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ORIGINAL ARTICLE

Estimation of Dry-Season Fluctuation in Specific Yield using Water Budgeting Approach in Bonasuria Micro-watershed of Damodar River Basin, India

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ABSTRACT

Heterogeneity in lithological and structural characteristics results in variation of specific yield (S_y) value in spatial domain. It also depends upon degree of saturation of aquifer. This imparts temporal variation in S_y value in an aquifer. Bonasuria micro-watershed of Damodar river-basin in India is selected to undertake the study of estimation of temporal variation in S_y based upon monthly ground water budgeting for three non-monsoon months. S_y value gradually changes with progression of summer months. Average specific yield value has been estimated as 0.002593 in March and 0.001446 in April. Determined specific yield values indicate low water storage capacity of the shallow aquifer system. This highlights the need of efficient water management for sustainable development of the area. Present study indicates that this can be achieved through storing the effluent seepage going out of the micro- water shed system as base flow. By constructing appropriate water storage structure at the mouth of the water shed and diverting the same back to the aquifer through suitable means is expected to rejuvenate the aquifer system. Holistically this intervention will lead towards development of sustainable dry-season agricultural practices in the study area.

INTRODUCTION

Specific yield is defined as the volume of water that an unconfined aquifer releases from storage per unit surface area of the aquifer per unit decline in the water level under gravity (Meinzer, 1923). It implies that specific yield of an aquifer will change with its gradual desaturation. (Lwimbo et al., 2019). However this change is difficult to measure as it requires precise estimation of recharge-discharge scenario. It is well understood that owing to the complexity of hydrogeological situations, it is almost impossible to measure groundwater recharge directly (Kinzelbach et al., 2002; Chen et al., 2005). According to Taylor et al., (2013) and Batelan et al., (2007), spatial and temporal variation of rainfall controls the groundwater recharge. Recharge of groundwater also takes place from neighbouring aquifers, artificial recharge, irrigation return flows and water network losses (Demiroglu et al., 2019; Crosbie et al., 2010). In semi-arid region however, more rainfall is not accompanied with more groundwater recharge as increased temperature converts the excess precipitation to evapotranspiration.

However, reliable groundwater recharge estimation is strongly needed for sustainable water resources management. Hydrogeological studies help to find out groundwater recharge quantities and discharge quantities ratio for the assessment of groundwater budgets in the specific regions (Simsek et al., 2020). Therefore, to ensure effective groundwater resource estimation, all recharge and discharge parameters have to be properly assessed in spatio-temporal domain and a comprehensive assessment of the available groundwater resources may be attempted. In the present study, specific yield of shallow aquifer of the watershed is estimated using monthly ground water budgeting for three consecutive non-monsoon months. Present study is approached on the basis of monitoring of water level from the observation dug wells across the watershed, measurement of the effluent seepage (base flow) to the stream, generation and interpretation of data on ground water abstraction structures along with drafts, surface water irrigation command area mapping and study of cropping pattern etc.

STUDY AREA

Bonasuria micro-watershed of Damodar river bbasin is located in Bankura district of West Bengal, India (Fig 1) covering an area of 16.37 sq. km. It's a drought-prone region with annual normal rainfall of 1423 mm with monsoon months from July to September. Elevation of the area varies between 140 and 150 m amsl with regional slope towards north east. The area is characterized by undulating uplands, ridges, valleys and is underlain by hard crystalline rocks of Archean age.

The micro-watershed is elliptical in shape and elongated in the direction of NE-SW and is drained by the second order tributary of the river Damodar. The tributary, henceforth, called as the trunk stream is flowing along the axis of the watershed. At the closure of the Bonasuria micro-watershed, trunk stream merges with another stream. The entire drainage system of the micro-watershed is ephemeral in nature. First order streams become dry within a short period after the withdrawal of the monsoon. With gradual progression of non-monsoon months, the trunk stream starts drying up from its upper reaches and stream discharge in the downstream reduces. By the end of May no significant flow in the trunk stream is observed.

An estimated population of 10000 depends on this micro-watershed for their livelihood. The entire drinking needs in the area is met from the groundwater resources tapping shallow unconfined aquifer comprising weathered mantle which extends down to the depth of 13 to 14 mbgl. For the domestic uses, river and ponds are used at few places. For irrigation purposes, irrigation from the trunk stream, locally called as 'Jhor' is mainly used during monsoon season, supplemented

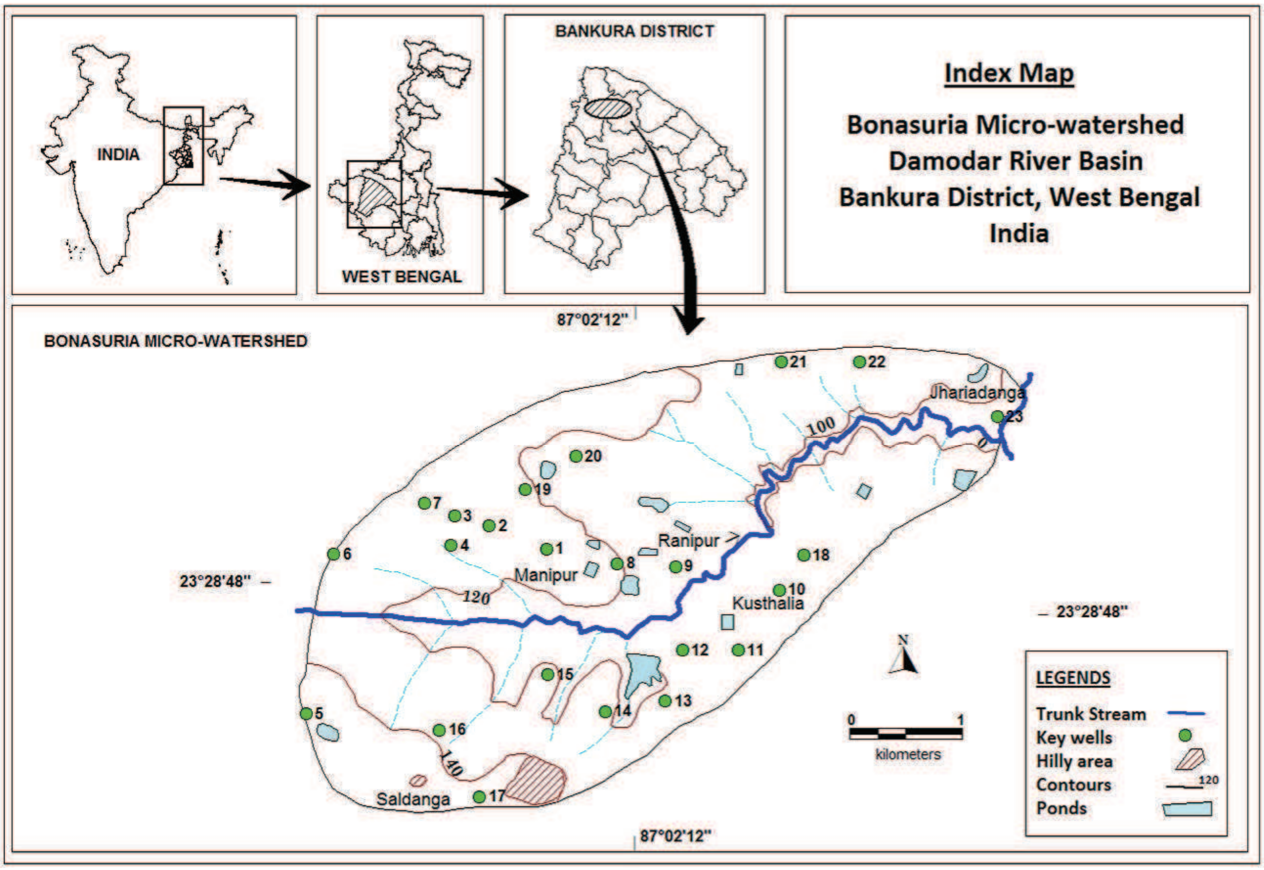

Fig.1. Location map of the watershed indicating the trunk stream and key observation wells.

by ponds, tanks, and large diameter dugwells with limited command area. With dwindling water in river, large diameter dug wells are commonly used for ground water based irrigation in the area.

AQUIFER CHARACTERIZATION

The ground water in the area occurs under unconfined condition in weathered residuum and in shallow fractures. Depending upon the nature of basement rocks and degree of weathering, depth of weathered residuum varies from place to place. Below the weathered residuum hard crystalline rocks are present. The most dominant rock type in the area is granite gneiss. Augen-gneiss is exposed in and around the Manipur village. Phyllite and schists are encountered around Saldanga village. The country rocks at places are intruded by anorthosites and metabasic intrusions. Several set of fractures criss-cross the basement.

Groundwater development in the area is restricted within shallow aquifer. The shallow aquifer is mostly developed by dug wells and large diameter dug wells. Most of the dug wells tap the entire thickness of the weathered zone. Depth of the inventoried dug wells (6.18 - 13.50 m bgl) shows variation in thickness of weathered residuum. The hand pumps/ India Mark II wells tapping the shallow potential fractures are used for drinking water need. No deep tube well is located in the watershed. Large diameter dug wells are commonly used for ground water irrigation in the area.

MATERIAL AND METHODS

According to Lwimbo et al. (2019), water-level fluctuation (WLF) technique, is one of the reliable method to interpret well hydrographs. Although water level fluctuation method imparts outstanding results in comparison to other methods of estimation, continuous monitoring of groundwater levels is desired (Dandekar et al., 2018). Hence, to understand the water level behavior of the shallow aquifer, a complete well inventory of the area has been carried out. Of the dataset, 23 representative dug wells, more or less evenly distributed throughout the watershed, were selected for monthly water level measurement during February to April (see Table 1).

Village wise census of irrigation dug wells is prepared based on the field observation and information from the local Panchayats. The dug wells are fitted with 3 HP and 5 HP centrifugal diesel pumpsets and in a few cases are operated manually by buckets and ropes. Based on the personal interview of the farmers (owner of the well) actual area irrigated, nature of crops cultivated during the months and mode of operation (pump fitted or manual) the village wise average unit draft for individual months were arrived at.

Monthly monitoring of water level for 3 non-monsoon months reveals that water level depth gradually decreases from February to April. Water table depth ranges between 2.3 and 7.7 mbgl, 2.90 and 8.60 mbgl and 4 and 8.75 mbgl in Feb, March and April respectively. Deeper water level is witnessed in upper reaches of the micro-watershed whereas in downstream area water level varies from 2.7 to 3.4 mbgl during February to April. Observed average fluctuation in water level during March-Feb and April-March are 0.57 m and 0.58 m respectively. Depth to water level maps for February, March and April are given in Fig.2 a-c. Water table contour map for the month of April (Fig.2d) shows that the ground water flow is from south-west to north-east.

Specific capacity (C) of dugwell is used to understand availability and discharge-drawdown relationship of ground water of the area. Specific capacity of a well is the well flow for unit fall of water level in the well (Kumbhar, 2019). To determine specific capacity, pumping test was carried out in a large diameter dug well in the study area (2.65 m diameter and 8.30 m depth) at Ranipur village. After removal of storage water in the well through 20 min of pumping with a discharge of 450 lpm the well has been emptied. With pre- pumping water level at 6 mbgl, dewatering procedure created a drawdown of 1.78 m. After

Table 1. Depth to Water-level details of Inventoried Key observation wells in the Study Area

Well no	Village	Gram Panchayat	Block	Depth of Well (m bgl)	MP (m agl)	Dia (m)	SWL (mbgl) Feb	SWL (mbgl) March	SWL (mbgl) April	Fluctuation (m) March-Feb	Fluctuation (m) April-March
1	Manipur	Pabra	Saltora	7.4	0.4	2.4	5.9	6.30	6.65	0.40	0.35
2	Chattapathar	Kanuri	Saltora	7.62	0.58	1.2	5.42	5.82	6.62	0.40	0.80
3	Chattapathar	Kanuri	Saltora	6.4	0.3	2.1	2.9	3.35	4.2	0.45	0.85
4	Chattapathar (Dakhinpra)	Kanuri	Saltora	7.3	GL	2.2	4.92	5.80	6.05	0.88	0.25
5	Tilabaid	Kanuri	Saltora	9.6	0.6	1.7	4.1	4.60	4.85	0.50	0.25
6	Raghunath chak	Kanuri	Saltora	8.55	0.75	1.2	4.25	4.95	5.81	0.70	0.86
7	Chattapathar (crusher)	Kanuri	Saltora	6.67	0.63	1.6	3	4.07	5.32	1.07	1.25
8	Ranipur	Pabra	Saltora	7.72	0.78	1.2	4.6	5.12	5.6	0.52	0.48
9	Ranipur	Pabra	Saltora	8.6	0.8	3.3	2.3	2.90	4	0.60	1.10
10	Kusthal	Bonasuria	Gangajalghati	10	0.75	1.2	4.9	5.15	5.95	0.25	0.80
11	Kusthal	Bonasuria	Gangajalghati	13.55	0.75	1.3	7.3	8.05	8.75	0.75	0.70
12	Bonkusthalia	Bonasuria	Gangajalghati	9	0.65	1.5	7.15	7.40	7.85	0.25	0.45
13	Dangapara	Bonasuria	Gangajalghati	9.55	0.85	1.2	4.8	5.45	5.95	0.65	0.50
14	Narayanpur	Bonasuria	Gangajalghati	9.4	0.65	1.2	6.35	6.71	7.15	0.36	0.44
15	Dhadanga	Kanuri	Saltora	10.8	0.7	1.25	5.6	6.00	6.4	0.40	0.40
16	Kharuabari	Kanuri	Saltora	11.15	0.35	1.1	6.58	7.20	7.95	0.62	0.75
17	Saldanga	Kanuri	Saltora	8.2	0.7	1	3.23	4.04	4.85	0.81	0.81
18	Kusthal	Bonasuria	Gangajalghati	8.22	0.68	2	4	4.62	5	0.62	0.38
19	Manipur	Pabra	Saltora	6.65	0.85	1.1	4.05	4.65	5.11	0.60	0.46
20	Damodarpur	Pabra	Saltora	6.18	0.62	1.3	3	3.58	4.33	0.58	0.75
21	Sukabad	Pabra	Saltora	11.6	0.5	1.2	5.3	5.80	6.3	0.50	0.50
22	Katabad	Pabra	Saltora	11	0.7	1.1	7.7	8.60	8.4	0.90	-0.20
23	Jhariadanga	Bonasuria	Gangajalghati	12	0.5	1.2	2.7	3.10	3.4	0.40	0.30
Average Fluctuation										0.57	0.58

MP: Height of Measuring Point; Dia: Diameter; SWL: Static Water Level;

emptying the well, recovery data is collected for 180 min. The recovery data has been utilised to determine the specific capacity of the well. Slichter's method (Slichter, 1906; Bouwer, 1978) has been utilised for interpretation of recovery data to arrive at specific capacity of the well and further assumed to be representative of wells tapping the same aquifer Recovery data after plotting in semi-log paper gave specific capacity of the well using Eq. 1. Specific Capacity was calculated as 12.78 lpm/m drawdown.

$$C = \frac{2.303 \times A \times \log S_1/S_2}{t'} \quad \text{(Eq.1)}$$

Where, C = specific capacity in lpm/m drawdown; A= Cross sectional area of the well in m^2; S_1= Final drawdown at the time when pumping was stopped; S_2=Residual drawdown at the time t'.

DETERMINATION OF SPECIFIC YIELD THROUGH WATER BUDGET METHOD

Amount of water that penetrates through several mechanisms to the subsurface and reaches groundwater reservoir is termed as groundwater recharge (Lerner et al., 1990; Gemitzi et al., 2017; and Malik et al., 2020). Water recharge reaching the water table is the major factor controlling the rise of groundwater level in unconfined aquifer (Healy, 2010, Mukherjee et al., 2017; Ray et al., 2020). Along with recharge, magnitude of groundwater level fluctuation also controls specific yield of the aquifer (Ray et al., 2014; Lwimbo et al., 2019). Specific yield is known as volume of water that an aquifer releases under hydrostatic conditions from a unit volume of aquifer material and is expressed as either percent or dimensionless fraction of total volume of aquifer (Chenini et al., 2008).

Monthly water budget method for non-monsoon months with no rainfall or negligible rainfall is a comprehensive approach for determination of specific yield (Saha and Agarwal, 2006). The water budget relation (Eq. 2) proposed by Healy and Cook (2002) is used in the study to estimate the net volume of the water that leaves the aquifer:

$$V_{out} = W_p - S_{pt} - RE + ET + E_{sr} \quad \text{(Eq.2)}$$

where V_{out}= Net volume of the water discharged from the aquifer; W_p = Gross ground water draft for domestic, irrigation and industrial uses; S_{pt}= Seepage from tanks and ponds; RE = Recharge due to return flow of water applied for irrigation; ET = Evapotranspiration; E_{sr}= Effluent seepage from the aquifer to the stream

Finally, specific yield is determined by the following equation (Eq. 3)

$$\text{Specific Yield } (S_y) = \frac{\text{Net vol. of water removed from the aquifer}}{\text{Volume of rock de-saturated}} \quad \text{(Eq.3)}$$

Using the above equations, specific yield is determined for two consecutive non-monsoon months, namely for March and April. Specific yield value obtained from above exercise was also compared by applying Dry Season Ground Water Balance equation (Eq. 4).

$$S_Y \times h \times A = D_g - R_{gw} - R_{sw} - R_{tank} + B \quad \text{(Eq.4)}$$

$$S_Y = \frac{D_g - R_{gw} - R_{sw} - R_{tank} + B}{h \times A}$$

Where, h= decline in water level in successive non monsoon months; S_Y = specific yield; A = area of the micro-watershed; R_{gw}= recharge due to ground water irrigation; R_{sw}= recharge due to surface water irrigation; R_{tank} = recharge from tanks; D_g= gross ground water draft; B = base flow in non monsoon months.

Basically both these equations (Eq. 3 and Eq. 4) are derivative of ground water balance equation. However, the volume of aquifer de-saturated in Eq. 3 and change in ground water storage (h x A) in Eq. 4, has been arrived at by two separate approaches. In Eq. 3 the volume

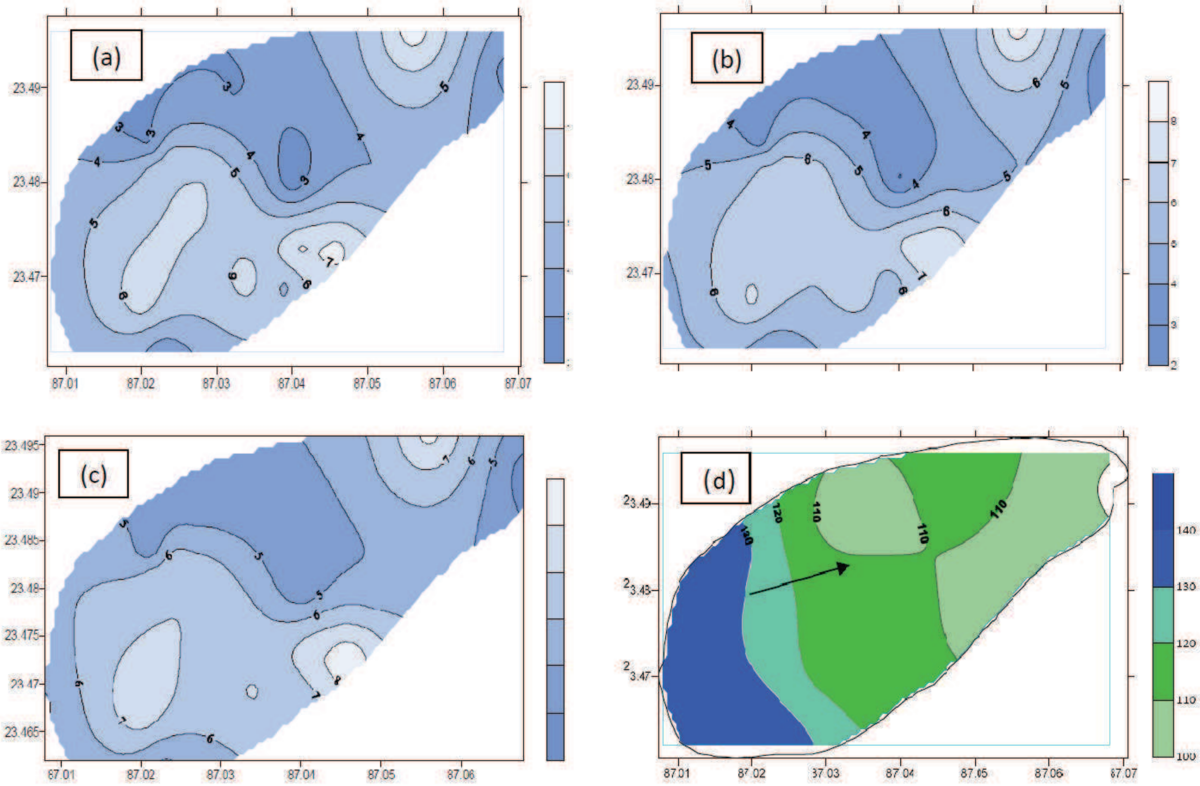

Fig.2. Depth to water level map (a) February, (b) March, (c) April and (d) Water table contour map for April in mbgl. Contour interval is 10 m.

of aquifer de-saturated has been integrated through numerical analysis using Trapezoidal and Simpson's rule. This method produces accurate volume calculations even with fewer inputs (Slaviniæ and Cvetkoviæ, 2016). On the other hand, in Eq. (4), change in storage has been assessed using average GW level fluctuation between March and February and between April and March.

Gross Ground Water Draft from the Aquifer

Gross ground water draft of the micro-watershed is mainly for drinking, domestic and irrigation purposes. In drinking-domestic sector, dependency on ground water is 100%. Based on complete well inventory carried out, groundwater draft for drinking-domestic sector is estimated considering the total population (Census, 2001) and per capita water demand. In line with practices of Public Health Engineering Department, Govt. of West Bengal, per capita demand for drinking and domestic uses is estimated as 40 lit/day for the month of March and 30 lit/day for the month of April. It concurs with the progressive water scarcity in the dry months compelling the populace to restrict water consumption. Computed drinking-domestic drafts are 10399.2 m^3 and 7799.4 m^3 in March and April respectively for the micro-watershed. Based on village-wise census of irrigation dug wells and estimated village wise average unit draft, gross ground water draft for irrigation in the watershed is 3436 m^3 and 2800 m^3 in the month of March and April respectively (Table 2). Only one industrial unit i.e. one brick factory at Chhatapathar village operates in the entire micro-watershed. The industrial unit utilizes ground water for its water needs. Estimated groundwater draft by the industrial unit is 660 m^3 in March and 300 m^3 in April. Summing up, gross ground water drafts for all uses in the micro-watershed during the months of March and April are 14195 m^3 and 10899.4 m^3 respectively.

Base flow, Effluent Seepage to the Trunk Stream

Seepage to the stream in the absence of rainfall in non-monsoon months, represented by the flow in the stream, is considered the base flow of the system. The watershed being a closed ground water system; no flow is received from elsewhere in the watershed except the effluent seepage which goes out of the system through the trunk stream. Stream flow is measured near the outlet of the watershed in the village Jhariadanga by volumetric and velocity methods.

Both these modus operandi perform well for the low discharge conditions or for lower-order stream (Gore et al., 2017). In volumetric method the total volume of flow through the stream was arranged to pass through a narrow passage from where a known volume of water was collected in a given time. This observation was recorded at different time and day during the period of study. The average flow recorded at different time of a particular day was considered as the flow for that day, similarly the observation recorded at different day was averaged to get the monthly water flow through the stream. Cumulative flow measured by volumetric method is 18252 m^3 and 9293.53 m^3 in March and April respectively. Volume of flow was also measured using velocity method. The amount of time required by a float (wooden block) to travel a given distance along the stream in a suitable location in the downstream was measured and the velocity of flow was estimated (Gore et al., 2017). Velocity of flow multiplied by the cross section area of the stream at that particular location gives volume of flow for a particular time. Observations were made in this regard at different points of time and day. The cumulative flow measured by velocity method is 24184.80 m^3 and 13418.40m^3 in March and April respectively. Finally, average of these two methods of observation arrives at monthly ground water flow through the stream, which is 21218.4 m^3 and 11356 m^3 in March and April respectively.

Evapotranspiration Loses

Evapotranspiration (ET) is the total loss of ground water due to evaporation and /or transpiration. ET is of paramount importance in water budget as it can affect the required capacity of reservoirs, size of pumping units and yield of aquifers (Khairy et al., 2019). ET decreases rapidly with the depth of the water level and becomes

Table 2. Estimation of domestic and irrigation draft in the watershed.

Village	Population	Domestic draft		No of irrigation dugwells	Unit draft m^3/month March	Gross draft in m^3		
		March (@ 40 lit/day/capita	April (@ 30 lit/day/capita			April	March	April
Ranipur	646	775200	581400	12	140	120	1680	1440
Manipur	91	109200	81900	2	120	100	240	200
Katabad	2000	2400000	1800000	3	150	120	450	360
Sukabad	700	840000	630000	2	45	30	90	60
Damodarpur	400	480000	360000	3	70	50	210	150
Jhariadanga	300	360000	270000	0			0	0
Narayanpur	150	180000	135000	0			0	0
Dangapara	100	120000	90000	0			0	0
Kusthol	1579	1894800	1421100	1	120	60	120	60
Chattapathar	450	540000	405000	2	72	50	144	100
Chattapathar (Dakhinpara)	250	300000	225000	7	10	10	70	70
Bonkusthalia	350	420000	315000	0			0	0
Dhadanga	350	420000	315000	1	36	30	36	30
Saldanga	300	360000	270000	2	36	30	72	60
Kharuabari	450	540000	405000	5	36	30	180	150
Raghunathchak	200	240000	180000	4	36	30	144	120
Tilabaid	350	420000	315000	0			0	0

negligible when the water level is below 3.5 mbgl (White, 1932). Except a few wells in the month of February, all the wells during the period of observation show water level below 3.5 mbgl. Therefore, the ET loses from the watershed during the month of March and April has been ignored.

Infiltration from Tanks and Ponds

Surface reservoirs may capture excess precipitation runoff in the wet season, rendering it available during dry periods and in this manner mitigating drought hazards (Pavelick et al., 2015). In the micro-watershed, there are 14 tanks with significant water spread area. Based on field measurements, average water spread area is considered as 60 % and 50 % of the total area for March and April respectively for these ponds. Recharge from ponds is assumed to be 1.44 mm/day as per GEC-1997 (CGWB, 1997). Estimated, total infiltration from tanks and ponds during March is 6480 m^3 and during April is 5400 m^3 (Table 3).

Return Seepage from Irrigation

Return seepage from irrigation is termed as the excess of irrigation water not utilized by plants that ultimately returns to an aquifer (Hu et al., 2017). It is also the prominent recharge source in arid regions (Simons et al., 2015). Major crop in the micro-watershed during non-monsoon period are mustard, pulses, onion, sesam, pumpkin and other summer vegetables. No paddy is cultivated during summer. These non-paddy crops are irrigated from ground water through large diameter dug wells with small command area. Field observations show that 12-10 hr / 0.25 ha watering was required with 3-5 HP pumps (30-35m^3/hr discharge) in summer months (say for a season of 90 days). Hence, about 400 m^3 water is used to irrigate 01 ha of land per month during summer season.

In the absence of precise measurement of return seepage from ground water and surface water irrigation, a modified norm value of GEC (1997) and GEC (2015), 15% of total volume of water applied is considered based on the prevailing soil, lithological disposition and nature of crops in the study area. Computed return seepage from ground water irrigation is 515.40 m^3 in March and 420 m^3 in the month of April. An area of about 120 acres are irrigated from surface water resource during the same period is identified. Potato, onion, pulses, wheat, and summer vegetables are grown in the area. Measured surface water irrigation in the area is 30000 $m^3$and 22500 m^3 in the month of March and April respectively. Assuming 15% return seepage from surface water irrigation, 4500 m^3 and 3375 m^3 of water is recharged during March and April respectively

Table 3. Estimation of Infiltration from tanks and ponds

Tank	Tank surface area in sq km.	Average water spread area in sq km		No. of days	Seepage from tanks in m^3	
		March (60% of area)	April (50% of area)		March	April
Tank 1	0.02	0.012	0.010	30	518.4	432
Tank 2	0.07	0.044	0.037	30	1892.16	1576.8
Tank 3	0.01	0.008	0.007	30	336.96	280.8
Tank 4	0.01	0.005	0.005	30	233.28	194.4
Tank 5	0.02	0.014	0.012	30	622.08	518.4
Tank 6	0.01	0.008	0.007	30	362.88	302.4
Tank 7	0.01	0.003	0.003	30	129.6	108
Tank 8	0.02	0.013	0.011	30	570.24	475.2
Tank 9	0.02	0.010	0.008	30	414.72	345.6
Tank 10	0.01	0.004	0.003	30	155.52	129.6
Tank 11	0.01	0.005	0.005	30	233.28	194.4
Tank 12	0.02	0.013	0.011	30	570.24	475.2
Tank 13	0.01	0.004	0.004	30	181.44	151.2
Tank 14	0.01	0.006	0.005	30	259.2	216

Volume of De-saturated Aquifer

Depth of water level map of key observation wells are used to determine volume of aquifer de-saturated in the time interval between two successive months. Water table data from key o bservation wells are processed in Mapping software (Surfer^{TM} Ver. 8.5) to generate water table maps. The prepared maps were field checked for reliability with pre-defined water level monitoring stations. Thus calibrated maps are combined with elevation contour model of the area to arrive at 3-D surfaces of depth to water level of February, March and April. These 3-D maps reflect progressive decline of the water level in the area for non-monsoon seasons (Fig. 3).

In the first case, the water level surface of March was taken as the lower surface and the same for February as upper surface, as these are the water levels below ground level. The change in volume was measured by three methods viz. Trapezoidal rule, Simpson's rule and

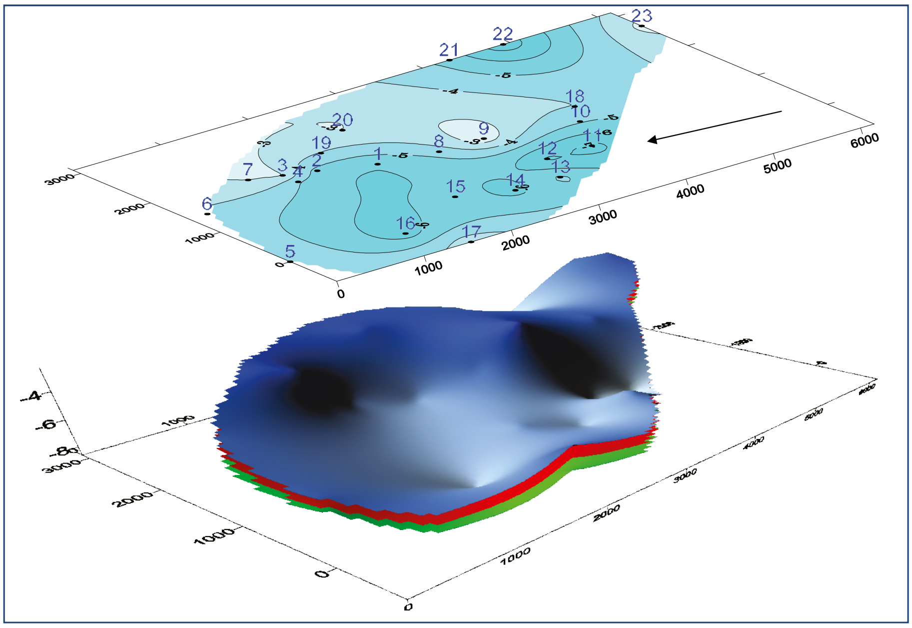

Fig.3. 3-D Surface map showing depth to water map of February, March, April 2008. The contours showing the depth to water of February, 2008 (plan) with the location of the key wells.

Simpson's 3/8 rule using Surfer™ Ver. 8.5 software and finally the average of the three was selected, which gives 9.12 MCM of aquifer de-saturated in March. Similarly, in the other case the water level surface of April was considered as lower surface and that of March as upper surface. The volume of aquifer de-saturated in the month of April is 8.61 MCM. Now, applying the Eq. (3), specific yield for March and April is 0.002623 and 0.001517. Supplementary to above, applying the dry season ground water balance equation (Eq. (4)) specific yield for March and April are 0.002563 and 0.001376 respectively considering average GW level fluctuation between March and February and between April and March. Combining these two methods, average specific yield for March and April are 0.002593 and 0.0014465 respectively.

DISCUSSION AND CONCLUSION

Bonasuria micro-watershed has limited ground water resource. Domestic and drinking water is the prime component of the gross draft of the area. Of the scarce groundwater resource, a sizable quantum of groundwater gets drained out as effluent seepage through the trunk stream. Total volume of water gets out of the micro-watershed is actually more than present gross draft in the area. Determination of precise specific yield values is key to proper groundwater resource management in terms of precise groundwater resource estimation. Present study highlights the changes in specific yield values with falling water level with progression of summer months. Estimated specific yield value for March is 0.002593 and for April is 0.001446. Estimated specific yield values although appears low, compares well with the earlier estimates in various hard rock terrains (Saha and Agarwal, 2006; Marechal et al., 2006).

Estimated specific yield value shows temporal variation. In Bonasuria micro-watershed, shallow aquifer gradually merges with underlying fractured granite-gneissic basement rocks through a horizon of weathered residuum with a stratified aquifer model. With falling water level, the water bearing horizon within the aquifer also changes affecting water yielding capacity of the aquifer. Hence, it may be safely assumed that difference in hydrogeological properties of different layers of the aquifer may induce impact of compactness of the aquifer matrix. In terms of spatial variation of estimated specific yield value, it is observed that measured water levels do not vary abruptly. This indicates that the area more or less represents same hydro-geomorphic unit. Therefore, the scope for rapid variation of the estimated specific yield in space is limited. Observed volume of effluent seepage reduces progressively from November to May. Determined specific yield values indicate low water storage capacity of the shallow aquifer system.

However, observed surface flow in the stream during non-monsoon months in absence of rainfall, indicates continuous effluent seepage to the stream from aquifer system. Base flow measurement at the mouth of the micro-watershed shows that aquifer system loses about 20000 m^3 and 11000 m^3 in the months of March and April respectively. These volumes significantly exceed the corresponding gross groundwater drafts in the area under study. Efficient water management may be achieved through implementation of water storage structure near the mouth of the micro-water shed. This stored water may be channelized or pumped to the upstream or periphery of the water-shed and used for dry-season agricultural practices so that it in turn replenishes the aquifer system. The command area developed in the vicinity of the water storage structure may also be used for round the year agricultural practice in the area.

Table 4. Summarised Results of Groundwater Budgeting Method

	Gross Ground Water Draft	March (m^3)	April (m^3)
I	a) Drinking-Domestic	10399.2	7799.4
	b) Irrigation	3436	2800
	c) Brick making factory	660	300
II	Base flow or the effluent seepage to the trunk stream	21218.4	11356
III	Evaporation losses	Nil	Nil
IV	Infiltration from Tanks and Ponds	6480	5400
V	Return Seepage from irrigation		
	a) Ground Water Irrigation	515.4	420
	b) Surface Water Irrigation	4500	3375
VI	Net volume of water removed from the aquifer	23918	13060.40
VII	Volume of aquifer desaturated (m^3/month)	9.12×10^6	8.61×10^6
VIII	Specific Yield	0.002623	0.001517

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