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Examining the Scope of Rooftop Rainwater Harvesting for the Production of Vegetables in the District of Nadia, India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

In order to determine the extent of groundwater overexploitation and investigate potential mitigation strategies such as artificial groundwater recharge, an investigation was carried out for each block in the district of Nadia, West Bengal. The current farming methods have irrigation water needs of 0.48 BCM, with the except the monsoon month. It was discovered that the ground water recharge was 0.48 BCM. Therefore, if ground water is completely sufficient to meet irrigation needs, 0.00042 BCM of ground water is discovered to be overexploited annually. The overexploitation of $2.73x10^{-4}$ m^3 might be reduced if a 31830.13 m^2 rooftop water collection structure and recharging facilities were

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built. The cost of this facility to build found Rs. 54.76 crore. The construction of this plant may potentially have a significant impact on the district's arsenic-contaminated ground water supply and the residential water supply.

Keywords: Water requirement; rainfall; recharge; rainfall penetration; roof top water harvesting; recharging ground water; ground water estimation; ground water resources.

1. INTRODUCTION

"Water is the most important element for the growth of plants. Different types of plants require different quantities of water at different times during their growing period. Water is supplied to the plants through direct rain or flood waters of the rivers which inundate large land areas during floods. In the last two decades, for instance, the groundwater irrigated areas in India increased by 105%, whereas the surface-water irrigated areas rose by only 28%" [1]. "But the indiscriminate use of this vital natural resource has resulted fast falling of groundwater table in many parts of India. Ground water plays a key role in meeting the water needs of various user-sectors in India. As per the report, the annual replenish able Ground Water Resource for the entire country is 433 billion cubic metre (BCM), Net Annual Ground Water Availability is estimated as 399 billion cubic metre whereas the Annual ground water draft for irrigation, Domestic & Industrial was 231 billion cubic metre and their Stage of Ground Water Development for the Country as a whole is 58%" [2]. "The country is blessed with 1190 mm average annual rainfall with 1953 billion m^3 (BCM) available water and 1123 BCM usable water. Out of the total usable water, 728 BCM is contributed from surface water and 395 BCM by replenish able groundwater. Out of the total water used in India, share for agriculture is 85 per cent that will shrink to 71.6 per cent in 2025 and to 64.6 per cent in 2050 (Min. Agriculture, GOI).According to USDA, out of total rice area in India, 47 percent is irrigated that uses up to 45 per cent of country's water withdrawals for irrigation as rice is a water loving crop. This reducing availability of water compounded by climate change would further deteriorate the condition; the agricultural research body said.Ground water is being used as the major source of irrigation water in most of the district of West Bengal. There are nos. of registered deep tube wells and many nos. 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, wheat, jute, mustard, potato etc. 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. Haringhata Block located in southern part of Nadia district, West Bengal is suffering from water shortage problems both qualitatively and quantitatively. As the main occupation of the local people is agriculture, the water scarcity problem greatly hampers the socio-economic condition in the area. The block is mainly irrigated through extraction of ground water. There are 3477 shallow tube wells, 42 Deep Tube wells run by the Department of Agri-irrigation, Govt. of West Bengal. High demand of water for rice, wheat, jute, mustard, potato etc. 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). It was reported that the groundwater drops 5 to 8 m from the ground surface at most sites during the dry season, whereas, mean post-monsoon (November) groundwater depth varies from 2 to 4 m" [3]. "It was observed that they had found 51.4% and 17.3% of the tube-wells had arsenic above 10 and 50 µg/L, respectively and observed that groundwater of all 17 blocks contained arsenic above 50 µg/L with maximum observed level of 3200 µg/L. Arsenic have entered in food chain which is very alarming situation" [4]. The situation is sometime so alarming that the state Water Resources Investigation & Development 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 estimate the crop water requirement of different vegetables crops, the safe exploitation of ground water and examine the extent of roof top water harvesting.

2. MATERIALS AND METHODS

2.1 Location and Geographical Area

The district is bounded on the North and North-west by the district of Murshidabad. On the North-east it is bounded by the Republic of Bangladesh, in the south and south east, by the district of North 24 Parganas.

2.2 Estimation of Total Crop Water Requirement for Each Crop

Evapotranspiration of crop determined by using the following formula:

$$ET_{crop} = ET_o \times K_c \qquad \text{Eq.1}$$

Where

ET_{crop} = crop evapotranspiration or crop water need (mm/day)
K_c = crop factor
ET_o = reference evapotranspiration (mm/day)

2.2.1 Determination of reference crop evapotranspiration(ETo)

If no measured data on pan evaporation are available locally, a theoretical method (e.g. the Blaney-Criddle method) is usually used to calculate the reference crop evapotranspiration ET_o. There are a large number of theoretical methods to determine the ET_o. Many of them have been determined and tested locally. If such local formulae are available they should be used. If such local formulae are not available one of the general theoretical methods has to be used. In the present study the most commonly used theoretical method, the Blaney-Cridle method has been used to determine the reference cop evpotranspiration [5]

The Blaney-Criddle formula:

$$ET_o = p\,(0.46\ T\ mean + 8) \qquad \text{Eq.2}$$

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

2.2.2 Determination of the mean daily temperature:

T_{max}=sum of all T_{max} values during the month/number of days of the month
T_{min}=sum of all T_{min} values during the month/number of days of the month
$T_{mean} = (T_{max} + T_{min})/2$ (Table 2)

2.2.3 Determination of the mean daily percentage of annual daytime hours

The mean daily percentage of annual daytime hours were calculated by using the approximate latitude of the area and the number of degrees north or south (Table 3).

2.2.4 Determination of crop factor

By using the crop and its different stages i.e. initial stage, crop development stage, mid season stage late season stage and the days of duration of different stage of that crop the crop factors of different crops were calculated.

2.3 Total Crop Water Requirement for Growing Period of Each Crop

Total crop water requirement for growing period of each crop=Total growing period (days) of that crop x ET crop of that crop (mm/day)

During June to mid of September, most of the crop field in the district remains wet. Therefore irrigation water is 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.

2.4 Total Block wise Crop Water Requirement for Each Crop

Total crop water requirement was calculated as below:

Total crop water requirement for growing period x area of cultivation of that crop at that block.

Table 1. Monthly and annual rainfall (mm) during 2013-2023 in the district of Nadia

Month	January	Feb	March	April	May	June	July	August	Sept	October	Nov	Dec	Total annual rainfall
2013	0	19	113	3	326	184	323	201	102	238	0	1	1510
2014	6	0	0	38	91	193	112	217	541	70	0	9	1277
2015	16	2	88	3	62	168	214	110	122	402	0	7	1194
2016	0	0	0	6	152	76	229	184	159	31	1	0	838
2017	0	81	36	20	54	227	424	284	419	87	67	0	1699
2018	76.2	39.4	29	43	203.4	231.4	389.6	65.8	389	127	0	0	1593.8
2019	15	6	10	0	152	152	199	454	321	54	23	0	1386
2020	0	109	0	30	95	141	72	85	212	114	2	2	862
2021	0	76.4	26.19	22.23	83.61	607.2	189	244.8	81.96	0	0	0	1331.39
2022	48.6	12.8	0	68.4	112	181.1	258.9	163.5	254	76.4	31.4	7	1214.1
2023	1.2	6.6	0	118.4	194.1	182.6	251.3	428.4	231.2	313.3	0	0	1727.1

Source: Meteorological Dept., Govt. Of India
Average annual rainfall = 1330.22 mm (From 2013-2023)

Table 2. 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 (2018) [7]

Table 3. Mean daily percentage of annual daytime hours for different latitudes

Latitudes	North	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sept	Oct	Nov	Dec
	South	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June
60		.15	.20	.26	.32	.38	.41	.40	.34	.28	.22	.17	.13
55		.17	.21	.26	.32	.36	.39	.38	.33	.28	.23	.18	.16
50		.19	.23	.27	.31	.34	.36	.35	.32	.28	.24	.20	.18
45		.20	.23	.27	.30	.34	.35	.34	.32	.28	.24	.21	.20
40		.22	.24	.27	.30	.32	.34	.33	.31	.28	.25	.22	.21
35		.23	.25	.27	.9	.31	.32	.32	.30	.28	.25	.23	.22
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
15		.26	.26	.27	.28	.29	.29	.29	.28	.28	.27	.26	.25
10		.26	.27	.27	.28	.28	.29	.29	.28	.28	.27	.26	.25
5		.26	.27	.27	.28	.28	.29	.28	.28	.27	.27	.26	.26

Source: FAO, 1986[8]

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

2.5 Total Block Wise Crop Water Requirement for all Crops

Total crop water requirement for all the crops in a block was calculated by summation of water requirement for each crop which are cultivated at that block.

2.6 Recharge from Rainfall

The recharges due to rainfalls were calculated by taking the average of the estimated recharges following the different formulas [5]

2.7 Requirement of Extra Recharge

"Requirement of extra recharge due to deficit in rainfall recharge was calculated as below :

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 x geographical area of that block).Following the suggestion of Ground Water Resource Estimation Committee (GEC),out of irrigation amount 35% as return seepage of the water delivered was taken into consideration for calculating the net requirement of extra recharge"[6]. Therefore, Net Requirement of extra recharge= Requirement of recharge due to deficit in rainfall recharge -35% of recharge due to irrigation.

2.8 Relation between Rooftop are and Recharge to Ground Water

"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" [9].

3. RESULTS AND DISCUSSION

3.1 Determination of Reference Crop Evapotranspiration (ET_o)

By using the Blaney-Criddle formula (Eq.1) the reference crop evapotranspiration for different months were calculated from the known values of mean daily percentage of annual daytime hours (p) and mean daily temperature (T_{mean}) and tabulated in Table 4.

3.2 Total Crop Water Requirement

The crop factor and length of growth phases for a variety of field crops have been used to calculate and tabulate the crop co-efficient of different crops in different months.The calculation of crop co-efficient are also shown in the respective table. Total crop water requirement for growing period of each crop was calculated by the multiplication of total growing period (days of the crop) and ET_{crop} of those crop (mm/day) .The values of crop water requirements for major crops of the district are shown in Table 5.

3.3 Estimation of Recharge due to Rainfall

Total average rainfall of the Nadia District per year =1330.22mm=133.02 cm (Table1)

The estimated recharge due to rainfall taking the average of different methods are tabulated in Table 6.

3.4 Requirement of Extra Recharge

It appears that there are deficit and over exploitation in the district except in consideration to water requirement and recharge scopes. The crop water requirement, recharge and deficit are shown in Table 7.It was estimated that the total volume of recharge in the district as (3927km^{2}x 0.22m) =0.864BCM (billion cubic meter).Out of which almost 55% of ground water used for irrigation purpose in this district [2].

The return flow from irrigation has been left out of the assessment of the recharge deficit. Due to return flow the deficit decreased and the net requirement of extra recharge are tabulated in Table 8.

3.5 Roof Top Area and the Cost for Net Recharge Requirement

It has been found that a roof top area of 534 m^2 area is required for recharging 458m^{3}water (Anonymous) [2]. Therefore, for recharging 2.73x10^{-4} BCM water, the roof top area is required 31830.13 m^2.The initial cost of 534 m^2 roof top water harvesting structure is Rs.91875/-. The cost of the roof top structure required to recharge the desired volume of water given in Table 8.

Table 4. 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

Table 5. Total water requirement

Major Vegetables	Months	K_c	ET_o	Days	ET_{crop} (mm/day)	Total Crop Water requirement (mm)	Cropped Area (ha)	Volume (Cubic metre)
Tomato	November	1.05	4.82	30	5.06	416.54	4725	19681515
	December	1.05	4.23	31	4.44			
	January	1.05	3.9	31	4.1			
brinjal	January	1.05	3.9	31	4.1	1096.5	12390	135856350
	February	1.05	4.89	28	5.13			
	March	1.05	5.64	31	5.92			
	April	1.05	6.52	30	6.85			
	May	1.05	6.81	31	7.15			
	June	1.05	6.83	30	7.17			
CABBAGE	July	1.05	6.61	31	6.94	786.15	8133	63937579.5
	August	1.05	6.39	31	6.71			
	September	1.05	5.91	30	6.21			
	October	1.05	5.43	31	5.7			
Cauliflower	June	1.05	6.83	30	7.17	1001.2065	7533	75420886
	July	1.05	6.61	31	6.94			
	August	1.05	6.39	31	6.71			
	September	1.05	5.91	30	6.21			
	October	1.05	5.43	31	5.70			
Peas	October	1.05	5.43	31	5.70	466.14	2700	12585780
	November	1.05	4.82	30	5.06			
	December	1.05	4.23	31	4.44			
Lady's Finger(Okra)	January	1.05	3.9	31	4.1	465.26	9312	43325011.2
	February	1.05	4.89	28	5.13			
	March	1.05	5.64	31	5.92			
Beans	June	1.05	6.83	30	7.17	430.24	2661	11448686.4
	July	1.05	6.61	31	6.94			

Major Vegetables	Months	K_c	ET_o	Days	ET_{crop} (mm/day)	Total Crop Water requirement (mm)	Cropped Area (ha)	Volume (Cubic metre)
Cucurbit	March	1.05	5.64	31	5.92	610.67	11896	72645303.2
	April	1.05	6.52	30	6.85			
	May	1.05	6.81	31	7.15			
Raddish	April	1.05	6.52	30	6.85	427.15	5528	23612852
	May	1.05	6.81	31	7.15			
Potato	November	1.05	4.82	30	5.06	743.7	2300	17105100
	December	1.05	4.23	31	4.44			
	January	1.05	3.9	31	4.1			
	February	1.05	4.89	28	5.13			
	March	1.05	5.64	31	5.92			
Total water requirement								475619063

Table 6. Estimation of recharge due to rainfall

Formula	Annual rainfall		Annual recharge	
	cm	inch	inch	cm
Bhattacharjee (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

Average annual recharge=22.2 cm=0.22

Table 7. Requirement of Extra Recharge

Total crop water requirement (BCM)	Total amount of ground water(BCM)	Requirement of extra recharge(BCM)
0.47562	0.47520	0.00042

Table 8. Net requirement of extra recharge, requirement of roof top area and cost of the roof top structure

Total crop water requirement (BCM)	Requirement of recharge due to deficit in rainfall (BCM)	35% of recharge due to irrigation (BCM)	Net requirement of extra recharges (BCM)	Requirement of roof top area (sq.m)	Cost of the roof top structure (Rs.in crore)
0.47562	0.00042	1.47×10^{-4}	2.73×10^{-4}	31830.13	54.76

4. CONCLUSIONS

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 different major crops 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 the major crops in the district was 0.47562 BCM and during this time the ground water recharge was 0.864BCM.Out of which only 55% of water available for irrigation purpose. There was the overexploitation of ground water. This amount of overexploitation could be mitigated by the creation of 31830.13 m^2 roof top areas for rain water harvesting and thereby ground water recharge. The expenditure of this facility requires Rs. 54.76 crores. The expenditure is apparently large .However, creation of this facility in phase wise not only serves the purpose of irrigation water 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 application and selection of crops as far as practicable which require less water.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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