Vol. 48, No. 1, pp 47-56, 2020
Indian Journal of Soil Conservation

Efficacy of water harvesting structures in sugarcane based farming system in India

U.K. Maurya[1], Ambrish Kumar[1,*], Satyendr Kumar[2], R.C. Srivastava[3], A.K. Gupta[1] and R.K. Arya[1]

[1]ICAR-Indian Institute of Soil and Water Conservation, 218, Kaulagarh Road, Dehradun-248 195, Uttarakhand; [2]ICAR-Central Soil Salinity Research Institute, Zarifa Farm, Kachhwa Road, Karnal - 132001 Haryana; [3]Dr Rajendra Prasad Central Agricultural University, PUSA, Samastipur, Bihar.

*Corresponding author:
E-mail: aktswc@gmail.com (Ambrish Kumar)

ARTICLE INFO

Article history:
Received : September, 2019
Revised : April, 2020
Accepted : April, 2020

Key words:
Impact assessment
Water harvesting structure
Farming system

ABSTRACT

Study were conducted by constructing two water harvesting structures (WHS) (WHS-I and WHS-II) in the Harsauli drain of Rasulpur block of Muzaffarnagar district to see the impact on recharge of groundwater. Study indicated that intervention of WHS in Harsauli drain resulted extension of back water upto 1200 m and 1500 m behind WHS-I and WHS-II, respectively. Impact of WHS-II on groundwater table was monitored by placing four piezometers (P1, P2, P3, P4) across the drain at intervals of 0 m, 50 m, 100 m, and 200 m with depth of 30 m, 33 m, and 27 m, respectively. Variation in piezometric level was observed during the impounding in all the piezometers, and its effect was more in the piezometer installed near to the drain in comparison to P2, P3, P4 and fluctuated at piezometer location at 50 m, 100 m and 200 m. Drill core observation showed that fine sand fraction were the main stratum of aquifer. Study indicated that sugarcane field has higher infiltration rate than drain due to textural variation in soils. Gradual decrease in the infiltration rate with time due to saturation of soil particles indicated uniform sedimentation and deposition of sediment in the indo gangetic plain (IGP) region and subsequently development of soil over it, an indicator of similar climate during their formation. Presence of moderately alkaline water indicated that the source material of soils were derived dominantly from Himalayan limestone, shale and slate and deposited there by weathering, erosion and transportation by Himalayan rivers, and it (moderately alkaline water) also have potential beneficial effects on nutrition (extra source of Ca and Mg) for sugarcane crops grown in the area. Study indicated that to make the sugarcane cultivated area of water positive zone, water harvesting structure can be highly effective.

1. INTRODUCTION

Agriculture sector is the largest consumer of water in India. About 83% of available water is used for agriculture alone (CWC, 2002). Due to various constraints of topography and uneven distribution of water resources over space and time, only a part of total potential of surface water can be put to beneficial use. On the other hand, ground water is another major component of the total available water resources. Presently, share of groundwater in providing irrigation is 61% (Pathak *et al.,* 2014), which is likely to increase further for expansion of irrigated agriculture and to achieve national targets of food production. Climate change will affect the groundwater availability in terms of both quantity and quality. It is obvious that the projected climate change resulting in warming, melting of glaciers will adversely affect the water balance in different parts of India (CWC, 2002). The decline of snow melt runoff may seriously affect the recharge of groundwater causing shortage in water availability in Punjab, Haryana, Uttar Pradesh and Rajasthan (CWC, 2002). Further, changes in precipitation and evapo-transpiration (ET) due to climate change are likely to affect groundwater. Increased rainfall intensity may lead to higher runoff and possibly reduced recharge (Ministry of Environment, Forest and Climate Change, 2004). Changes in cropping and land-use pattern, over-exploitation of water storage, and changes in irrigation and drainage in the Gangetic basin show a reduction in discharge by 60% over 25 years. This has led to about 50% drop in water availability in surface water resources and groundwater table (Adel, 2002). Agricultural demand, particularly for irrigation water, which is a major share of total water demand of the country, is considered more sensitive to climate change. It is projected that most irrigated areas in India would require more water around the year 2025, and global net irrigation requirements would increase by 3.5–5.0% by 2025 and 6.0–8.0% by 2075 due to climate change (Döll and Stepan, 2002).The IPCC models for irrigated areas indicate that the gap between potential ET and effective rainfall will be about 17% by 2050 under a high-emission scenario, putting extra stress on the demand for irrigation water. Key constraints to the uptake of climate change information for effective rural livelihoods decision-making support might be either or in combination of many factors such as lack off integration of indigenous knowledge systems, low accuracy, spatial and temporal resolution of the products, lack of access to the information, saleable skill, etc. Both the global environment fund (GEF) framework and Kyoto Protocol advocated and encouraged the states to promote and facilitate adaptation, and set out adaptation technologies to address climate change (Smith *et al.,* 2001; UNFCCC, 1998).

Most of the present information available on water and energy savings and yield response of the crops under irrigation systems are based on the observations in small treatment plots either in research farms or in farmers' field. However, the irrigation performance in large fields differs from that in small fields. Further, studies on irrigation efficiency in groundwater irrigated commands through improved irrigation techniques are very limited. There is a need to study the irrigation efficiency and crop responses to irrigation systems in large scale through pilot studies, especially in over-exploited groundwater irrigated areas. Studies on rainwater harvesting, groundwater recharging and optimal groundwater use through efficient irrigation methods for cropping systems in an intensively groundwater irrigated region with impermeable sub-soil layer under sub-humid hot climate is limited. Thus, it is essential to evaluate the feasibility of ground water recharge and its use through efficient irrigation methods in crops in a water scarce region with sub-surface impermeable layer. Information on efficacy and effectiveness of different ground water recharge approaches in a particular geo-hydrological condition is scanty. Thus, it is utmost essential to standardize the recharging techniques for a region. This information may also be used for the areas having similar geo-hydrological conditions of the study site.

Study indicated that there were steep decline in groundwater level from 0.3 m yr^{-1} to 1 m yr^{-1} in different blocks of Muzaffarnagar district due to inefficient on-farm water management, over exploitation by excessive running of tube wells irrespective of irrigation requirement, flooding through unlined channels and higher irrigation depth (10 cm or more each time) leading to huge loss of water, nutrient and energy (Kumar *et al.,* 1998 and 2011). It was observed that Baghra, Budhana and Shahpur blocks were over-exploited for irrigation (>100%), whereas, Muzaffarnagar, Charthwal and Jansath were in semi-critical range (70-90% exploitation) having more than 80% exploitation; only Purkazi, Khatauli and Morna blocks were in safe zone. To overcome the problem, experiments were conducted by constructing two water harvesting structures (WHSs) in a series in Harsauli drain of Rasulpur block of Muzaffarnagar district to enhance water productivity by recharging the drain and to observe its effect on surrounding water table *vis-a-vis* sugar cane productivity. Present study demonstrated an evaluation of technological interventions on a pilot basis for sustainable use of groundwater for enhancing adaptive capacity to climate change in sugarcane based farming system in Muzaffarnagar district of Uttar Pradesh.

2. MATERIALS AND METHODS

Experimental sites were located at 29°21'22" latitude, 77°33'22" longitude with elevation of 241 m above mean sea level near Shahpur Police Station in vicinity of the selected Village Rasulpur Jaton, district Muzaffarnagar (Fig.1a). Data on tubewell and related command areas indicated 141 operational tube wells in the village equipped with submersible pump and electric motor with an average irrigation command area of 2.36 ha and spread over 333.97 ha agricultural land of the village. The depth of tubewell varies from 24 m to 96 m and power of pumps equipped with the tube wells varies from 7.5 hp to 15 hp. For irrigation, water from tube wells to the farms is conveyed through open water courses which are on an average 0.6 m wide and 0.3 m deep.It was observed that Baghra Minor served as source to impound water in the drain for recharging groundwater as its trail is connected to Harsauli drain (Fig. 1b) whenever there is surplus water in the canal.

WHS-I and WHS-II were designed based on hydrological, hydraulic and structural parameters with dimensions of 8.86 m (span) and 2.16 m (height), and 10 m (span) and 1.50 m (height), respectively, and were constructed in the drain at an interval of 7.36 km, having water storage capacity of 35021.88 cum and 11812.5 cum, and surface area of impounding water 32427.6 m^2 and 15750.0 m^2, respectively, in order to replenish the depleted water table. Four piezometers along the line perpendicular to the drain and intersecting near the WHS-II were installed at 0 m, 50 m, 100 m, and 200 m by drilling up to depth of 27-33 m for monitoring the impact of WHS on ground water table. Schematic view of location of piezometers along the Harsauli drain is given in Fig. 2a and b. For drilling operation, PVC pipe (0.1016 m) was placed in observation well, and thereafter, 6.096 m perforated pipe wrapped with fine filter net was inserted at normal pipe. Infiltration studies were conducted in the drain and cultivated land using double ring infiltrometers. Soil and water samples were collected from different sites during March 2016-2017 and analyzed for their alkalinity (HCO_3^-)

Fig. 1. (a) Experimental Harsauli drain before intervention, (b) Harsauli Drain at the Baghra Minor tail end located near WHS-II.

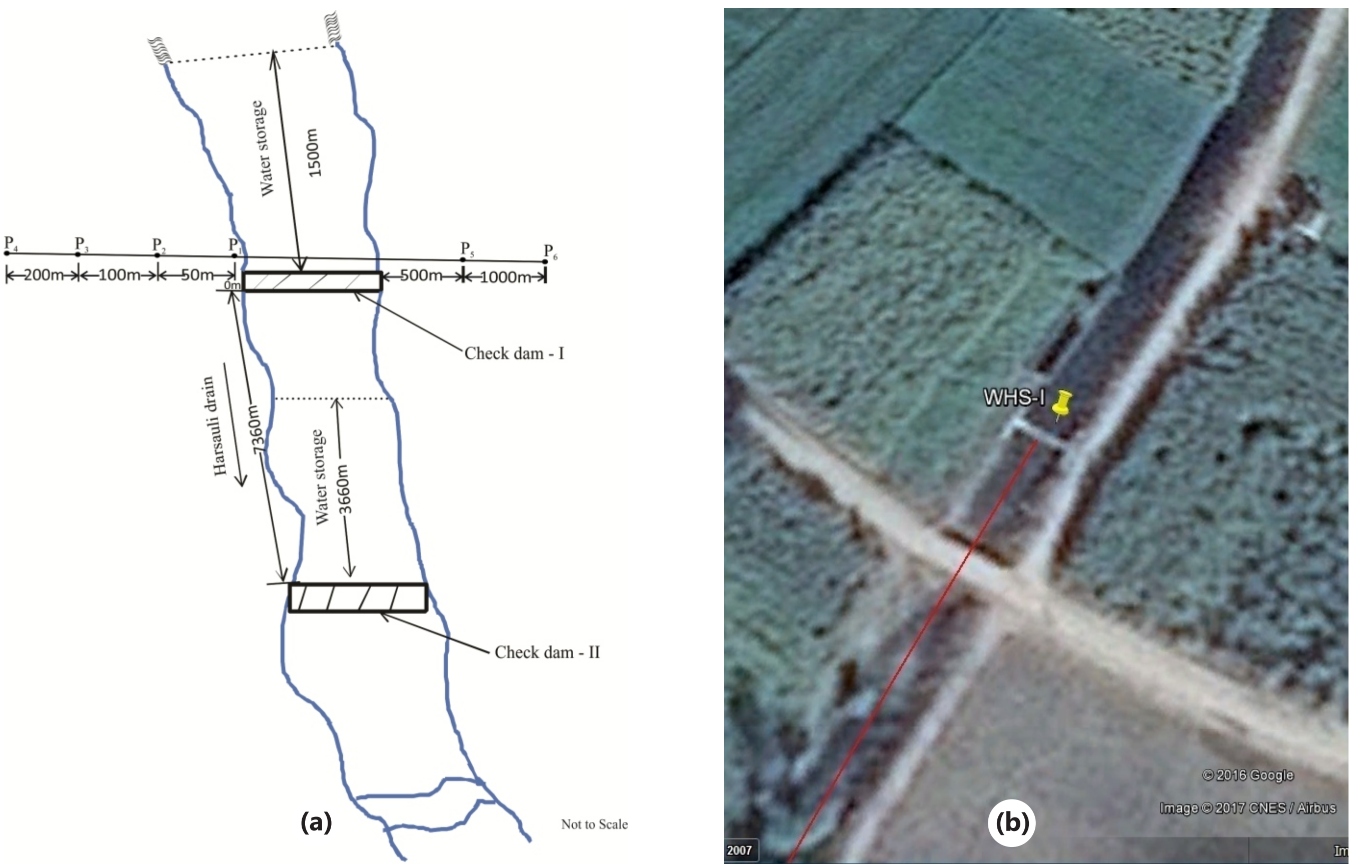

Fig. 2. (a) Schematic location of piezometer along Harsauli drain, (b) Harsauli drain

and major ions (Cl^-, F^-, SO_4^{2-}, NO^{3-},Na^+, K^+, Mg^{2+}, Ca^{2+}) following Singh *et al.,* 2005. pH, EC and temperature as well as particle size were measured following standard procedures. WHSs, piezometers, infiltrometers, soil and water sampling sites were recorded for their altitude, latitude and longitude by global positioning system (GPS).

3. RESULTS AND DISCUSSION

Experiments were conducted in lower and upper reach of Harsauli drain, Rasulpur block of Muzaffarnagar district, Uttar Pradesh near to Shahpur and Harsauli village by constructing two water harvesting structures (WHS-I and WHS-II) in a series (Fig. 3a and b). The distance between

Fig. 3. (a) Overview of check dam WHS-I, (b) WHS II with water impounding in Harsauli drain of Rasulpur block, Muzaffarnagar district

WHS-I and WHS-II were 7.36 km with an average bed slope of the drain 0.3% and width 7 m with dimensions of 8.86 m (span) and 2.16 m (height); and, 10 m (span) and 1.50 m (height), respectively (Fig. 4a and b). The potential water storage capacity of WHS-I and WHS-II were 35021.88 cum and 11812.5 cum, whereas, surface area of water spread were 32427.6 and 15750 m^2 with expectation that back water could extend upto 3660 m and 1500 m, respectively.

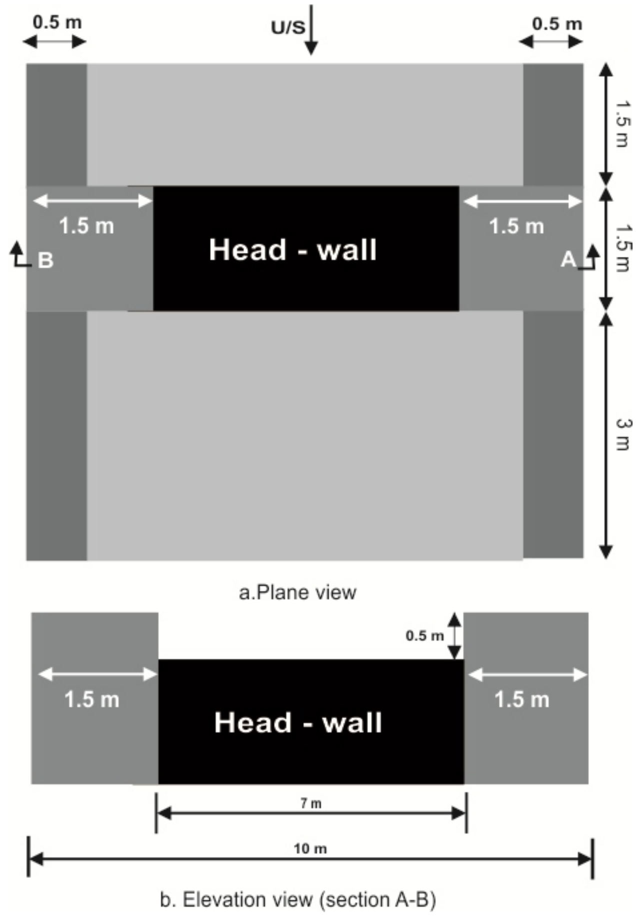

Fig. 4. Cross section of check dam design: (a) Plane view and (b) Elevational view of Head-wall

Study indicated that intervention of WHS in Harsauli drain resulted in extension of back water upto 1200 m and 1500 m behind the WHS-I and WHS-II, respectively. The three times reduced extension of back water behind WHS-I was due to the larger surface area and drainage line treatment in the experimental sites.

Four piezometers were installed in such a way that they could capture the influence of surface water body on the water table in proximity of the structure to the extent of possibility at specified locations along the line marked perpendicular to the drain and intersecting near the innovative water harvesting masonry structure (WHS-II). The location details with depth of different piezometers are given in Table 1. Drilling operations were conducted till thick horizon of fine sand fraction, an indicator of water bearing stratum, were reached (Fig. 5 a-d). Horizon characteristics along with depth where monitored closely with change in size of sand, silt and clay particles. Results indicated that in most of the wells, depth varies from of 27-33 m, and fine sand fraction were the main stratum of aquifer in all the studied sites (Fig. 5e). Piezometric levels were recorded from all the wells after satisfactory drilling operation (Fig. 5f) and the lithological details with their textural classification of

Table: 1
Locations of observation wells

Site name	Latitude	Longitude	Depth of observation well (m)	Length of perforated PVC pipe (m)
Harsauli (P1)	29°24'06.5"N	77°35'50.0"E	30	6.096
Harsauli (P2)	29°24'07.3"N	77°35'47.4"E	33	6.096
Harsauli (P3)	29°24'05.4"N	77°35'55.3"E	27	6.096
Harsauli (P4)	29°24'15.9"N	77°35'30.5"E	27	6.096

Fig. 5. Piezometer installation: (a & b) PVC pipe (2"dia) is placed in observation well, (c) 20 ft perforated pipe wrapped with fine filter net at normal pipe, (d) drilling operation, (e) observations of drill core material, (f) view of one of the installed observation well

piezometer (P1) installed near Harsauli drain is given in Fig. 6 and Table 2. Study indicated that variation in piezometric level were observed during the impounding in all the four piezometers, and its effect was more in the piezometer installed near to the drain at 0 m distance and fluctuated at 50 m, 100 m, and 200 m. Data indicated piezometric levels varied from 17.5 m to 18 m in all the four piezometers (Fig. 7). pH of water collected from different piezometers varied from moderately to strongly alkaline, whereas, electrical conductivity (EC) were non saline (0-2 ds m^{-1}) (Table 3). Presence of moderately alkaline water indicated that the source material of soils were derived dominantly from Himalayan limestone, shale and slate, and deposited there by weathering, erosion and transportation by Himalayan rivers (Chakrapani, 2002), and it (moderately alkaline water) also has potential beneficial effects on nutrition (extra source of Ca and Mg) for different crops grown in the area.

Infiltration study at every one km interval in a total of 5 km stretch of Harsauli drain, and also in the cultivated land were conducted at different locations (Table 4) to know the water retention and movement in different intervals of time in different land use systems (Fig. 8a, b and c). It was

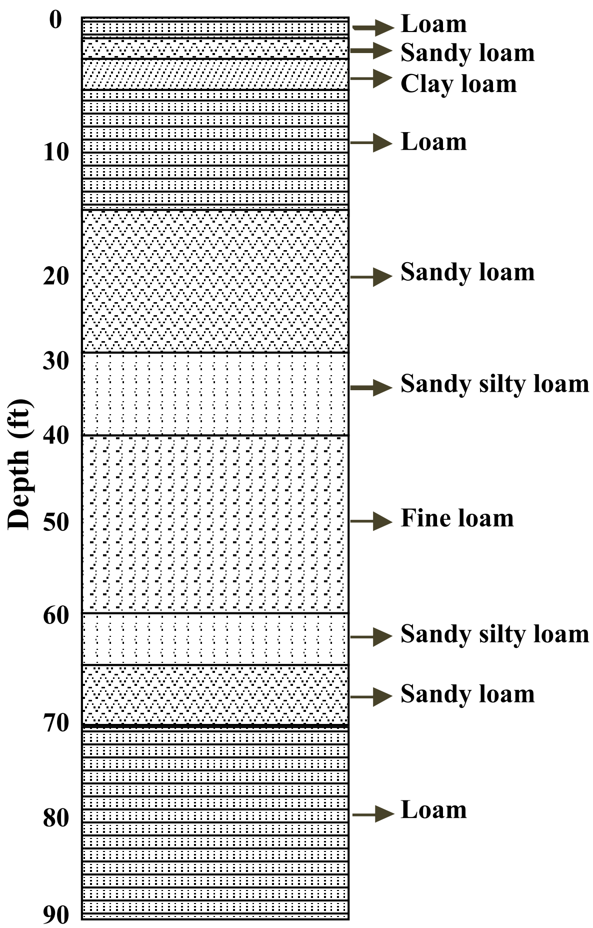

Fig. 6. Litholog with their textural classification of piezometer (P1) installed near Harsauli drain

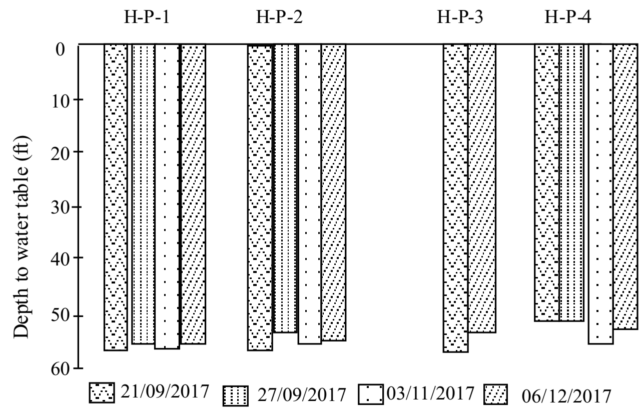

Fig. 7. Temporal changes in groundwater table depth at Harsauli village

Table: 2
Textural lithology of Piezometer (P1) near the Harsauli drain

S.No.	Depth in (ft)	Sand (%)	Silt (%)	Clay (%)
1	0-1.5	41.8	52.8	5.4
2	1.5-3.0	64.8	21.4	13.8
3	3.0-5.0	28.25	40.28	31.47
4	5-10	42.74	38.31	18.94
5	10-15	40.1	44.9	15.0
6	15-25	59.14	25.4	15.5
7	25-30	61.85	19.53	18.62
8	30-40	49.68	26.58	23.75
9	40-50	35.36	41.01	23.63
10	50-60	32.0	42.78	25.22
11	60-65	49.95	29.83	20.22
12	65-70	54.95	31.7	13.35
13	70-80	41.67	39.53	18.78
14	80-90	40.9	42.7	16.40

Table: 3
pH and EC of water samples of piezometers (PZM) 1 to 4

Piezometer site location	Date	EC (dS m^{-1})	pH
PZM-1	27/9/2017	0.60	7.60
	2/11/2017	0.57	8.62
	6/12/2017	0.61	7.58
PZM-2	27/9/2017	0.61	6.79
	2/11/2017	0.67	8.70
	6/12/2017	0.91	7.28
PZM-3	27/9/2017	0.44	8.20
	2/11/2017	0.52	7.04
	6/12/2017	0.51	7.93
PZM-4	27/9/2017	1.77	7.00
	2/11/2017	1.36	7.30
	6/12/2017	0.76	7.95

observed that in the drain, initial and final infiltration rate varied from 100 mm hr^{-1} to 200 mm hr^{-1} and from 3.5 mm hr^{-1} to 5.3 mm hr^{-1}, respectively, whereas, in cultivated land it varied from 6.9 mm hr^{-1} to 10 mm hr^{-1} (Fig. 9a-h).The soils of streambed in the selected stretch varied from silt to silty loam, showing heterogeneity in surface soils of stream bed with poor water retention capacity, whereas, soil textural class were loam to silty loam in the cultivated land which indicated high porosity with good aeration. Although sugarcane can be grown in all types of soils, from sandy loam to clay loam, it however, thrives best on well drained soils. Gradual decrease in the infiltration rate with time due to saturation of soil particles indicated uniform sedimentation and deposition of sediment in the IGP region (Kumar *et al.,* 1996) and subsequently development of soil over it, an indicator of similar climate during their formation (Singh *et al.,* 2006; Pal *et al.,* 2009). Present study on infiltrometer indicated that soils are well drained and very suited for higher production of sugarcane crop.

Water quality of irrigation water has an important bearing on sugarcane production (Subramanian, 2000 and Pawar *et al.,*1998). Water samples were collected from the tube wells located in different blocks of the district for their evaluation of suitability for irrigation (Ding *et al.,* 2020; Khatri *et al.,* 2020). Sampling location with their analytical results are shown in Table 5 and Fig. 10. It was observed that groundwater quality (pH, EC, Cl^-, Ca^{2+}, Mg^{2+}, Na^+, K^+,

Table: 4
Location sites of infiltrometer at Rasulpur block of Muzaffarnagar district

Site No.	Location	Geo-referenced point		
		Latitude	Longitude	Elevation (m) amsl
1	Shahpur School	29°21'43.2''N	77°33'14.4''E	185
2	Shahpur Thana, I[st] Point	29°21'10.8''N	77°33'28.8''E	181
3	Shahpur Thana, II[nd] point	29°21'14.4''N	77°33'28.8''E	183
4	Shahpur Harsauli Nala	29°23'38.4''N	77°35'16.8''E	189
5	Shahpur Harsauli Road	29°24'7.2''N	77°35'49.2''E	187
6	Rasulpur Village (Maize field)	29°22'19.2''N	77°34'37.2''E	187
7	Rasulpur Village (Sugarcane field)	29°22'19.2''N	77°34'37.2''E	186
8	RasulpurVillage (Fellow field, Control)	29°22'19.2''N	77°34'37.2''E	186

Fig. 8. Infiltration study at different locations, (a) in Harsauli drain, (b and c) in cultivated land

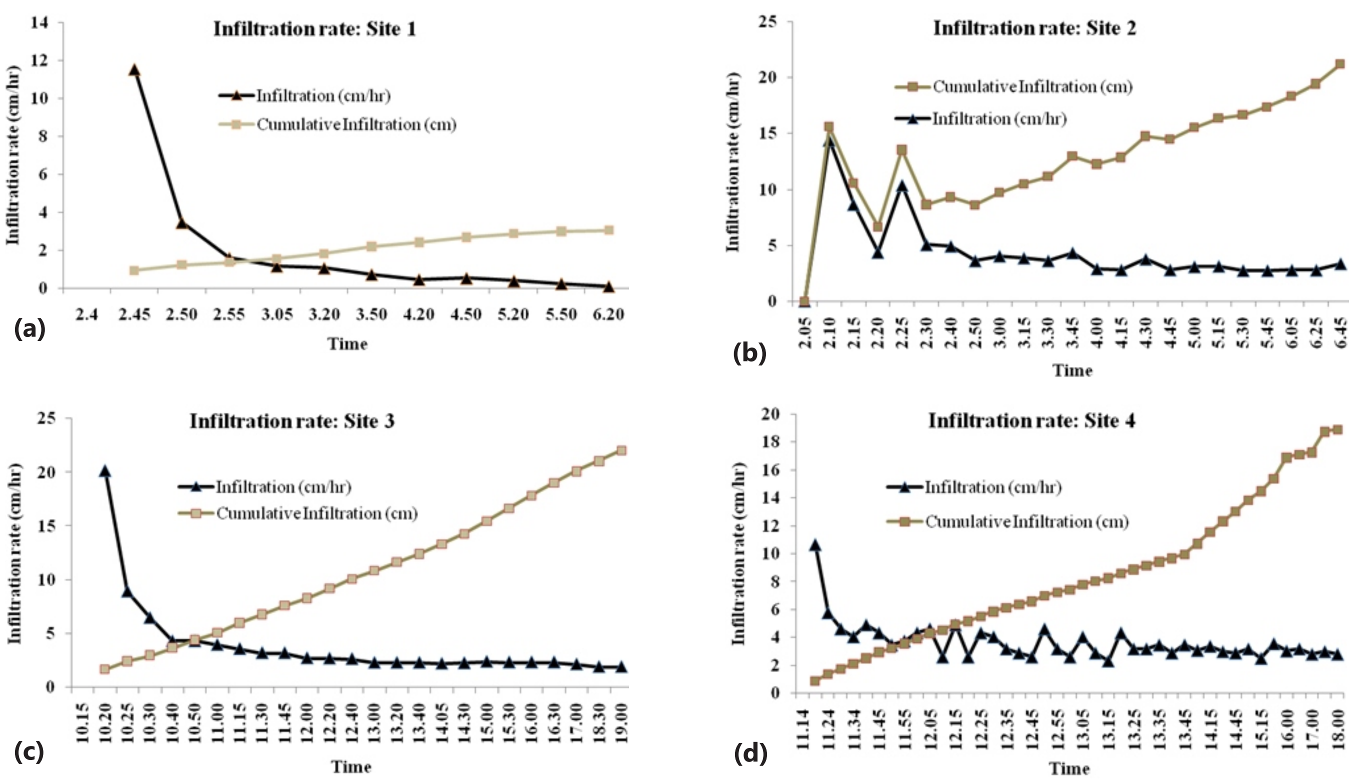

Fig. 9 (a-d). Temporal variations in infiltration rate and cumulative infiltration from different sites of cultivated land as well as in Harsauli drain sites

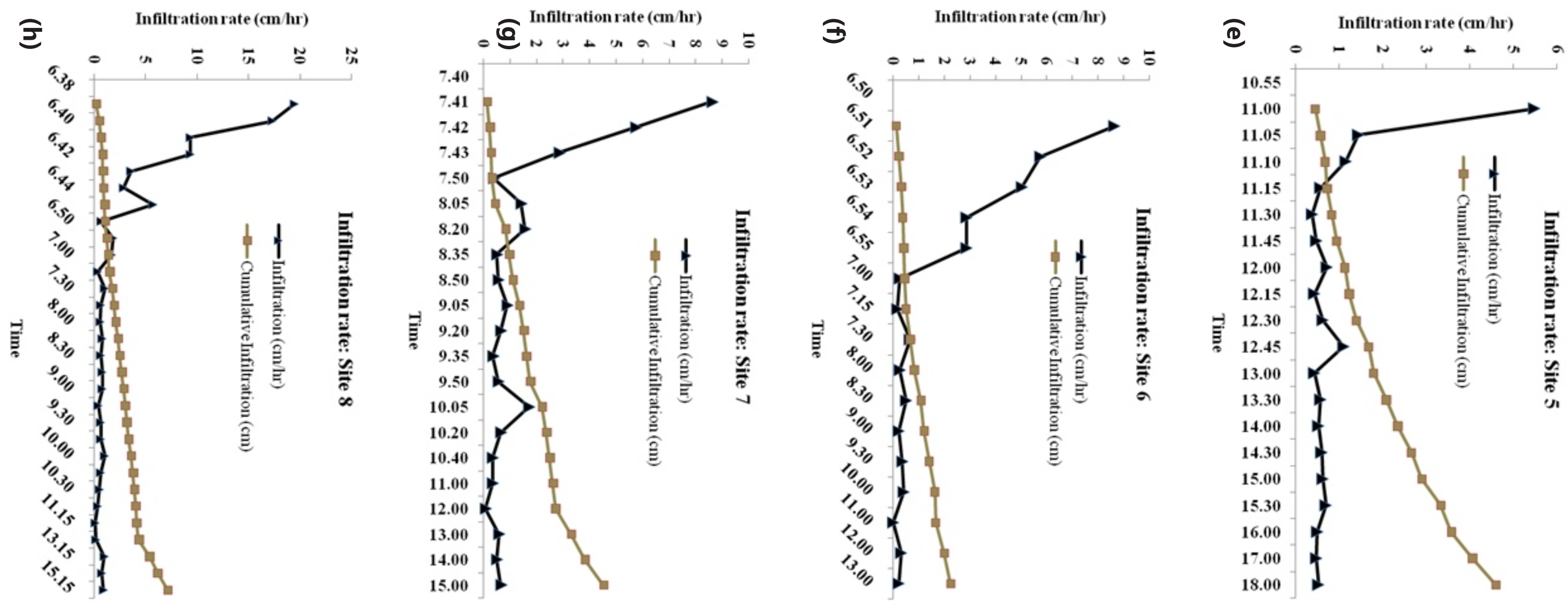

Fig. 9 (e-h). Temporal variations in infiltration rate and cumulative infiltration from different sites of cultivated land as well as in Harsauli drain sites

Table: 5
Analysis of water samples

S.No.	Sampling sites	Latitude (N)	Longitude (E)	Altitude (m)	pH	EC (µS cm^{-1})	DO	Cl^-	Ca^{2+}	Mg^{2+}	Na^+	K^+	HCO_3^-	So_4^{2-}	Total Hard.	No_3^-
							(Ppm)									
1	Star Paper Mill, Haharanpur Block	29054'03.780"	77035'41.964"	267	7.7	782	7.2	19.99	105.5	24.3	250	45	436.5	216.36	210.0	47
2	Maheshpur vill., Nanauta Block	29042'21.960"	77033'26.640"	183	7.5	886	6.5	59.98	72.6	19.5	430	50	523.2	167.51	199.5	50
3	Shahpur vill, Shahpur Block	29022'19.668"	77034'36.192"	190	7.7	655	7.9	15.00	35.6	9.5	410	45	325.6	116.28	136.5	35
4	Shahpur vill, Shahpur Block	29022'21.396"	77034'34.716"	200	7.7	863	10.0	20.00	41.2	12.4	465	55	314.2	115.51	220.5	36
5	Near Check Dam , Shahpur Block	29021'06.588"	77033'41.220"	190	7.4	542	8.4	24.99	27.5	5.6	310	30	280.0	52.60	142.8	32
6	Kakra vill, Shahpur Block	29022'39.000"	77034'36.912"	175	8.1	635	9.2	14.99	28.6	6.8	315	35	294.2	64.02	168.0	43
7	Harshauli vill, Baghra Block	29023'53.520"	77035'42.864"	190	7.3	711	8.2	14.99	31.2	6.4	305	35	268.5	51.56	176.4	46
8	Baghra vill, Baghra Block	29024'08.014"	77035'51.324"	188	7.5	689	7.9	17.49	33.2	9.8	300	40	315.5	54.33	178.5	33
9	Tauli vill, Baghra Block	29024'48.600"	77037'11.640"	201	7.7	793	8.5	19.99	36.0	11.4	295	35	451.3	70.24	191.1	48
10	Chanjhak vill, Baghra Block	29026'11.040"	77038'13.056"	199	8.0	523	10.2	12.50	26.8	8.1	200	35	421.6	72.32	168.0	46
11	Mirapur vill, Sujru Block	29026'22.200"	77040'04.080"	174	7.5	558	8.5	24.99	31.2	8.2	225	35	348.8	85.12	155.4	41
12	Bibipur vill, Nai Mandi Block	29025'47.928"	77043'46.596"	232	7.2	651	7.2	19.99	44.5	13.4	170	15	411.2	117.83	197.4	36

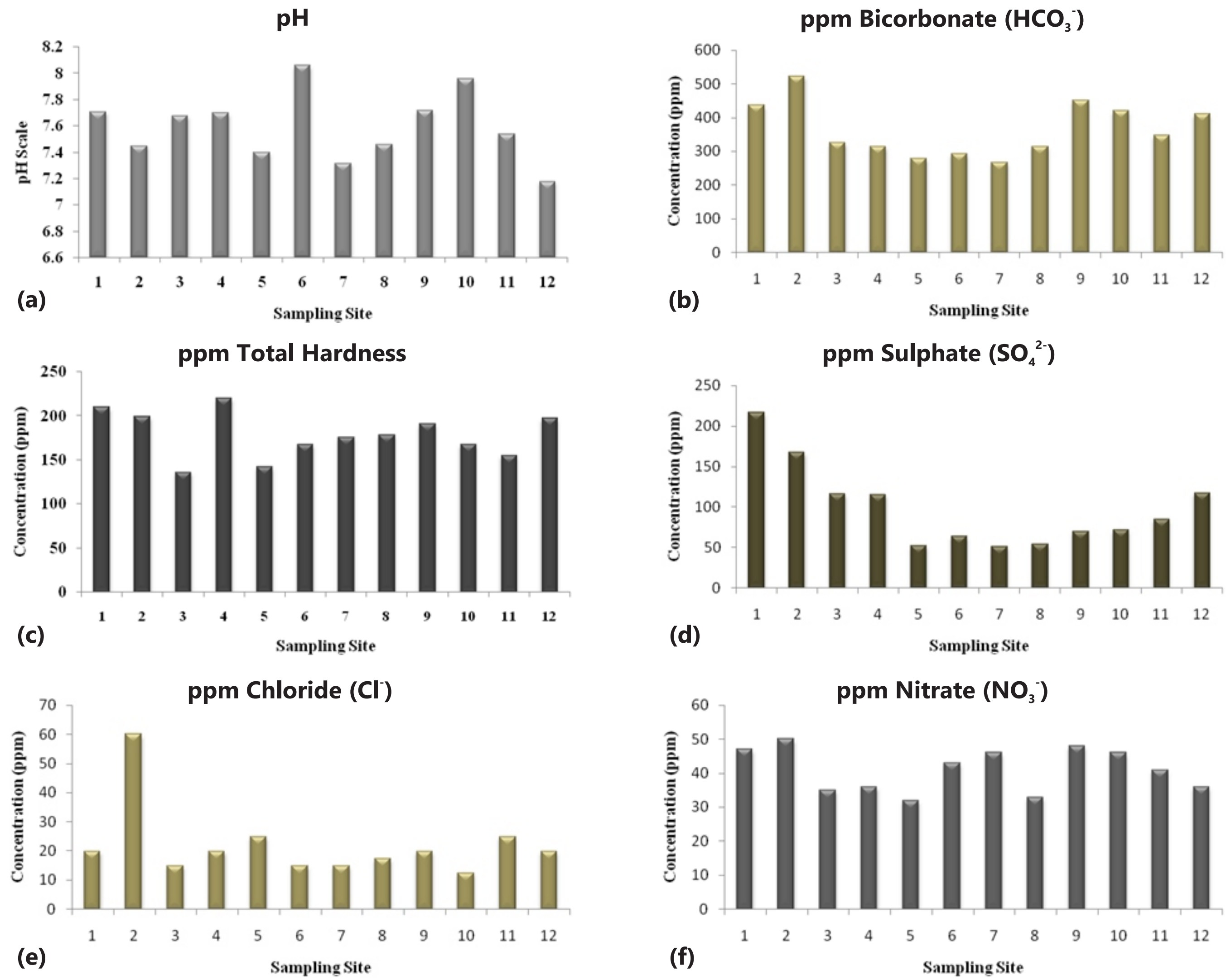

Fig. 10. (a, b, c, d, e, f): Sampling sites vs pH, HCO_3^-, total hardness, SO_4^{2-}, Cl^- and NO_3^- concentration

HCO_3^-, So_4^{2-}, Total Hardness and NO_3^-) were well within the permissible limits of irrigation water as defined by FAO (Table 6), except potassium and nitrate which may be due to fertilizer application. Based on above observation it can be inferred that groundwater quality is good for sugarcane crop production (Subramanian, 2000).

Table: 6
FAO guidelines for irrigation water quality

Water parameter	Symbol	Units	Range in irrigation water
Electrical Conductivity	EC_w	dS m^{-1}	0 - 3
Calcium	Ca^{++}	me l^{-1}	0 - 20
Magnesium	Mg^{++}	me l^{-1}	0 - 5
Sodium	Na^+	me l^{-1}	0 - 40
Carbonate	$CO\text{--}_3$	me l^{-1}	0 - .1
Bicarbonate	HCO_3-	me l^{-1}	0 - 10
Chloride	Cl^-	me l^{-1}	0 - 30
Sulphate	So_4–	me l^{-1}	0 - 20
Nitrate-Nitrogen	NO_3-N	me l^{-1}	0 - 10
Potassium	K^+	me l^{-1}	0 - 2
Acid/ Basicity	pH		6.0 - 8.5

Soils were also sampled from different agricultural fields from 0-20 cm) for its particle size analysis to know their role in engineering intervention and also analyzed for their textural class for resource characterization following standard procedures of Soil Survey Staff (1999). Study indicated that soils were silty loam to loam texture (Table 7) and if sugarcane crop is grown in such a soil textural arrangements which has sufficient moisture in their pore spaces, it may result in higher yield of sugarcane crop.

4. CONCLUSIONS

Intervention of WHS in Harsauli drain resulted in extension of back water upto 1200 m and 1500 m behind the WHS-I and WHS-II, respectively. Drill core samples indicated that fine sand fraction were the main stratum of aquifer in all the study sites. Infiltration study indicated uniform sedimentation and deposition of sediment and soil development over

Table: 7
Soil textural analysis of representative samples from sugarcane fields

S.No.	Clay (%)	Silt (%)	Fine sand (%)	Coarse Sand (%)	Textural class (%)
1	7.0	41.0	51.0	1.0	Silty Loam
2	16.0	33.0	50.0	1.0	Silty Loam
3	21.0	30.0	48.0	1.0	Silty Loam
4	14.0	20.0	64.0	2.0	Loam
5	13.0	20.0	66.0	1.0	Loam
6	12.0	16.0	70.0	2.0	Loam

it, an indicator of similar climate during their formation. pH and EC were mildly alkaline, non-saline are good for irrigation and drinking purposes. Water quality parameters (Total Hardness, Cl^-, Na, K, HCO_3^-, So_4^{2-} and NO_3^-) were well within the permissible limits of irrigation water. The textural analysis soils indicated that the crop grown in such situation will get sufficient moisture available in soil pore spaces. Variation in piezometric level was observed during the impounding in all the piezometers and its effect was more in the piezometer installed near to the drain. Since sugarcane requires intensive rainwater that exerts heavy pumping pressure on ground water, to make the sugarcane cultivated area of water positive zone, such WHS can be highly effective.

ACKNOWLEDGEMENTS

Authors are thankful to the Ministry of Agriculture and Farmers Welfare (MoA&FW) for financial help under National Mission on Sustainable Agriculture (MNSA) project and Director, Indian Institute of Soil and Water Conservation, Dehradun for providing facilities for research during the course of studies.

REFERENCES

Adel, M.M. 2002. Man-made climatic changes in the Ganges basin. *Int. J. Climatol.,* 22: 993-1016, doi:10.1002/joc.732.

Chakrapani, G. 2002.Water and sediment geochemistry of major Kumaun Himalayan lakes, India. *Environ. Geol.,* 43(1):99-107, doi: 10.1007/s 00254-002-0613-0.

CWC. 2002. Water and Related Statistics, Central Water Commission, MOWR, New Delhi, 479p.

Ding, T., Du, S., Zhang, Y., Wang, H., Zhang, Y., Cao, Y., Zhang, J. and He, L. 2020. Hardness-dependent water quality criteria for cadmium and an ecological risk assessment of the Shaying river basin, China. *Ecotoxicol. Environ. Saf.,* 198: 110666, doi.org/10.1016/j.ecoenv.2020.110666.

Döll, P. and Stefan, S. 2002. Global modeling of irrigation water requirements. *Water Resour. Res.,* 38(4): 1037, doi: 10.1029/2001WR 000355.

Khatri, N., Tyagi, S., Rawtani, D., Tharmavaram, M. and Kamboj, R.D. 2020. Analysis and assessment of ground water quality in Satlasana Taluka, Mehsana district, Gujarat, India through application of water quality indices. *Groundw. Sustain. Develop.,* 10: 100321, doi.org/10.1016/j.gsd.2019.100321

Kumar, A., Shyam, R., Tyagi, N.K. and Peralta, R.C.1998. Reconnaissance optimal sustainable groundwater pumping strategies for the lower Ghaggar basin. *In: Water and the Environment: Innovative Issues in Irrigation and Drainage.* L.S. Pereira and J.W. Gowing (eds). Pub. E & FN Spons. ISBN 0 419 23710 0.8.

Kumar, A., Sharma, H.C. and Kumar, S. 2011. Planning for replenishing the depleted groundwater in upper Gangetic plains using RS and GIS. *Indian J. Soil Cons.,* 39(3): 195-201.

Kumar, S., Parkash, B., Manchanda, M.L., Singhvi, A.K. and Srivastava, P. 1996. Holocene landform and soil evolution of the western Gangetic Plains: implications of neotectonics and climate. *Z. Geomorphol. NF, Suppl.,* 103: 283-312.

Ministry of Environment, Forest and Climate Change, 2004. *Annual Report: 2004-2005.* MoEF&CC, New Delhi.

Pal, D.K., Bhattacharyya, T., Chandran, P., Ray, S.K., Satyavathi, P.L.A., Durge, S.L., Raja, P. and Maurya, U.K. 2009. Vertisols (cracking clay soils) in a climosequence of Peninsular India: Evidence for Holocene climate changes. *Quater. Int.,* 209: 6-21.

Pathak, H., Pramanik, P., Khanna, M. and Kumar, A. 2014. Climate change and water availability in Indian agriculture: Impacts and adaptation. *Indian J. Agric. Sci.,* 84(6): 671-679.

Pawar, N.J., Pondhe, G.M. and Patil, S.F. 1998. Groundwater pollution due to sugarmill effluent at Sonai, Maharashtra, India. *Environ Geol.,* 34:151-158.

Singh, D., Chhonkar, P.K. and Dwivedi, B.S. 2005. *Manual on Soil, Plant and Water Analysis.* Westville Publishing House, New Delhi, 200p.

Singh, S., Parkash, B., Rao, M.S., Arora, M. and Bhosle, B. 2006. Geomorphology, pedology and sedimentology of the Deoha/Ganga-Ghghara Interfluve, Upper Gangetic Plains (Himalayan Foreland Basin)- extensional tectonic implications. *Catena,* 67: 183-203.

Smith Davip, R., Villella Riva, E. and Lemarie David, P. 2001. Survey protocol for assessment of endangered freshwater mussels in the Allegheny river, Pennsylvania. *J.N. Am. Benthal. Soc.,* 20(1): 118-132.

Soil Survey Staff. 1999. *Soil Taxonomy: A basic System of Soil Classification for making and interpreting Soil Surveys.* Agri. Handbook, USDA, 436, 869p.

Subramanian, V. 2000. *Water: Quantity-Quality Perspectives in South Asia.* Kingston International Publishers, Surrey, UK, 256p.

UNFCCC. 1998. *Kyoto Protocol to the United Nations Framework Convention on Climate Change.* United Nations, 20p.