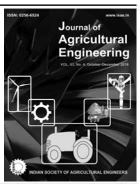
http://www.isae.in / journal_jae.aspx

Journal of Agricultural Engineering

Vol. 56 (4): October-December, 2019



Evaluating Efficacy of Recharge Structures in Augmenting Groundwater Resources in Muzaffarnagar, Uttar Pradesh

Satyendra Kumar[1]*, A. L. Pathan[2], Vivekanand[3] and S.K. Kamra[4]

[1]Principal Scientist, [2]Scientist, [3]Senior Research Fellow, [4]Emeritus Scientist, ICAR-Central Soil Salinity Research Institute, Karnal – 132001, Haryana. *Corresponding author email address: s.kumar2@icar.gov.in

Article Info

Manuscript received: August, 2019

Revised manuscript accepted: November, 2019

ABSTRACT

Groundwater play a vital role in stabilizing Indian agriculture, but its indiscriminate uses is resulting in fast depletion and degradation of this key natural resource. Sustainable groundwater resource management is, therefore, a priority issue before the country. Enhancing artificial groundwater recharge by adopting suitable technological interventions can be an option. Two cavity-type recharge structures with radial filter were designed and installed with village ponds at *Kutba* and *Nirmana* villages, and their impact on groundwater was assessed. Recharge rates varied from 382 m^3.day-^{1}to 906 m^3.day-^{1} during three test cycles,each of 8 days duration. As estimated, 27,304 m^3 surplus water was recharged through the recharge well at *Kutba* site during December 2017 to March 2018. Similarly,0.2 mgroundwater rise was recorded beneath and around the structure at *Nirmana* during monsoon 2018. Results of field investigations revealed that cavity-type recharge structure in combination with a pond and radial filter can be a good option for recharging surplus canal and rainwater for augmentation of water resources in groundwater depleting areas.

Keywords: Recharge structure, radial filter, pond, recharge rate

In India, groundwater is a major source for supplying water to agriculture, industrial and domestic sectors. It accounts for 61.6 % of the total irrigated area of the country, and thus,plays a vital role in stabilizing Indian agriculture (Suhag, 2016). However, ever-increasing population, industrialization and increasing demands in agricultural sector have posed a great pressure on the available groundwater resources. The mean stage of groundwater development in the country is about 62 % (CGWB, 2017), but it is highly non- uniform: more than 100 % in fast-depleting north-west Indian states and under-developed in the eastern region of the country (Sharma, 2014). Due to easy access, operational convenience and private ownership, the groundwater development has been quick but unregulated and has resulted in decline in water table at alarming rates in about 15 % of India's geographical area.The states of Haryana, Punjab, Uttar Pradesh and Gujarat account for 27 % of country's 839 over-exploited groundwater blocks in which the level of groundwater development is more than 100 % (Kamra, 2010). The sustainability of agriculture in thesehighly-productive and water-intensive states, particularly Haryana, Punjab and western Uttar Pradeshwith widely prevalent rice-wheat system, is getting threatened due to alarming rate of water-table decline, increase in pumping cost and deterioration of groundwater quality (Bhaskar *et al*., 2014).

Climate change is likely to increase uncertainty of highly variable rainfall patterns, requiring greater efforts in managing both water scarcity and floods. The rate of declining groundwater can be slowed down to some extent by enhancing groundwater recharge. Artificial groundwater recharging could be a viable option as aquifer is recharged at a higher rate than the natural recharge process. It involves regulated movement of excess surface water into an aquifer through a constructed recharge structure.

A number of agencies in India, including the Central Ground Water Board (CGWB), research institutes, universities and non-governmental organizations (NGOs) had undertaken various studies on artificial groundwater recharge (Chadha, 2002). However, post-installation monitoring revealed that though big artificial groundwater recharge structures (diameter >2m) are effective, their success is limited due to poor post-installation maintenance. In general, big structures are installed in or along the drains or on community land, which lack a sense of belonging with the local population. Relatively much smaller recharge structure (diameter ≤ 0.45m) were designed and developed at Central Soil Salinity Research Institute (CSSRI), Karnal with the hypothesis that individual or group of local people will look after post-installation maintenance of these recharge structures (Kamra, 2013). To safeguard against clogging of these structures, the surface runoff or excess canal water was first passed through a designed three-layer sand filter consisting oflayers of coarse sand, gravel and boulders in a small brick-masonry chamber (Kaledhonkar *et al*., 2003; Kumar *et al*., 2012).

Most of the previous studies including those performed by CSSRI on artificial recharge were focused on horizontal and vertical shafts, strainer tube well and providing a boulder or gravel,or both alone or in combination of top sand layer, for retaining physical sediments in the storm water used for recharge. Frequent clogging of recharge filter and/or structure was reported as a major limitation in effective operation of recharge structures. In order to delay clogging of filtering unit, a radial type filter was developed and evaluated at laboratory scale (Kumar *et al*., 2014). Radial filter performed better than sand-based vertical filters,and pre-sedimentation facility can further improve efficacy of filtering unitand recharge structures.

Keeping above facts in view, this study was undertaken with the objective of designing of two recharge wells with a radial filtering unit, which were installed and operated in combination with village water ponds at two sites in Muzzafarnagar district of Uttar Pradesh. Performance of both the structures was also evaluated.

MATERIALS AND METHODS

Description of Study Area

The study was conducted on two locations, one each in *Kutba* and *Nirmana* villages of *Baghra* **block of Muzaffarnagar district, Uttar Pradesh (district area of 2,95,800 ha) during 2016-2018.** Sugarcane based cropping system is prevalent in the area, and the district is known as *"Sugar Bowl of India"*. **The average annual potential evapotranspiration of the district is about 1546 mm (CGWB, 2017).** Due to indiscriminate use of groundwater, the water level has declined alarmingly at a rate of about 1 m.year^{-1} in *Budhana, Baghra and Shahpur* blocks, which have been declared as dark / over-exploited blocks (CGWB, 2013).

The study area is located at northern part of the State covering an area of 662 ha (*Kutba*) and 468 ha (*Nirmana*) (Fig. 1). The whole agricultural area of these villages was irrigated. The major source of irrigation was groundwater (about 77 %), while 21.8 % area was covered by canal irrigation. The annual groundwater withdrawal was more than the replenishment. The canal water supply was for one week on on-and-off basis. The surplus canal water was available during monsoon season as well as in December-January months. At *Kutba*, farm pond was receiving excess water from adjoining canal distributary, while at *Nirmana*, source of water for pond was runoff water. **The climate of the study area was characterized as hot dry sub-humid with average annual rainfall of 750 mm, about 85 % of which occurring during monsoon period of July-October.**

The whole district is underlain by quaternary alluvium deposited by Ganga-Yamuna river system. Sand, silt and gravel are major configuration of water-bearing aquifers. Three distinct groups of aquifers exist in the area. The first aquifer exists down to the depth of 162m below ground level (bgl), second aquifer lies between 145-327 m and the third one between 288-463 mbgl (CGWB,2017). The unconfined aquifer near the ground surface is usually tapped by dug wells.

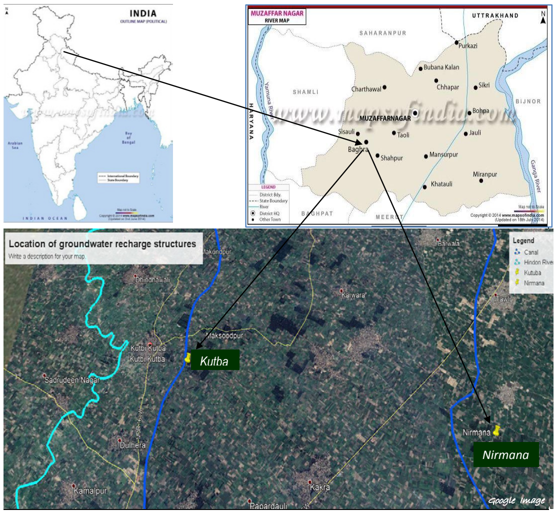


Fig.1: Location of study site at Muzaffarnagar district, Uttar Pradesh, India

Lithological Analysis

Lithologic samples from two sites were collected at an interval of 1.5 m during November-December, 2016 through drilling process during installation of recharge structures and observation wells. The collected samples were analysed in laboratory of ICAR-CSSRI, Karnalto determine texture and chemical properties. The textural class of lithological samples was analysed by using standard pipette method (Miller and Miller, 1987). Electrical conductivity and pH of subsurface soil samples was determined using EC meter (CON 700, EUTECH, Range: 0-200 ds.m^{-1}, Accuracy: ($\pm$) 1 %) and pH meter (pH 700, EUTECH, Range: (-)2 to 20 pH, Accuracy: ($\pm$) 0.01 pH).

Design and Construction of Recharge Structures

Based on lithology of the area, cavity-type recharge structures were designed and installed during November-December, 2016 at *Kutba* (29º39'9.84"N; 77°54'20.8"E) and *Nirmana* (29º23'7.6" N; 77º36'58.7"E) villages of *Baghra* block of Muzaffarnagar district. Availability of an existing pond and quantity and quality of pond water to be recharged were considered in the selection of suitable sites.Both sites had different conditions as at *Kutba*, pond was canal fed, while, source of water at *Nirmana* was rain water.Besides, expected quantity of recharged water and size of tube well pipe wasalso governed by size of drilling bits and size and price of available PVC pipes in the market.

Drillingof sub-soil formation up to the suitable water-bearing strata was done by percussion drilling method, which involved cutting of subsoil materials by blades fixed at bottom of a plunger and bringing the cuttings out of the bore. After completion of drilling operation, PVC pipes were inserted in drilled bore-holeby piercing the clay layer below which cavity was to be made. Additional strainer filter (perforated pipe wrapped with synthetic filter) was provided in sand strata above the clay layer to enhance recharge rates. Submersible pump of 11 kW was placed just above the clay layer, and was used to pump out sand along with water from the water-bearing strata to form a cavity below the clay layer. A filtering unit consisting of radial filter was used for effective functioning of recharge structure. For this purpose, one 3 m × 3 m ×3 m size brick-masonry chamber was constructed around the recharge pipe. A 2.5 m long bigger PVC pipe of 300 mm diameter was connected with 225 mm diameter drilled recharge pipe where one m length above the base of the chamber was not perforated to provide settlement space for sediments carried with inflow water. The remaining portion was perforated and wrapped with synthetic filter. A non-perforated 225 mm diameter PVC pipe was fixed horizontally in recharge chamber at 1 m above the base, which ensured a minimum storage of water in the pond for other purposes and entry of only surplus water into the recharge chamber.

The recharge structure was installed in the corner of an existing pond in *Kutba* village, while the structure was constructed along the side of an existing pond in *Nirmana* village. The estimated surface area of pond at full capacity was 5,580 m^2 at *Kutba* with a mean depth of 2.3 m and 1:2.3 side slope. At *Nirmana*, maximum surface area of pond was about26,066 m^2 with 3 m depth and irregular shape with varying side slopes. Since, the quantification of recharging water was difficult at *Nirmana* site, impact of recharge structure was observed in terms of water table fluctuations beneath and around the structure. At both the sites, a large proportion of sediments brought bycanal/runoff water first settled down in the pond before entering into the filter chamber of the recharge well.

Estimation of Recharge Rate

Rate of recharging water through the recharge well at *Kutba* site was estimated using water balance equation for a pond. To measure fluctuation in pond water level, a scale was fixed on the wall of masonary chamber constructed in one corner inside the pond. Pond was filled with surplus canal water to a certain depth i.e about 2.3 m. Recharge rate of water was estimated by diverting surplus canal water into the pond for three consecutive periods of 8 days duration each during December, 2017 to March, 2018. During the study period, no water was diverted into the pond after filling it once to its full capacity (2.3 m depth),and there was no rainfall as well. It was considered that decline in level of pond water was due to the seepage from bed and sides of the pond, evaporation losses occurring from the pond water surface and recharging through structure. Following water balance equation was used for estimating rate of recharge:

$$V_{rs} = V_{pl} - V_{sl} - V_{Ep} \qquad \ldots(1)$$

Where,

V_{pl} = Decline in volume of stored water in pond, m^3,

V_{sl} = Seepage loss, from pond, m^3,

V_{Ep} = Evaporation loss from pond water surface, m^3, and

V_{rs} = Volume of water recharged through the structure overa certain period of time, m^3.

The rate of recharge (V_{rs}) was estimated at one-day interval (m^3.day^{-1}). The change in pond water level and evaporation loss from pond surface was measured on depth basis, and multiplied with surface area of the pond water on respective day to convert into volume. The rate of seepage loss (cm.day^{-1}) was adopted from literature on the basis of soil texture of pond surface (FAO, 2003), on and multiplied with wetted area of the pond on respective day to convert into volume. The water lost as evaporation from the pond was taken as equal to value of evaporation measured from evaporation pan multiplied with pan coefficient value of 0.75. The daily pan evaporation data, availableat the nearest meteorological observatory situated at ICAR-CSSRI, Karnal, about 65 km from the study site, were collected.

Impact Analysis of Recharge Structures

The impacts of constructed recharge structures were monitored in terms of groundwater fluctuation and improvement in groundwater quality at both sites. For this purpose, water table depth and water quality parameters such as electrical conductivity (EC) and pH of water samples were periodically monitored at one-month intervals during February, 2017-March, 2018. The water samples were collected through structure's pipe as well as installed observation wells. Three observation wells were installed at *Nirmana* at different distances from the structure such that two observation wells were within the expected recharge zone, while third was beyond the influence zone of recharge structure. The radius of influence for recharge structure was considered as two-third of radius of influence of pumping (150 m in case of alluvium plane, Pandey, 2005). Three observation wells were installed at 7.5, 60 and 350 m from the recharge well at *Nirmana* and at 5, 60 and 300 m at *Kutba.* Depth of each observation well was kept similar to the depth of recharge structure. Manual drilling of 62-75 mm diameter bore well was done up to 54 m and 41 m bgl respectively in *Kutba* and *Nirmana* villages, and 50 mm diameter PVC pipes were fitted in the bore well to act as observation wells for monitoring water table fluctuations. The observation wells pipes were kept perforated and wrapped with synthetic net filter in sections below the saturated water table level, while blind (no perforation) pipe was used in the upper unsaturated zone. For safety of the observation wells, 1 m galvanized iron (GI) pipe of 50 mm diameter were connected to the PVC pipe at about 300 mm below the ground level; the joint reinforced further with aconcrete base of 300 mm × 300 mm × 300 mm size.

RESULTS AND DISCUSSION

Lithology of Study Sites

The lithology of *Kutba* and *Nirmana* recharge sites is presented in Fig. 2. The well log of *Kutba* revealed that top 1.5 m layer was clay loam, followed by 4.5 m thick layer of sandy loam (Fig. 2a). A 1.5 m thick fine sand layer was present at 6 m depth from the ground surface, which was repeated at 36 m and 42 m depths in 4.5 m thick layers. The cavity was developed at 57.1 m depth, where a layer of clay soil was present.

At Nirmana site, first 4.5 m was clay loam, followed by sandy loam strata (Fig. 2b). At this site, cavity was developed at about 41 m from the ground surface. Above this layer, a 6 m thick clay layer was present which was prerequisite for cavity formation. The chemical analysis of lithological samples collected from different layers during drilling revealed that the

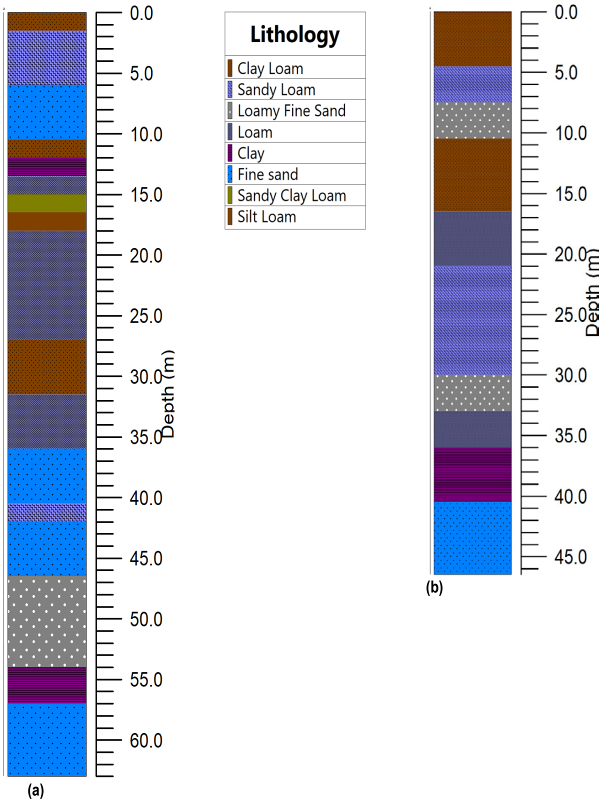


Fig. 2: Lithological details of recharge site at a) *Kutbavillage* and b) *Nirmanavillage*

area did not have any issue of salinity or alkalinity problems as recorded electrical conductivity (EC) and pH fell in fair and good categories (Table 1a,1b), respectively (WHO, 2011).

Operational Features of Recharge Structures and Filtering Units

The design features of installed structures are illustrated in Fig. 3. Based on lithology of sites, recharge structures were designed to form cavity below 3 m thick clay layer present at 54-57 m depth at *Kutba* and 36-40.5 m depth at *Nirmana* site. A 3 m strainer (slots wrapped with synthetic filter) in sandy depth zones above the clay layer was also provided. At *Kutba* site, a bore hole of 250 mm diameter was drilled to the depth of 54 m bgl, beyond that 125 mm diameter hole was drilled in the hard pan layer up to the water-bearing strata. High pressure (10 kg.cm^{-2}) PVC pipe of 225 mm diameter and 54 m length was inserted in 250 mm drilled bore hole. A PVC reducer of 225 mm × 150 mm size was

Table 1a. Chemical analysis of samples collected during drilling from different depth at *Kutba*

Sl. No.	Depth (bgl), m	EC, dS.m^{-1}	pH	Depth (bgl), m	EC, dS.m^{-1}	pH
1.	0.0-1.5	0.33	7.30	24.0-27.0	0.92	7.03
2.	1.5-3.0	0.18	7.30	27.0-30.0	0.22	7.34
3.	3.0-4.5	0.27	7.70	30.0-33.0	0.24	7.00
4.	4.5-6.0	0.29	7.41	33.0-36.0	0.42	7.35
5.	6.0-7.5	0.23	7.31	36.0-39.0	0.21	7.25
6.	7.5-9.0	0.27	7.27	39.0-42.0	1.20	6.99
7.	9.0-10.5	0.22	7.38	42.0-45.0	0.24	7.15
8.	10.5-12.0	1.91	6.95	45.0-48.0	0.40	7.18
9.	12.0-13.5	1.52	6.95	48.0-51.0	0.21	7.22
10.	13.5-15.0	0.34	7.33	51.0-54.0	0.23	7.38
11.	15.0-18.0	0.24	7.06	54.0-57.0	0.33	7.16
12.	18.0-21.0	0.24	6.96	57.0-60.0	0.35	7.15
13.	21.0-24.0	0.26	6.92			

Note: bgl:below ground level

Table 1b. Chemical analysis of samples collected during drilling from different depth at *Nirmana*

Sl. No.	Depth (bgl), m	EC, dS.m^{-1}	pH	Depth (bgl), m	EC, dS.m^{-1}	pH
1.	0.0-1.5	0.35	8.27	19.5-21.0	0.37	8.47
2.	1.5-3.0	0.19	8.40	21.0-22.5	0.38	8.43
3.	3.0-4.5	0.28	8.42	22.5-24.0	0.35	8.35
4.	4.5-6.0	0.30	8.32	24.0-25.5	0.39	8.37
5.	6.0-7.5	0.25	8.32	25.5-27.0	0.40	8.34
6.	7.5-9.0	0.28	8.33	27.0-28.5	0.37	8.49
7.	9.0-10.5	0.23	8.36	28.5-30.0	0.37	8.47
8.	10.5-12.0	0.25	8.30	30.0-31.5	0.37	8.40
9.	12.0-13.5	0.21	8.11	31.5-33.0	0.34	8.41
10.	13.5-15.0	0.27	8.33	33.0-34.5	0.27	8.35
11.	15.0-16.5	0.31	8.34	34.5-35.0	0.31	8.39
12.	16.5-18.0	0.35	8.37	35.0-40.5	0.28	8.31
13.	18.0-19.5	0.33	8.36	40.5-46.5	0.16	8.43

Note: Bgl: below ground level

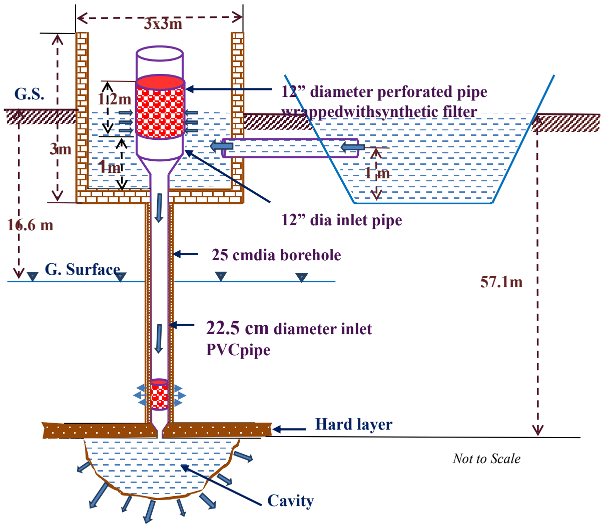


Fig.3: Design specification of recharge cavity installed at study sites

fixed at the bottom of recharge well PVC pipe and rested whole length (57.1 m) on hard pan with the help of this reducer. The entire PVC pipe of 54 m length was non-perforated, except in sections at 42-47 m bgl where sand strata were encountered. In this portion, 1-2 mm wide slots were made and wrapped with synthetic (70 mesh) filter to enhance the recharge capacity of the well. With this modification, these recharge structures can be stated as recharge cavity-cum-strainer well instead of simply a recharge cavity. A 11-kW submersible pump was placed just above the hard pan, and continuously operated for10-12 h to form a stable semi-spherical cavity below the clay layer.

At *Nirmana* site, design (size of pipe and construction methodology) of installed recharge structure was kept similar to that adopted at *Kutba* site. However, drilling depth was different as cavity was formed at 40.5 mbgl, as the hard pan layer at this site appeared at a depth of 36 mbgl. At both sites, recharge structure received water from pond after settlement of most of the sediments in pond water itself before entering into the filtration unit.

A recharge cavity was preferred for these two sites since it can also be used for occasional pumping with a 5.6-7.5 kW submersible pump for cleaning the clogged sediments deposited in the cavity.

The total cost incurred in construction of recharge structures was estimated as ₹ 1,92,500/- at *Kutba* and ₹ 1,57,500/- at *Nirmana* site, with the average construction cost of ₹ 3,500 per meter depth of drilling.

Rate of Recharge through Recharge Structures

The estimated rate of recharge for structure constructed at *Kutba* site is presented in Fig. 4. Recharge rate varied with operation time and ranged from 382 $m^3.day^{-1}$ to 906 $m^3.day^{-1}$during 3 test cycles of 8-day durations. In the beginning of each test cycle, recharge rate was high (>780 $m^3.day^{-1}$), which decreased with each passing day (Fig. 4). Declining recharge rate was linked to combined effect of the drop in water level in the pond, clogging of recharge filter and reduced recharge capacity of structure with time. The rate of decline was steeper during the first three days of test cycle, and thereafter, it got stabilized. Cumulative amount of recharged water was estimated as 4682m^3, 4094m^3 and 4331 m^3, respectively, in 3 test cycles (Fig.4). Considering daily average recharge rate ofthree test cycles and operation period of 50 days between December, 2017 and March, 2018; about 27,304 m^3 surplus canal water was recharged through the structure at *Kutba* site. The capital cost for 50-day period worked out as ₹ 7.02 per m^3 of recharge water, which will reduce with each passing year as construction of recharge unit is a one-time investment. Considering 10 years of effective life of the structure and 75-day recharge period in a year, the construction cost was estimated to be ₹ 0.47 per $m^3$of recharge water. It is worth mentioning that life of a recharge structure can be more than 10 years, if maintained properly.

Impact of Recharge Structures

The temporal changes in water table depths at *Kutba* and *Nirmana* recharge sites are presented in Fig. 5. The data presented in Fig. 5 show that water table declined during summer months of May and June. The water table decline during summer months was due to groundwater pumping in nearby areas for

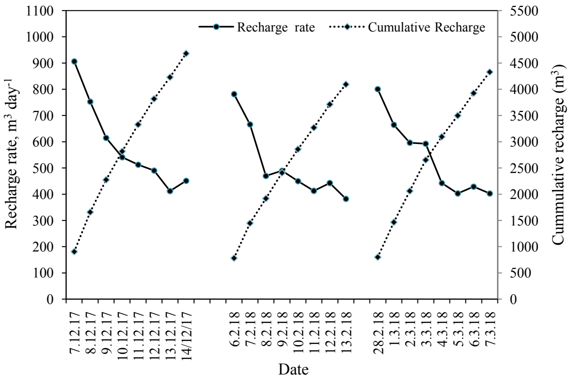


Fig. 4: Estimated recharge rate and cumulative recharge during three test cycles forinstalled recharge structure at *Kutbasite*

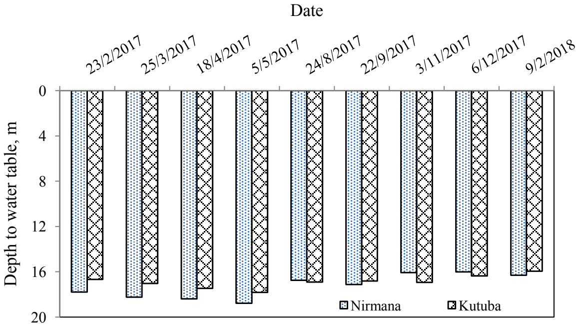


Fig. 5: Temporal change in water table depth at *Kutbaand Nirmana* sites

irrigating sugarcane crop. However, in monsoon season (September, 2018), groundwater rise of 1.26 m and 0.65 m was recorded beneath the structure at *Nirmana* and *Kutba* sites, respectively, due to recharge taking place during the rainy season. The water table rise at *Nirmana* site was more as compared to *Kutba*site due to recharging rain water at *Nirmana* site, while no recharge occurred at *Kutba* site during this period as the pond had minimum storage of less than 1.3 m most of the time. However, during February 2018, higher rise (0.86 m) in water table was witnessed at *Kutba* site due to diversion of surplus canal water supply into the pond that was recharged. This finding suggested that canal water can be successfully used for augmenting groundwater levels during surplus availability.

Water table depths recorded in three observation wells at *Nirmana* site are shown in Fig. 6. A rise of 0.98 mwas recorded in observation well (N-P-1) installed near the recharge structure during September, 2017-February, 2018, while a rise of 0.78 min water table was observed in observation well (N-P-3)located 350 maway from the pond representing natural water table depth beyond the area of influence of recharge structure. An additional rise of 0.20 min water level beneath and around the structure as compared to the natural water table rise evidenced the impact of artificial recharge through the structure.

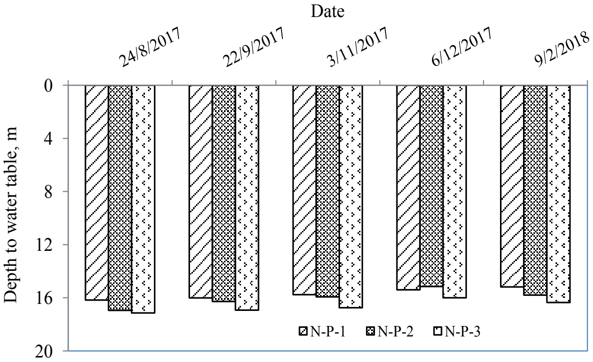


Fig.6: Temporal change in water level of three observation wells at *Nirmanasite*

Analysis of electrical conductivity (EC) and pH of groundwater indicated slightly high pH (8.25) at *Nirmana* site during summer season (in June), but that values decreased during rainy season due to dilution effect of recharged rainwater (Table 2). However, slightly better (EC = 0.24; pH =7.40) groundwater quality parameters were found at *Kutba* site. Overall, grountwater quality in the study area was found to be of good quality, hence improvements in quality was not perceptible.

CONCLUSIONS

Two recharge structures were installed in combination with village pond each at *Kutba* and *Nirmana* villages of Baghra block in Muzaffarnagar district of Uttar Pradesh. Based on lithologicalstrata, recharge cavity was formed at 57.1 m and 40.5 m depths at these sites while strainer filter of PVC pipes was provided in upper sandy zones for further improving the recharge rates. The recharge rate for recharge wells varied between 382 - 906 $m^3.day^{-1}$ during three 8-day test cycles. The total amount of recharge duringthree test cycles was 4,094, 4,331 and 4,682 m^3 at *Kutba* site A rise of 19.80 cm in water table was recorded beneath and around the structure during monsoon season of the year 2018 at

Table 2. Chemical analysis of water samples collected from recharge structures at *Kutba* and *Nirmana* sites

Sl. No.	Date of sampling	Kutba		Nirmana	
		EC, $dS.m^{-1}$	pH	EC, $dS.m^{-1}$	pH
1.	23/02/2017	0.32	761	0.58	8.10
2.	18/04/2017	0.90	7.42	0.73	8.32
3.	02/06/2017	0.24	7.40	0.80	8.25
4.	24/08/2017	0.20	7.89	0.78	8.15
5.	03/11/2017	0.18	7.82	0.76	8.00
6.	06/12/2017	0.23	8.25	0.82	8.15
7.	09/02/2018	0.30	7.50	0.78	8.10

Nirmana site, which shows contribution of installed structure on groundwater. The groundwater in the study area was in general of good quality. The overall results of the study suggest that a recharge well in combination of pondand radial filter can be an effective option for recharging groundwater with surplus canal and rainwater in water table depleting areas in alluvium plane.

ACKNOWLEDGEMENT

Study included information generated in a project on "Efficient Groundwater Management for Enhancing Adaptive Capacity to Climate Change in Sugarcane based Farming System in Muzaffarnagar district" funded by Department of Agriculture and Cooperation (DOAC&FW), Government of India. The authors are grateful to funding agency for financial support and sincerely acknowledge the technical and logistics support provided by the Director, ICAR-Central Soil Salinity Research Institute, Karnal and Indian Institute of Water Management (IIWM), Bhubaneswar.

REFERENCES

CGWB. 2013. Dynamic Groundwater Resources of India. Report of the Central Ground Water Board (CGWB), Ministry of Water Resources, New Delhi, India, pp: 308.

CGWB. 2017. Ground Water Year Book- India, 2016-17. http://cgwb.gov.in/Ground-Water/Groundwater %20Year %20Book %202016-17.pdf (accessed on13 June, 2019).

Chadha D K. 2002. State of art of artificial recharge applied on village level scheme in India. In: Report, Management of Aquifer Recharge and Subsurface Storage: Making Better Use of Our Largest Reservoir. (Ed. Tuinhof A; HeederikJP), Netherlands National Committee –Intl. Assoc. Hydrogeologists NNC-IAH Publication No 4, 19-24.

FAO. 2003. Estimates of Water Requirements, Chapter 2. Manual on Water for Freshwater Fish Culture, Volume 4, FAO Training Series: Simple Methods for Aquaculture, Version-I. CD ROM/DVD, Food and Agriculture Organization (FAO), Rome.

Kamra S K. 2010. Recharge and skimming: Opportunities and technologies for poor quality groundwater areas. In: Compendium (Ed.Yadav RK; Meena RL; Jat HS; Singh RK; Lal K;Gupta SK),Use of Poor Quality Water in Agriculture, Central Soil Salinity Research Institute, Karnal, India, 134-143.

Kamra S K. 2013. Role of farmers' participation for effective management of groundwater recharge structures in Haryana. In: Proc. Workshop on 'Roadmap for Sustainable Groundwater Resources in Punjab and Haryana' organized by CGWB North West Region, Chandigarh India, February 27, 88–99.

Kaledhonkar M J; Singh O P; Ambast S K; Tyagi N K; Tyagi K C. 2003. Artificial groundwater recharge through recharge tube wells: A case study. Inst. Eng. (I) J. (AG), 84, 28-32.

Kumar S; Kamra S K; Yadav R K; Narjary B. 2014. Effectiveness of horizontal filter for artificial groundwater recharge structure.J. Agric. Eng., 51(3), 24 - 33.

Kumar S; **Kamra S K; Yadav R K;Sharma J P**. 2012. Evaluation of sand-based storm water filtration system for groundwater recharge wells. Curr. Sci., 103(4), 395-404.

Miller W P; Miller D M.1987. A micro-pipette method for soil mechanical analysis. Communications in Soil Sci. and Plant Analy., 18(1), 1-15.

Narjary B; Kumar S; Kamra S K; Bundela D S; Sharma D K. 2014. Impact of rainfall variability on groundwater resources and opportunities of artificial recharge structure to reduce its exploitation in fresh groundwater zones of Haryana. Curr. Sci., 107(8), 1305-1312.

Pandey H. 2005**.**Hydraulic analysis of cavity well during pumping and recharge. Unpublished M. Tech. Thesis submitted to MPUAT, Udaipur, Rajasthan), pp: 104.

Sharma H. 2014. Evaluation of groundwater depletion scenario and its impacts in NW India by geodetic techniques & modelling approaches.Unpublished M. Tech. Thesis submitted to Andhra University, Visakhapatnam. Assessed on 14 May, 2019. *https:// www.iirs.gov.in/iirs/sites/.../Student Thesis/ Hemanti_ Sharma_mtech_2012-14.p.*

Suhag R. 2016. Overview of Ground Water in India, PRS. http://www.prsindia.org/administrator/uploads/ general/ 1455682937 ~~ Overview of Ground Water in India.pdf. (assessed on 10June, 2019).

WHO. 2011. Guidelines for drinking water quality. *IVEd., World Health Organization's (WHO),* Geneva, Switzerland, pp: 564