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AGRONOMY

Study on Scope of Roof Top Water Harvesting for Recharging Ground Water for Combating Excess Ground Water Withdrawal for Rice Cultivation in the District of Nadia in West Bengal

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Abstract

Investigation was conducted for all the blocks in the district of Nadia, West Bengal to estimate the over exploitation of ground water and to examine the possibility of mitigation of it through artificial ground water recharge. There were approximately 1.16×10^9 m^3 irrigation water requirement except monsoon month (June to September) for rice cultivation. The estimated ground water recharge was found approximately 0.82×10^9 m^3. Thus, approximately 0.34×10^9 m^3 of ground water was found over exploited every year if irrigation demands entirely satisfied through ground water. This 0.34×10^9 m^3 of overexploitation could be mitigated if approximately 3.88×10^8 m^2 roof top water harvesting structure along with the recharge facilities were created. The estimated cost for this purpose was approximately ₹ 666.488 billion. The creation of this facility may also contribute to large extent in domestic water supply along with the improvement of arsenic contaminated ground water of this district.

Highlights

- Estimation of block wise ground water recharge
- Estimation of block wise water requirement of rice
- Estimation of safe exploitation of ground water
- Estimation of extent of roof top water harvesting for ground water recharging to mitigate excess withdrawal of ground water

Keywords: Artificial ground water recharges, over exploitation, roof top water harvesting structure

Ground water is being used as the major source of irrigation water in most of the district of West Bengal. In the district of Nadia the summer rice is the popular crop cultivated in 2, 40,745 ha area (Anonymous, 2009a). There are many numbers of registered deep tube wells and many numbers of registered and non-registered shallow tube wells draw the ground water for satisfying the requirement of irrigation water. The withdrawal of ground water takes place almost throughout the year. High demand of water for rice cultivation and particularly the summer rice, the requirement of withdrawal of ground water excess to the amount of water get recharged under natural process during the period of monsoon (June/Jul-Sept/Oct). The situation is sometime so alarming that the state concerned department become compels to declare some region as black zone to check the excessive withdrawal of ground water. However farmers have high demand for summer rice cultivation due to its characteristics of assured good yield vis-à-vis the economy. In such situation it is very difficult to restrict the withdrawal of ground water. There may be a possible alternative of enhancing ground water recharge by artificial way to overcome the excessive withdrawal of ground water. With the above in view the present study was undertaken to examine the extent of roof top water harvesting for ground water recharging to mitigate excess withdrawal of ground water.

Materials and Methods

The study was conducted at the district of Nadia, West Bengal, India during 2013-2014. District Nadia is agriculture based district and located in the heart of West Bengal. Nadia represents the biggest agro-climatic zone in the new alluvium zone. The area lies between 22° 53′ and 24° 11′ north latitude and between 88° 09′ and 88° 48′ east longitude. Total geographical area of the district is 3,927 sq kms. Nadia district has 1250 villages in 17 blocks under four subdivisions and 96 of the villages are un-inhabited. Out of total 373414 ha area, about 85733 ha is not available for agriculture which is 23% of the total land of the district. The different texture of soil like clay, sandy loam, sandy clay loam, sandy clay, alluvium, silty clay, silty clay loam, silty and sandy are occupied 50501 ha, 106972 ha, 5446 ha, 47020 ha, 13757 ha, 25727 ha, 11610 ha, 5660 ha and 5446 ha area respectively(Anonymous, 2009b). Monthly Meteorological datas from 2003-2013 were collected from the Agricultural Meteorology and Physics Department, B.C.K.V., Mohanpur, Nadia. Nadia district has 160 – 170 rainy days each year and an average rainfall of 1330.22 mm (From 2003-2013) annually.

Evapotranspiration of crop was determined by using the formula of $ET_{crop} = ET_o \times K_c$ Where ET_{crop} = crop evapotranspiration or crop water need (mm/day), K_c = crop factor, ET_o = reference evapotranspiration (mm/day). The Blaney-Cridle method had been used to determine the reference crop evpotranspiration : $ET_o = p\ (0.46\ T\ mean + 8)$ where ET_o = Reference crop evapotranspiration (mm/day) as an average for a period of 1 month, T_{mean}= mean daily temperature (°C), p = mean daily percentage of annual daytime hours. Table 1 had represented the mean daily temperature. The mean daily percentage of annual daytime hours was calculated by using the approximate latitude of the area and the number of degrees north or south and has shown in Table 2. Table 3 and Table 4 had represented the crop factor and the duration of different stage of rice respectively.

Total crop water requirement for growing period of each crop was calculated by total growing period (days) × ET_{crop} (mm/day). During mid of June to September, most of the crop field in the district remains wet. Therefore, irrigation water was assumed to be not required. May be sometime some irrigation is required but that amount may be adjusted with the rainfall contribution other than this period. Total block wise crop water requirement was calculated by total crop water requirement for growing period × area of cultivation of that rice at that block. Total crop water requirement for all the crops in a block was calculated by summation of water requirement for each crop.

Table 1: Maximum and minimum monthly temperature (degree Celsius) in the district of Nadia (Centre Krishnanagar)

Month	T_{max}	T_{min}	T_{mean}
January	25	11	18
February	31	16	23.5
March	35	21	28
April	37	26	31.5
May	37	27	32
June	35	26	30.5
July	32	26	29
August	34	27	30.5
September	31	26	28.5
October	32	24	28
November	30	19	24.5
December	28	14	21

Source: District Statistical Handbook, Nadia

A different approach for estimating natural groundwater recharge in India was documented by (Kumar, 1977). In the present study recharges due to rainfalls were calculated by taking the average of the estimated recharges following the Bhattacharjee (1954), Chaturvedi (1973) and Datta *et al.* (1973) formulas. Requirement of extra recharge due to deficit in rainfall recharge was

Table 2: Mean daily percentage of annual daytime hours for different latitudes

Latitudes	N	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
	S	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June
30		.24	.25	.27	.29	.31	.32	.31	.30	.28	.26	.24	.23
25		**.24**	**.26**	**.27**	**.29**	**.30**	**.31**	**.31**	**.29**	**.28**	**.26**	**.25**	**.24**
20		.25	.26	.27	.28	.29	.30	.30	.29	.28	.26	.25	.25

Source: FAO

calculated by requirement of extra recharge due to deficit in rainfall recharge = (block wise crop water requirement for all crops) – (block wise recharge due to rainfall) = (block wise crop water requirement for all crops) — (average annual recharge × geographical area of that block).

Ground Water Resource Estimation Committee (GEC) stated that out of irrigation amount 35% as return seepage of the water delivered was taken into consideration for calculating the net requirement of extra recharge (Anonymous, 1984). Therefore, net Requirement of extra recharge = Requirement of recharge due to deficit in rainfall recharge -35% of recharge due to return seepage.

Latitude of the Nadia district is 23º28'15.48" N. So approximately we take the p values of 25ºN latitude

Table 3: Values of the crop factor (K_c) according to the growth stages

Name of the crop	Initial	Crop development stage	Mid season stage	Late season stage
Rice	1.1	1.1	1.3	1.0

Table 4: Approximate duration of growth stages for various field crops

Name of the crop	Total	Initial Stage	Crop development Stage	Mid season Stage	Late season stage
Rice	150	30	60	30	30

The relation between rooftop area as catchment for rain water harvesting and recharge to ground water, design of rain water harvesting structure, cost and the number of person whose demand could be satisfied for Nadia district were described by the Department of Water Resources and Development (WR&D), Govt. of West Bengal (Anonymous, 2011).

Details are as stated below:

1. Average annual rainfall =1497.8 mm
2. Average annual monsoon rainfall =1191.8 mm
3. Geo-hydrology= Lower Ganga Plain. Alluvial sediment composed of sandy loam up to 180 m underlined by thick deposits of sands of varying grade & texture occasionally separated by thin silt & clay layer.
4. Roof area = 534 m^2
5. Rainwater available from roof top during monsoon = roof area × rainfall = 534 m^2 × 11911.8 mm = 636 m^3
6. Quantity of harvested rainfall= Roof top rainfall × coeff. Of runoff of roof surface = 636 m^3 × 0.9 = 572.39 m^3
7. Quantity of harvested rainwater for the purpose of artificial recharge = 572.39 m^3 × 0.8 (Coefficient of first flash water & evap.) = 458 m^3

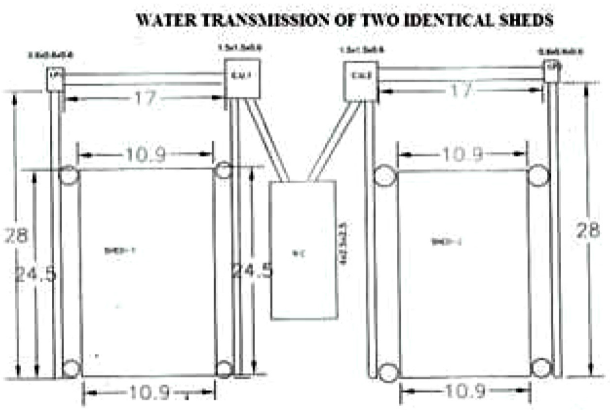

Fig. 1: Water transmission of two identical sheds (All dimensions were in meter)

8. Calculation for recharge chamber design
   (a) Recharge chamber will accommodate at least 20 min rainfall of highest per hour

   Rainfall intensity. For Nadia district it is 100 mm/hour.

20 min rainfall = 534 m^3 × 0.9 × 0.8 × 100 mm/h × 20min = 534 × 0.9 × 0.8 × 0.1 × 1/3 = 12.69 m^3

(b) Filter bed = 1.5m thick composed of sand and pebbles each 0.5 m thick

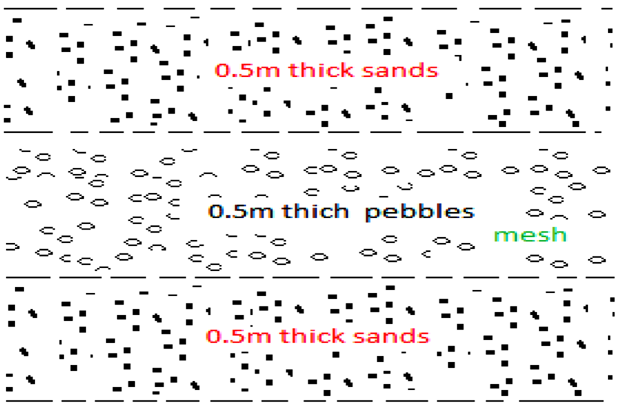

Fig. 2: Filter bed design

(c) X-sectional area of recharge chamber = Vol. of water to be accommodated/Effective Inside clear height =

12.69/ (1.5 × 0.4+1) = 7.25 m^2

(d) Additional clearance for clogging effect of filtered area=30%. So, total areas = 7.25 × 1.3 = 9.425 ≈ 10.0 m^2

(e) Recharge chamber dimension: Length = 4m, Width = 2.5m, Depth = 2.5m

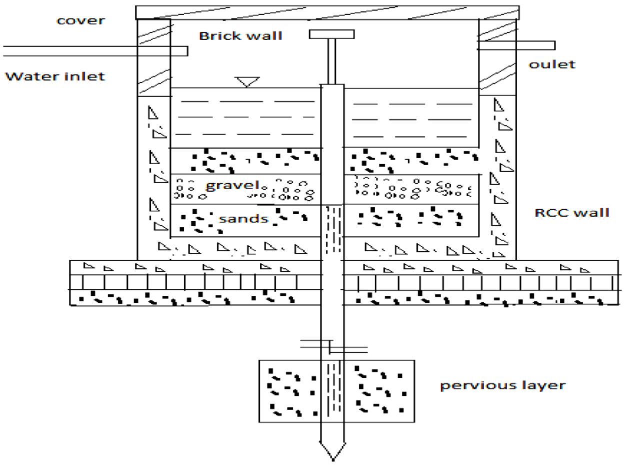

Fig. 3: Recharge chamber design

9. Cost: Benefit

(a) Cost of the project = ₹ 9,18,753

(b) Effective volume of water duly filled = 458 m^3 = 458000 lit

(c) Benefit = Benefit is equivalent to amount of drinking water requirement of 50 nos.

Family of 5 members in a family assuming 5.0 liter water requirement per member

(d) Assuming the cost of portable water ₹ 1.5/ lit, the benefit = 458000 × 1.5 = ₹ 6,87,000/ year

Service life = 12 years

(e) Annual investment = 918573/12 = 76,547.75

Interest at 10% on investment = 7654.77

Total = ₹ 84202.52

Cost: Benefit = ₹ 84, 202.533: ₹ 6, 87,000 = 1:8.16

Results and Discussion

Determination of Reference Crop Evapotranspiration (ET_o)

By using the Blaney-Criddle formula the reference crop evapotranspiration for different months were calculated from the known values of mean daily percentage of annual daytime hours (p) (Table 2) and mean daily temperature (T_{mean}) (Table 1) and tabulated in Table 5.

Table 5: Value of ET_O for different months for Nadia District (mm/day)

Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
3.90	4.89	5.64	6.52	6.81	6.83	6.61	6.39	5.91	5.43	4.82	4.23

Total Crop Water Requirement

Table 6, Table 7 and Table 8 have represented the total water requirement of autumn (*aush*) rice, winter (*aman*) rice and summer (*boro*) rice respectively with the help of crop factor.

Table 6: ET_{crop} for autumn *(aush)* rice (mm/day):

Month	June	July	Aug	Sept
$ET_{crop} = K_c \times ET_o$	7.513	7.271	8.307	5.91

Total water requirement = 15 × 7.513 = 113mm = 0.11m

Table 7: ET_{crop} for winter (*aman)* rice (mm/day):

Month	July	Aug	Sept	Oct	Nov	Dec
$ET_{crop} = K_c \times ET_o$	7.271	7.029	7.683	7.059	6.266	4.23

Total water requirement = 30x (7.059 + 6.266 + 4.23) = 526.65 mm = 0.53 m

Table 8: ET_{crop} for summer (*boro)* rice (mm/day):

Month	Nov	Dec	Jan	Feb
$ET_{crop} = K_c \times ET_o$	5.302	4.653	5.07	4.89

Total water requirement = 30x (5.302 + 4.653 + 5.07+4.89) = 597.45mm = 0.59m ~ 0.60m

Estimation of Recharge due to Rainfall

The estimated recharge due to rainfall was taken the average of different methods and it has tabulated in Table 10. The average annual recharge was estimated as (21.45+21.62 + 23.5)/3 = 22.2 cm =0.22 m.

Table 9 has represented the total block wise crop water requirement of *aush (*autumn rice), *aman* (winter rice) and *boro* (summer rice).

Requirement of Extra Recharge, Roof Top Area and the Cost for Net Recharge Requirement

Table 11 has represented the requirement of extra recharge due to deficit in rainfall recharge, Net requirement of extra recharge, requirement of roof top area and cost of the roof top structure. It appeared that there were deficit and over exploitation in Tehatta-I, Kaliganj, Nakashipara, Chapra, Krishnagunj, Krishnagar-I, Santipur, Hanskhali, Ranaghat-II, Chakdah and Haringhata blocks of the district in consideration to water requirement and recharge scopes. During the estimation of deficit in recharge the return flow due to irrigation have been omitted. In the net requirement of recharge there were three more block namely Tehatta-I, Krishnanagar-I and Ranaghat-II where were no deficit of recharge due to return flow

Table 9: Total Block Wise Crop Water Requirement

Name of the blocks	Autumn (*Aush*)		Winter (*Aman*)		Summer (*Boro*)		Total crop water requirement $\times 10^4$ m^3
	Area (ha)	Crop water requirement $\times 10^4$ m^3	Area (ha)	Crop water requirement $\times 10^4$ m^3	Area (ha)	Crop water requirement $\times 10^4$ m^3	
Karimpur-I	441	48	2440	1293	890	534	1875
Karimpur-II	913	100	3651	1935	2778	1666	3701
Tehatta-I	2019	222	2769	1760	2260	1356	3338
Tehatta-II	1427	157	2619	1388	2904	1742	3287
Kaliganj	2326	255	11270	5973	11193	6715	12943
Nakashipara	8422	926	9466	5016	8565	5139	11081
Chapra	5552	610	9045	4794	9814	5888	11292
Krishnaganj	1188	130	2080	1102	2530	1518	2750
Krishnanagar-I	3522	387	3964	2100	13214	7928	10415
Krishnanagar II	2725	299	1648	873	3433	2060	3232
Nabadwip	1222	134	18	09	2217	1330	1473
Santipur	1569	172	4338	2300	4787	2872	5344
Hanskhali	2086	229	8235	4364	8169	4901	9494
Ranaghat-I	2244	246	3666	1943	4182	2510	4699
Ranaghat-II	5728	630	7966	4222	6639	3983	8835
Chakdaha	1342	147	11361	6021	15035	9021	15189
Haringhata	3144	345	6089	3227	5640	3384	6956

Table 10: Estimation of recharge due to rainfall

Formula	Annual rainfall		Annual recharge	
	cm	inch	inch	cm
Bhattacharjee *et al.* (1954): $P = 3.47 (R-38)^{2/5}$ Where, P = Rainfall penetration in cm R = Annual rainfall in cm	133.02	—	—	21.45
Chaturvedi (1973): $R_p = 2.0 (R-15)^{2/5}$ Where, R_p= Recharge in inch R = Rainfall in inch	133.02	52.37	8.512	21.62
Datta *et al.* ((1973) $P= 0.4\ R.e^{-0.046C}$ Where, P, R and C denote the rainfall penetration in cm, annual rainfall in cm and average clay percentage in the top soil respectively C = 17.78% for Nadia	133.02	—	—	23.5

Table 11: Requirement of extra recharge due to deficit in rainfall recharge, Net requirement of extra recharge, requirement of roof top area and cost of the roof top structure

Name of the block	Block wise recharge due to rainfall $x10^4\ m^3$	Total crop water requirement $x10^4\ m^3$	Requirement of recharge due to deficit in rainfall recharge $x10^4\ m^3$	35% of total irrigation as return seepage $x10^4\ m^3$	Net requirement of extra recharges $x10^4\ m^3$	Require ment of roof top area $x10^4 m^2$	Cost of the roof top structure in rupees (Million) $x10^4$
Karimpur-I	6194	1875	No need	—	—	—	—
Karimpur-II	3747	3701	No need	—	—	—	—
Tehatta-I	2880	3338	458	1008	No need	—	—
Tehatta-II	5940	3287	No need	—	—	—	—
Kaliganj	3440	12943	9503	1204	8299	9676	16.6
Nakashipara	5970	11081	5111	2090	3021	3522	6.06
Chapra	2736	11292	8556	958	7598	8860	15.2
Krishnaganj	2034	2750	716	712	4	5	8.602×10^{-4}
Krishnanagar-I	7798	10415	2617	2730	No need	—	—
Krishnanagar-II	7060	3232	No need	—	—	—	—
Nabadwip	5490	1473	No need	—	—	—	—
Santipur	3794	5344	1550	1328	222	259	0.445
Hanskhali	4711	9494	4783	1649	3134	3654	6.2
Ranaghat-I	4936	4699	No need	—	—	—	—
Ranaghat-II	6731	8835	210	2356	No need	—	—
Chakdaha	3335	15189	11854	1167	10687	12461	21.4
Haringhata	5418	6956	1538	1167	371	432	0.743

of irrigation water. It has been found that a roof top area of 534 m^2 area is required for recharging 458 m^3 water. Therefore, for recharging $3.33 \times 10^8\ m^3$ water , the roof top area is required $3.88 \times 10^8\ m^2$. The initial cost of 534 m^2 roof top water harvesting structure is 9, 18,753 rupees (Anonymous, 2011).

Conclusion

The present study was undertaken to examine the over exploitation of ground water if any and to find out the required area of roof top rain water harvesting structure vis-à-vis the recharge facility to mitigate the over exploitation of ground water block wise in the district of Nadia. The over exploitation of ground water was estimated by comparing the water requirement of rice cultivated in the area in non-monsoon period and the ground water recharge due to rainfall and return flow of irrigation. The total irrigation water requirement in a year for rice in the district was approximately $1.16 \times 10^9 m^3$ and during this time the ground water recharge was $0.82 \times 10^9 m^3$. There was the overexploitation of $0.34 \times 10^9 m^3$ ground water. This amount of overexploitation could be mitigated by the creation of $3.88 \times 10^8 m^2$ roof top areas for rain water harvesting and thereby ground water recharge. The expenditure of this facility requires ₹ 666.488 billion. The expenditure was apparently large.

However, the creation of this facility in phase wise not only serves the purpose of irrigation water for rice cultivation but this also may be very much useful for improving the ground water quality and supplying water for domestic purposes which most of the blocks of this district needed badly due to alarming condition of arsenic contamination of ground water. In roof top water harvesting the buildings and erections for schools, colleges and offices may be used. In another way the requirement of irrigation water may be reduced by adopting appropriate methods of water applications. In the present study in estimating the overexploitation of ground water, the component of sub surface flow toward the streams which could add to the overexploitation of ground water and the irrigation through river lift which could reduce the overexploitation of ground water had not been considered. Similarly the water losses due to conveyance and improper application of water also had not been considered. A thorough study accounting all there components may be helpful to reach at the result very close to actual.

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