usage is accounted for by irrigation. This is so because 70 per cent of the country's population is dependent on agriculture and rainfall being highly seasonal, uncertain and erratic. Successful agriculture is not possible without irrigation. Hence, evaluation of the ground water resource of an area is very important. This needs estimation of ground water recharge from different sources, pump age and the resulting change in storage during 2005-06.

DhruvaNarayana *et al.* (1973) determined the value of storage co-efficient to be 0.90 and the same was used in finding the change in ground water storage. Sharma and Kampen (1975) have worked on small runoff storage facilities for supplemental irrigation at the ICRISAT and concluded that about 12 per cent of total annual rainfall was expected as runoff on cropped deep black cotton soils. Nagra and Sondhi (1990) estimated the various components of total annual recharge in the ground water basin of BistBoad tract by water balance studies.

This paper deals with the estimation of water balance of agricultural watershed for evaluating ground water potential during the year.

METHODOLOGY

In order to estimate the ground water balance in the watershed, the study was conducted during the year 2005-06 at Zonal Agricultural Research Station, Sindewahi Distt. Chandrapur a monoculture paddy area comprising the area under study had spread of over 76 ha. area. The predominant soils were mainly sandy clay loam soil. The average height of the watershed was about 7m.

The ground water storage changes were recorded fortnightly representing the water levels in 9 open wells located in the watershed. The relevant hydrological data were also recorded.

Recording of hydrological data :

The data related to precipitation, runoff, ground water fluctuations, soil moisture storage and open pan evaporation were recorded on the Agro-Meteorology services at Zonal Agricultural Research Station, Sindewahi. Precipitation, (daily rainfall depth) was recorded by the automatic syphon type recording rain gauge. The cumulative runoff from the watershed was measured with the help of 'H' flumes and the stage level recorders, that total evapotranspiration from a given area was calculated by the methods suggested by Tyagi *et al.* (1976) and Gulati (1987).

Soil moisture :

To monitor the soil moisture changes during the premonsoon, monsoon and post monsoon periods, the soil samples were collected from the experimental watershed and soil moisture was determined by gravimetric method.

Ground water :

To record the ground water fluctuations 9 open wells spread over the entire watershed were selected. The water table depths were measured fortnightly throughout the year. An electrical water level indicator (electrical depth gauge) was used to measure the water levels in the observation wells. The reduced levels of ground water were obtained by subtracting recorded water table depth from the reduced levels of top of the well. This difference was further subtracted from the elevations of the top of the well above MSL in order to express the ground water elevation with reference to MSL (222).

The water balance was estimated by hydrologic budget equation as suggested by Schicht and Walton (1961).

$$P = R + E_T + U \pm \Delta S_s \pm \Delta S_g \quad (1)$$

in which,

P is the cumulative precipitation for the WBP (mm)

R is the cumulative surface runoff for the WBP (mm)

E_T is the annual evapotranspiration (mm)

U is the subsurface flow (mm)

ΔSs is the change in soil moisture (mm)

ΔSg is the change in ground water storage (mm).

During the water budget periods (WBP) the rains continued from June 1 to September 2006 (*Kharif*). It could safely be assumed that during the above period the change in soil moisture storage (ΔSs) could be considered to be negligible and hence, the term aSs is eliminated from equation 1. With this assumption and substituting, ΔSg =Yg. ΔH, the equation 1 can be rewritten to obtain Yg as below (Anonymous, 1986) :

$$Y_g = \Delta S_g = \frac{P - R - E_T}{\Delta H} \times 100 \quad (2)$$

in which P, R, E_T and ΔSg have the same meaning as defined earlier and Yg is the gravity yield (ground water recharge in percentage) and ΔH mm is the difference in the ground water elevation at each well observed for the period of water balance (Sophocleous, 1991). The location of wells are given in Table A.

Table A : Location and use of experimental wells

Well No.	Location	Use of well water
1.	Guest house	Drinking
2.	Labour colony	Drinking
3.	Horticulture garden	Drinking
4.	Junior agronomy	Drinking + drip irrigation
5.	Near termarind tree	Irrigation
6.	Near *Kharif* fallow	Irrigation
7.	Near coconut tree	Irrigation
8.	NARP colony	Drinking
9.	Near Ranwadi	Irrigation

RESULTS AND DISCUSSION

The findings of the present study as well as relevant discussion have been presented under following heads :

Rainfall, runoff and evapotranspiration :

During the year 2005-06 the total rainfall recorded was only 1422 mm. The runoff hydrographs obtained from the stage level recorders were analysed for the estimation of cumulative runoff. On an average the surface runoff was observed to be about 8 per cent (113.76 mm) of the total rainfall for the *Kharif* and *Rabi* season water budget period (Table 4). The weighted average of the evapotranspiration over the season was observed to be 405 mm (about 36%) of rainfall during *Kharif* and *Rabi* seasons.The average monthly ground water table in meter from the mean sea level during the season for nine observations is shown in the Table 1.

The monthly cumulative fluctuations in the ground water levels for the period from May, 2005 to March, 2006 were calculated and presented against the water level of May, 2005 which is considered as the driest month. The base values (May, 2005) are treated to be zero and the results are presented in Table 2.

The data reveal that the average cumulative water fluctuations (H) were maximum in the month of September, 2006 (455 cm). The elevation difference between the ground water levels (Δh) was observed to be maximum (+ 185.11cm) in July 2005 followed by June (96.0 cm), August (88.56) and September (69.89) 2005. From the data it is observed than June, July, August and September were the only recharging months in which July contributes maximum (Cook and Salman, 1997).

The maximum value of fluctuation during this year was observed to be 612 cm in well No.2 in the month of September, 2005 and 210 cm in well No.9 'in the month September, 2005.

For each observation well the value of ground water recharge (Yg) was worked out by "(2)". The average annual gravity yield (ground water recharge) for the watershed was observed to be 18.67 per cent of the total precipitation (Table 3).

Table 1 : Average monthly ground water table (m) from MSL during the season 2005-2006

Well No.	RL of Top	Depth (m)	April	May	June	July	August	September	October	November	December	January	February	March
1.	223.48	11.27	216.83	216.13	217.11	220.07	220.69	222.08	221.98	221.78	221.10	219.91	219.43	219.08
2.	222.93	15.17	215.61	215.03	216.35	218.43	219.96	221.15	221.10	220.53	219.5	218.83	217.68	216.53
3.	240.80	10.84	233.35	232.95	233.95	235.95	236.20	236.25	236.00	235.80	234.85	234.50	234.35	234.03
4.	219.40	11.43	213.95	213.65	216.65	217.50	217.75	217.70	217.05	217.92	216.80	216.13	215.30	214.67
5.	219.10	11.28	212.55	212.35	213.61	216.30	217.30	217.70	217.25	217.05	216.55	215.23	214.30	213.35
6.	218.00	11.89	215.00	214.50	215.15	217.30	217.77	217.82	217.75	217.55	216.88	216.45	216.12	215.05
7.	218.79	9.77	212.99	212.59	213.29	214.54	216.84	217.69	216.74	215.74	214.63	213.74	213.14	212.89
8.	221.40	12.75	211.85	211.40	212.65	213.65	214.95	216.80	216.10	215.90	215.63	214.60	213.35	212.70
9.	216.20	7.50	214.8	214.20	215.40	215.75	216.00	216.30	216.00	215.80	215.57	215.42	215.05	214.95

Table 2 : Monthly ground water fluctuation (cm) considering the month of May as a driest month for 2005-2006

Month	Well No.									Ave. Fluctuation	Δh
	1	2	3	4	5	6	7	8	9		
April	70	58	40	30	20	50	40	45	60	45.88	-34.23
May	0	0	0	0	0	0	0	0	0	0	-45.88
June	98	132	98	120	126	65	70	125	30	96.0	96.00
July	394	340	300	385	395	280	195	225	155	296.55	185.11
August	456	493	325	410	495	327	425	355	180	385.11	88.56
September	595	612	330	435	535	332	510	540	210	455	69.89
October	585	607	305	430	490	325	415	470	185	423	-32
November	565	550	285	427	470	305	316	450	160	392	-31
December	497	447	190	315	420	238	204	423	137	319	-73
January	378	380	155	248	288	195	115	320	122	244	-75
February	330	265	140	165	195	162	55	195	85	176.88	-67.12
March	295	150	105	102	100	55	30	130	75	115.77	-61.11

During the monsoon period, the soil moisture contents were observed to be generally at the field capacity. There was a gradual recession during the post monsoon and heavy recession during the next premonsoon period. Similar results were reported earlier by Pawade (1981).Considering the depth, apparent specific gravity and moisture content of the soil during the water budget periods, the soil moisture storage was estimated to be 524.96 mm (Table 3), which is about 37 per cent of the annual precipitation.

Water balance :

Based on the rainfall data and estimated values of surface runoff, ground water recharge and soil moisture storage, the water balance for the watershed during *Kharif* season is prepared as suggested by Jozef *et al.* (2003) and presented in Table 4. It is observed that the availability of total water balance during the year 2005-06 was 964.94 mm (67.86%) of the total rainfall 37 per cent comprised soil moisture, 8 per cent surface runoff and about 22.94 per cent ground water recharge (Hussan and Bhutta, 1996 and Allen *et al*.,1998).

Ground water potential :

The monthly cumulative ground water storage of the watershed (Table 5) revealed that there was an increase in the

Table 3 : Gravity yield of observation wells 2005-2006

Well No.	Seasonal fluctuation H (mm)	Seasonal gravity yield Y_g (%)	Gravity yield on the basis of annual rainfall
1.	4970	14.83	12.01
2.	4800	15.36	12.44
3.	2320	31.79	25.75
4.	3150	23.41	18.96
5.	4090	18.00	14.58
6.	2670	27.62	22.37
7.	4400	16.76	13.57
8.	4150	17.77	14.40
9.	1800	40.97	33.97
Average gravity yield	22.94	18.67	

Table 4 : Water balance for 2005-06 based on estimated average value of different component of rainfall at the watershed

Season	Rainfall (P) mm	Surface runoff (R) mm	Ground water recharge (Yg) mm	Soil moisture storage (mm)	Total (mm)
Kharif	1253.2	100.26	287.50	462.50	850.26
(1st June to October 2nd)					
Rabi (Oct.-Jan.)	168.8	13.50	38.72	62.46	114.68
Total	1422	113.76	326.22	524.96	964.94
Per cent of rain fall	100.00	8.00	22.94	37	67.86

Table 5 : Monthly and cumulative ground water storage of ZARS, Sindewahi during 2005-2006

Month	Ave. fluctuation H (cm)	Storage (Δ h) (cm)	GWS/unit area ha - (cm)	GWS of W.S. (ha-m)	Cumulative GWS (ha-m)
April 05	45.88	-34.23	-7.83	0.0	0.0
May	0	-45.88	-10.50	0.0	0.0
June	96.00	96.00	21.99	16.50	16.50
July	296.55	185.11	42.40	31.80	48.30
August	385.11	88.56	20.20	15.15	63.45
Sept.	455.00	69.89	16.00	12.00	75.45
Oct.	423.00	-32.00	-7.32	-5.49	69.96
Nov.	392.00	-31.00	-7.00	-5.25	64.71
Dec.	319.00	-73.00	-16.71	-12.53	52.8
Jan. 06	244.00	-75.00	-17.17	-12.87	39.31
Feb. 06	176.88	-67.12	-15.37	-11.50	27.81
Mar. 06	115.77	-61.11	-13.90	-10.42	17.39

ground water storage from the month of June to September. The minimum 16.50 ha-m ground water storage was observed in the month of June and maximum 75.65 ha-m in September followed by 63.45 ha-m in August and 48.30 ha-m. in July 2005. From the month of the September there was continuous decrease in ground water storage. During *Rabi* season (October to January) the ground water storage were found to decrease from 69.96 to 39.31 ha-m. It was observed to decrease it further (17.39 ha-m) in the month of the March 2006.

This information is useful for proper planning of cropping ‘system and developing the water resources on the watershed during the least rainfall year.

From the data of average fluctuation of water level cumulative ground water storage can be predicted with the linear model y = 0.171x – 2.571 with co-efficient of determination $R^2 = 0.994$ as given in Fig. 2. From the co-efficient of determination it is clear that there is good correlation between the average fluctuations and cumulative ground water level (Thornthwaite and Mather, 1955).

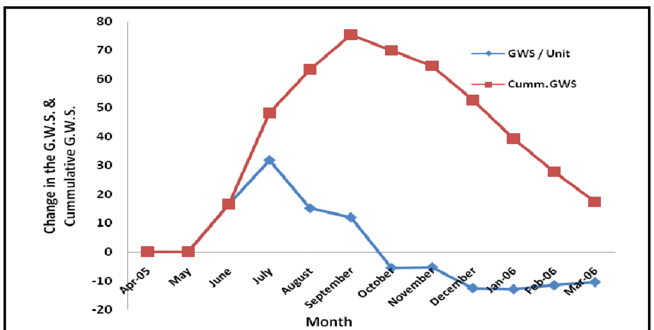

Fig. 1 : Monthly change in the ground water storage and cumulative ground water storage in watershad during the year 2005-06

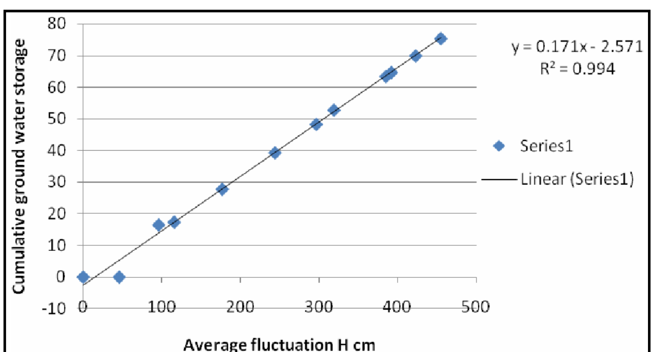

Fig. 2 : Linear model for prediction of cumulative ground water storage for sindewahi station

To find out the correlation between the average ground water fluctuation with month a polynomial model $y = -12.50x^2 + 174.8x - 213.1$ ($R^2 = 0.857$) was developed and is having good fit (Fig. 3).

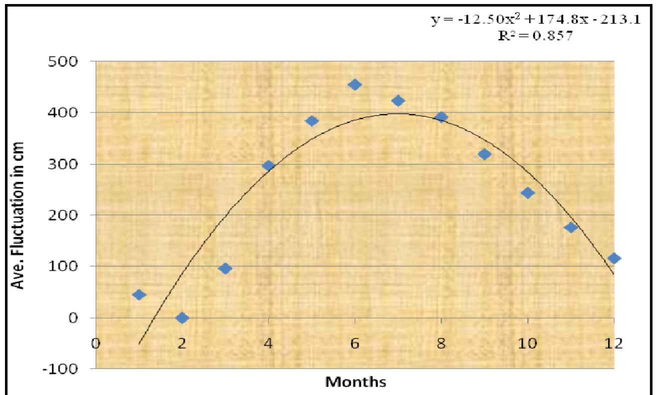

Fig. 3 : Monthwise average fluctuation in cm

Similarly to find out the correlation between cumulative ground water storage with the month the polynomial model for the above said watershed is developed and having good fit (Fig. 4).

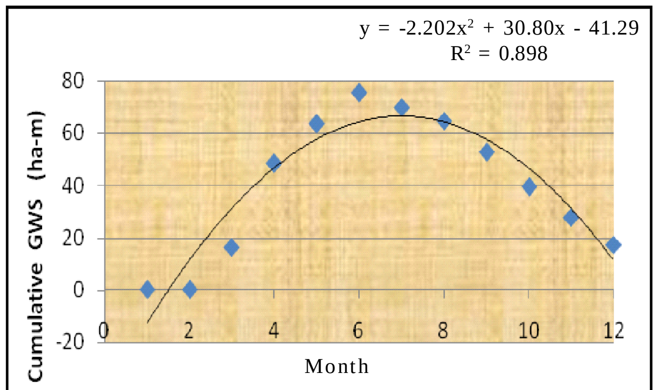

Fig. 4 : Monthwise cumulative GWS

Hence, from the fluctuations of the water level, the ground water resource development in the watershed can be directly predicted and accordingly based on this information the sustainable crop planning for *Rabi* and *Kharif* season can be safely made for successful crop venture. The crop planning with lack of this information in *Rabi* and *Kharif* season can lead to the failure of the cropping venture.

Suggested sustainable crop planning :

Due to climate change there is erratic and uncertain behaviour of the rainfall and dry spell occurs in the study area during critical growth period of the paddy crop and yield of the crop decreases up to 50 per cent even though other all input are provided sufficiently and livelihood security of the farming community comes in danger.

For providing irrigation surface storages like reservoirs requires huge financial budget and thereafter evaporation losses, damage to the crop and land, less efficiency of the project, no benefit to the end users and rehabilitation problem.

The above situation focused the need of this study. From the Table 4 the maximum ground water storage was observed in the month of September *i.e.* 75.45 ha-m.

Hence, the total available ground water in the 75 ha. Area will be =75.45 × 10000 m^3 =754500 m^3. If this is known then farmer can plan the following cropping model.

Being the monoculture paddy area the farmer can plan paddy in *Kharif* for total 75 ha. Paddy area and erratic and uncertain behaviour of the rainfall and thereby dry spell can be mitigated by providing three protective / life saving irrigation of 10 cm depth of each irrigation to the total watershed area during critical stages of the growth period of paddy like tillering, milky stage of the grain, grain formation etc. which will consume 2, 22,500 m^3 of water and can harvest sustainable production of the paddy crop and secure his livelihood.

Farmers in the study area keep the land barren after harvest of the paddy crop because the lack of information of the underground reservoir and water availability (Kothari *et al.*, 2007).

In *Rabi* season farmers can plan the sequence crop like chickpea for which three irrigation, at sowing, at flowering and at pod development are required for which total water required will be = 2,25,000 m^3 which can be consumed from the balance quantity of the ground water. Cultivating the chickpea crop on the total watershed area thereby increasing cropping intensity.

Farmers can plan the vegetable crops in *Rabi* and summer season in the balanced ground water of 309500 m^3 by providing eight irrigation of 5 cm depth requiring 300000 m^3 for total watershed area of 75 ha. Allen *et al.* (1998) worked on Crop evapotranspiration. Guideline for computing crop water requirements. Thornthwaite and Mather (1955) and Kothari *et al.* (2007) worked on water balance based crop planning for Bhilwara and Singh *et al.* (2004) worked on water balance components and effect of soil moisture on yield of wheat in mid Himalayan region of Uttaranchal and theis results are more or less similar to the results of present study.

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