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Abbreviations and Traditional Words

ACIAR	Australian Centre for International Agricultural Research
ASR	Aquifer Storage and Recovery
ASRA	Aquifer Storage and Recovery for Sustainable Agriculture
CGWB	Central Groundwater Board
DEM	Digital Elevation Map
DO	Dissolved Oxygen
EC	Electrical Conductivity
EF	Entrepreneurial Farmer
FFEC	Flowing Fluid Electrical Conductivity
GDP	Gross Domestic Product
GIS	Geographical Information System
IDW	Inverse Distance Weighted
INR	Indian Rupees
JRF	Junior Research Fellow
MAR	Managed Aquifer Recharge
SBS	School of Budhist Studies
SEES	School of Ecology and Environment Studies
SRF	Senior Research Fellow
TDS	Total Dissolved Solids
TH	Total Hardness
TN	Total Nitrogen
TOC	Total Organic Carbon
WHO	World Health Organization
ahar	A traditional water harvesting structure reported from South Bihar
kharif	Crop grown during June-October in this region
rabi	Crop grown during October-March in this region
zaid	Crop grown during March-July in this region

1 Acknowledgments

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We are grateful to all the experts, reviewers, and researchers who participated and offered constructive feedback and comments during the different events organised by the project team.

2 Executive Summary

This report presents the findings of the investigation on the potential of aquifer storage and recovery (ASR) technique for supporting sustainable agriculture intensification in South Bihar. South Bihar is one of the most water-challenged regions in the country, having semi-arid climatic conditions. The region faces occasional floods and droughts. Seasonal water availability determines the cropping pattern in South Bihar as agriculture in the region is mainly rainfed. Ensuring reliable irrigation sources is crucial for meeting the demands of sustainable agriculture in South Bihar. The agrarian region of South Bihar has the potential to emerge as one of the major agricultural hubs of eastern India.

The Australian Government-funded project “Aquifer characterization, artificial recharge and reuse of suddenly available water in South Bihar” was designed to focus on injecting surplus water available during the rainy season or during floods for recovery and use during dry periods. The ASR system is an effective tool to replenish depleted aquifers as well as a tool to reverse the falling groundwater tables and support sustainable intensification of agriculture. The system aimed at building resilience to climate change and to raise incomes from agriculture and allied activities. The main objective of this project was to demonstrate the technical viability of this technique and to deliver information for minimizing the uncertainties in planning and design for its future use.

To develop an understanding of the physical, chemical, and social aspects that affect the potential adoption of ASR in the South Bihar aquifer, we conducted primary fieldwork in selected villages of Rajgir block in Nalanda district of Bihar. This report presents the findings of the study conducted in South Bihar. The key components of the research work carried out in this project were:

- Identification of suitable sites for ASR installations in the Rajgir block
- A detailed groundwater level survey of selected sites before the ASR installation
- A detailed hydro-chemical characterization of the groundwater and surface water of the selected sites before the ASR installation
- A detailed hydrological mapping and geophysical characterization before ASR installation
- A quantitative survey of socio-economic indicators with around 80 households in the selected villages and qualitative interviews with farmers and other stakeholders at the local level for studying acceptability of ASR system

Based on geo-morphological parameters (i.e., rainfall, elevation, soil and aquifer characteristics, surface and groundwater quality) and socio-economic indicators (tacit knowledge, land ownership, willingness to participate), seven suitable sites were identified in two villages, Nekpur and Meyar of the Rajgir block, Nalanda, Bihar. The construction of seven ASR systems were completed in September 2020. The geophysical and geochemical characterization of the aquifer at the installation sites showed a highly heterogeneous nature of the aquifer. In both villages, the local community had supported the team in various ways. Focus group discussion, personal interviews and socio-economic surveys in the study area revealed the willingness of farmers to adopt and operate the new ASR systems. Overall, the project has demonstrated the feasibility of ASR in both hard rock and deep alluvial aquifers in the marginal alluvial plains of South Bihar.

A successful spread of ASR in South Bihar can augment usable water resources for agriculture during the winter cropping season. More importantly, ASR can adapt to local circumstances and challenges under changing climatic conditions. Based on the findings of this project, suggestions have been made for the potential application and adoption of ASR by farmers in similar hydrogeochemical and socio-economic conditions of South Bihar and other parts of India. This exploratory work generates interest for conducting long-term research on groundwater quality and quantity changes that may occur as a result of ASR.

3 Introduction

Climate change is altering India's hydrologic regimes, resulting in changed duration and frequency of severe floods and droughts (Goyal and Surampalli, 2018). The state of Bihar in India is especially vulnerable to floods and droughts, often leading to significant disruption in agriculture – the mainstay of people's life and property (Ward et al., 2014; Tesfaye et al., 2017; Jha and Gundimeda, 2019; Mishra and Sinha, 2020; Sahana et al., 2020). During the winter crops, especially wheat is particularly at risk due to the unavailability of reliable sources of irrigation and depletion of groundwater (Sharma, 2017; Kishore et al., 2017). Ensuring reliable irrigation sources is one of the major challenges for sustaining agriculture in South Bihar.

Bihar is one of the most populous states in India, ranked third after Uttar Pradesh and Maharashtra states. Approximately 89% of Bihar's population lives in the villages (Census of India, 2011). Bihar's per capita GDP in the year 2018-2019 was A$ 560 (INR 31,400), which was the lowest among the Indian states and way below the national average of A$ 1682 (INR 94,310) in 2012 prices based on the economic survey of 2018-2019 (Government of Bihar, 2019).

Geographically, the state is separated into two parts (North and South Bihar) by the river Ganges, whose southern tributaries such as the *Karamnasa, Durgawati, Sone, Punpun, Falgu, Harohar, Badua*, and *Chandan* rivers are seasonal, originating in the Chhotanagpur plateau, unlike the several perennial Himalayan rivers in the North. The annual rainfall in South Bihar (average 898 mm) is significantly low as compared to North Bihar (average 1,206 mm), and concentrated during the monsoon season (June-September months) (Guhathakurta et al., 2020). The annual rainfall variability is also wide, recording a maximum of 1,560 mm in 1971 and a minimum of 594 mm in 1992. While the overall water stress in South Bihar is acute during summers, it adversely affects the winter (*rabi*) crop, which is critically dependent on irrigation, primarily from groundwater sources. With an estimated 900,000 shallow and 1,700 deep tube wells constructed in the state (Jha and Sinha, 2009), groundwater has been the mainstay of irrigation in Bihar for quite some time (Sharma 2017; Sharma 2021). These numbers are estimated to have proliferated in recent years, accounting for significant farm investments, and often indebtedness. For instance, a large farmer invests an average of A$ 596 (INR 33,400) on the installation of tube wells, a marginal farmer invests A$ 350 (INR 19,600), according to a study in the Nalanda district of South Bihar, India (Singh et al., 2007).

As the need for more significant investments increases with increasing depth of tube-wells and a growing risk of failures due to limited aquifer capacity in the marginal alluvial plains, small and marginal farmers become more vulnerable. The percentage of landholding less than 1 ha has increased from 89% in 2005 to 91.2% in 2015. Farmers having less than 1 ha are categorized as marginal and those have a landholding between 1-2 ha as small farmers (NCAER, 2019; Sharma 2021) (Table 1). Most of these marginal and small farmers are economically weak. Approximately one fourth of Bihar's agriculture farmers income is under the poverty line (NCAER, 2019). These small and marginal farmers face severe socio-economic challenges to sustain their livelihoods in the region's rapidly changing agrarian economy (Singh 2013). Environmental stresses, including climatic variability and depleting groundwater sources, are further exacerbating their situation. Sustainable intensification of agriculture is not possible until irrigation sources are secured (Campbell et al., 2014), especially when farming has increasingly become dependent on groundwater in the state (Sharma 2017; Sharma 2021). Per capita GDP is one of the indicators of the economic growth and living standards of the people.

Table 1: Distribution of Operational Landholding in Bihar and India (Source: NCAER, 2019)

Operational Holdings (%)	**Bihar**		**India**	
	2005-06	**2015-16**	**2005-06**	**2015-16**
Marginal (<1.0 ha)	89.64	91.21	64.77	68.52
Small (1.0 - 2.0 ha)	6.67	5.75	18.52	17.69
Semi-medium (2.0 - 4.0 ha)	2.99	2.52	10.93	9.45
Medium (4.0 - 10.0 ha)	0.67	0.49	4.93	3.76
Large (> 10.0 ha)	0.03	0.02	0.85	0.57
All sizes	100	100	100	100

Several options, mainly variants of managed aquifer recharge (MAR) techniques, are being promoted in other parts of India and across the globe to enhance the depleted groundwater reserve through excess surface water in the rainy season (Shah, 2014; Dillon et al., 2019). Aquifer storage and recovery (ASR) is a well-known sub-surface technique to replenish depleted groundwater aquifers (Wilson 2007; Farid et al., 2018). However, the success of ASR is contingent upon the selection of appropriate sites based on the local hydrogeological, hydrometeorological, and socio-economical environments (Bandyopadhyay et al., 2021).

ASR can also be used for environmental benefits such as recharge of overexploited zones, control of deterioration of groundwater quality, and inhibit the destruction of the aquifer and land subsidence (Bagheri et al., 2020; Fan et al., 2020). Although relatively new, ASR projects have proliferated in several locations across India in response to needs of agriculture and domestic water supplies in overexploited regions of north Gujarat and southern Rajasthan (Shah 2014; Maheshwari et al., 2014), saline coastal regions of Tamil Nadu (Karunanidhi et al., 2019), and arid zones of Eastern India (Holländer et al., 2009; Boisson et al., 2014; Varua et al., 2016).

While various types of MAR techniques (such as *ahar-pynes*, farm ponds, and check-dams) are common in South Bihar, ASR has been proposed in the region that actively uses underground aquifers to store excess rainwater from the wet season for irrigation and for other uses during dry months. The ASR technique was piloted in two villages of Rajgir Block in Nalanda district of South Bihar, India during 2019-2021 by a multi-disciplinary team of researchers from Nalanda University (Bandyopadhyay et al., 2021). In this study, first, tentative sites were identified based on the available hydrometeorological and hydrogeological data, while specific sites were selected based on socio-economic field-data analysis (Maréchal et al., 2020). As appropriate infiltration/recharge pits are essential to prevent groundwater pollution due to the injection of contaminated water and possible clogging of the recharge system (Fan et al., 2020). The design shared with the stakeholder farmers, for installing ASR systems in the current study, included both infiltration pits and injection well at each selected site.

Before installing ASR systems in the piloted villages of Nekpur and Meyar, 137 wells (71 dug wells, 19 shallow-bore wells and 47 deep-bore wells) were monitored during 2019-20 to understand the seasonal water level variations. Most of the dug-wells and shallow bore-wells of the region were dried up during the winters, seriously affecting the *rabi* crop and even domestic water supplies. The villagers devised different coping strategies to tackle this seasonal water stress. A few economically better off and resourceful farmers opted for deeper bore-wells, whereas others had to rely on supplies received from water tankers and functional hand pumps for meeting drinking water and domestic needs. The deep bore-wells are generally a perennial water source, but they are expensive; moreover, only about one in four deep bore-wells are productive in Nekpur village.

Seasonal water availability determines the cropping pattern in South Bihar, since agriculture in the region is predominantly rainfed; even though increasingly the reliance on groundwater is increasing. Farmers in the low-lying areas can cultivate pulses (such as gram, green gram, lentil, mustard) during *rabi* season only after draining excess water from the land. On the other hand, farmers on higher reaches can cultivate two crops, usually paddy during *kharif* (June-October) and wheat, maize, onion, and other vegetables during *rabi* (October-March). ASR systems in those villages using the excess waters from low-lying farmlands could help the *rabi* crop and allow an additional harvest during *zaid* (March-July) by recovering the water stored in the aquifer. A socio-economic survey was conducted among farming communities of selected villages revealed a collective interest in ensuring the availability of water during *zaid* season. The individual willingness to contribute for installation of the ASR system was a maximum of A$ 890 (INR 50,000). Although it may not be adequate to cover the cost of a deep bore-well (A$ 1,500-1900), it may be enough to convert some of the defunct deep bore-wells owned by their neighbours into ASR structures for recharge and recovery managed by the users.

For this pilot study, seven entrepreneurial farmers (EFs) were identified in the two villages who formally agreed to own and operate the new ASR systems. The EFs, typically semi-medium, medium or large active farmers (holding more than 2 hectares of land) with deep bore-wells, whose primary source of family income was agriculture, were keen to protect and augment their farm incomes through assured irrigation. They had evaluated the potential of ASR, created their stakes through contributions, and negotiated the sharing of risks with their neighbours. Such arrangements ensured the land availability for construction and financial contributions necessary for the operation and maintenance of the ASR structures in future. Besides, clear ownership allowed bottom-up technological and design innovations, which might have moved the energy and water efficiency of ASR.

Objectives

- To study the rate of infiltration, the quantity of storage/recovery and transmissivity processes of contamination associated with aquifer storage and recovery (ASR).
- To assess the effectiveness of the recharge pits (as part of ASR) technologies for conjunctive use in the agriculture sector in South Bihar.
- To estimate user satisfaction, economic benefits, social acceptance and opportunities for the spread of recharge technologies through government schemes and market-based mechanisms.

4 Methodology

The methodology for the implementation of ASR includes the scientific understanding of groundwater recharge and recovery and developing an in-depth understanding of the socio-economic and cultural changes taking place in the selected villages of South Bihar. The study area, primary data collection, and secondary data collection are explained in the following section.

4.1 Study area

Nekpur and Meyar villages of Rajgir (district Nalanda) in the South Bihar region of India were selected in this study (Figure 1). Nalanda is one of the prominent agrarian districts in Bihar and agriculture is a key source of livelihood in this region. The main crops in the district are paddy, wheat, pulses, and vegetables (such as onion, potato, okra, and bottle-gourd). Nalanda is drought-prone due to anomalies in rainfall, often experiencing water scarcity during the summer season. Drinking water needs are primarily met from groundwater sources, while irrigation needs are fulfilled by seasonal rain mostly during June-September and by groundwater for the rest of the year. In recent years, the local communities have invested in deep borewells, many of which fail to provide an assured source of water. For instance, presently, there are 18 functional deep borewells in Nekpur village and 33 deep functional borewells in Meyar village. However, there are also 18 failed borewells (i.e., borewell was dug unto 200 m in the fractured aquifer by the farmer to search water for irrigation but they couldn’t produce any water) in Nekpur village attempted since 2018. Water scarcity and unreliability of groundwater have emerged as a crucial threat to the sustainability of agriculture in the region, dominated by small landholders and marginal farmers.

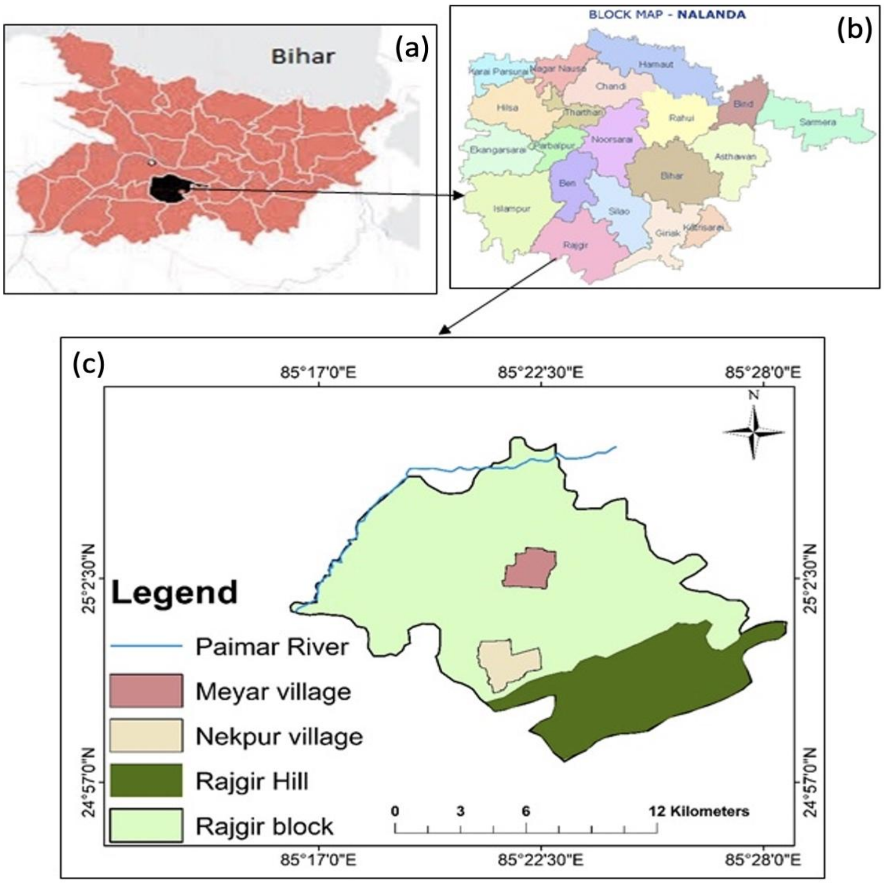


Figure 1: Location of the Nekpur and Meyar village in Rajgir block of Nalanda, Bihar, India (a) Bihar state (b) Nalanda district (c) Rajgir block

The study area is known for chronic water shortage during summer and is categorised as a semi-critical area by the Central Ground Water Board (CGWB) due to over-exploitation of groundwater. The severe water shortage is a direct result of the competitive and indiscriminate extraction of groundwater, coupled with prolonged drought conditions. Therefore, groundwater renewal through artificial recharge (such as ASR) is inevitable for the long-term sustenance of agriculture and the sustainable livelihood of farmers in the region.

4.2 Primary data collection

An ultrasonic water level recorder has been used to measure the depth of groundwater level in wells (dug wells, shallow bore wells, and deep bore wells) during the post- (October) and pre- (March) monsoon seasons for the years 2019 and 2020 (Figure 2). In this study, a total of 96 wells in Nekpur village and 27 wells in Meyar village were monitored to explore the seasonal and temporal variability in the groundwater level. A raster map of the depth to groundwater level was developed within the ArcMap environment and interpolated using the Inverse Distance Weighted (IDW) interpolation method.

Figure 2: Water level measurement in (a) Nekpur and (b) Meyar village

Four surface water samples were collected from the *ahars* of each village to understand the quality of source water being used for ASR techniques. As the water quality within the aquifer is also an important consideration for understanding possible interaction with the recharged water, more than 20 groundwater samples from the selected villages were collected and analysed in this study. The common water quality parameters examined were pH, electrical conductivity (EC), dissolved oxygen (DO), total dissolved solids (TDS), total hardness (TH), nitrate, total organic carbon (TOC), total nitrogen (TN), chloride, and total solid for both surface and groundwater samples. In the laboratory, pH, EC, DO, and TDS were measured using analytical instruments (Multiparameter, EUTECH 450). TH, chloride, and nitrate were analysed using titrimetric methods; TOC and TN were measured using TOC analyser (TOC-L, Shimadzu).

Land use and elevation maps were prepared using Google Earth and Digital Elevation Map (DEM) for a detailed understanding of suitable land availability. The maps were further derived with the help of the IDW method of interpolation within the ArcMap environment. Lithological data were collected from the farmers during the survey which was later complemented with soil sieve analysis using the soil samples collected during borewell drilling operation. The soil samples were collected during the construction of borewell at 3 m intervals from each ASR site up to 92 meters (Figure 3).

Figure 3: Soil samples collected during the borewell construction: (a) sieved sample (b) original sample

Drilling of seven borewells has taken place at the selected sites in both the villages by civil contractors which were selected based on a chosen set of parameters (Figure 4).

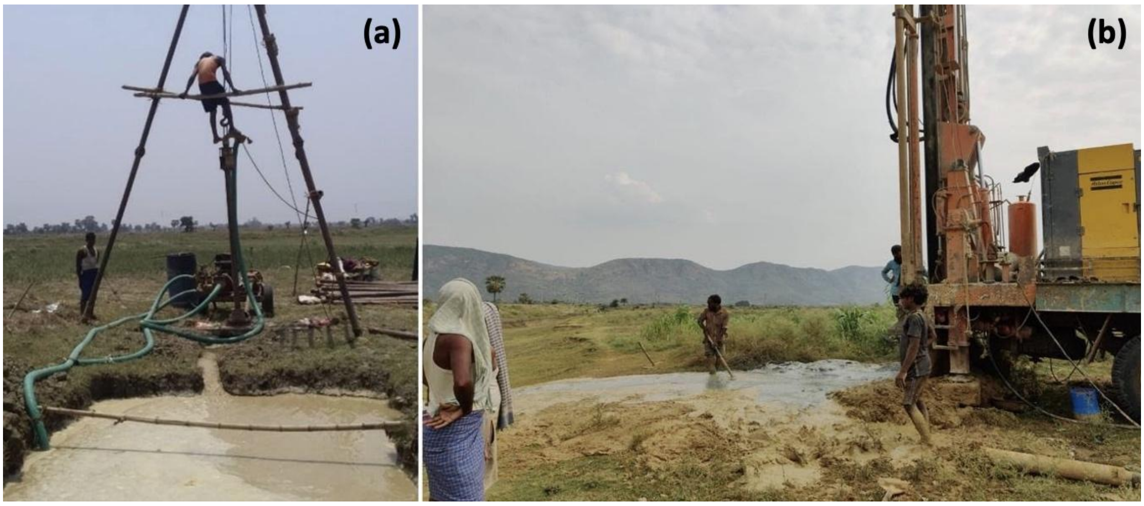


Figure 4: Drilling of borewells in (a) Meyar in consolidated materials and (b) Nekpur in hard rock

The recharge pit was co-designed with active inputs from the villagers. The farmers were supposed to maintain the recharge pits and the long-term sustainability of the pits demanded active involvement and participation of farmers. Locally and easily available replacement materials were used in the construction of the pits, like sand, bricks, mesh, gravels, activated charcoal (Figure 5).

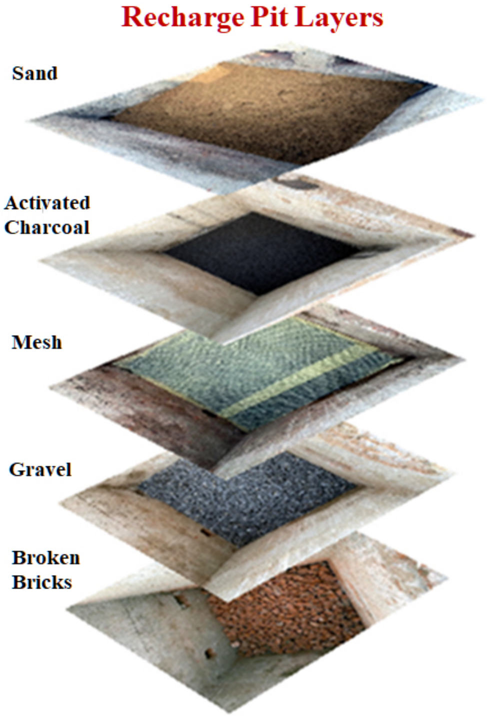


Figure 5: Used materials in recharge pits

The farmers, contractors, labourers had supported Nalanda University during various surveys as part of this project. Junior research fellows (JRFs), Mr Anurag Verma and Mr Ashutosh Kumar were involved in dug-well and borewell identification, water level monitoring, surface and groundwater sampling, socio-economic survey and life history interviews. JRFs got help from all project coordinators and Senior Research Fellows (SRFs) during life-history interviews. The JRFs and SRFs were trained by the project coordinators before the initiation of the fieldwork. Graduate students also volunteered in socio-economic surveys and groundwater monitoring.

Total 24 life history interviews were conducted with senior farmers in the age bracket of 50 to 85. The life history method was used to understand the environmental and agrarian change that has happened over the decades in the region. Life history methods have increasingly been used to study long-term changes from a grassroots' perspective. Purposive sampling was used to select the respondents. The interviews lasted between 30 minutes to 1 hour and 10 minutes. Around 6 semi-structured interviews with key farmers in the village and 80 socio-economic quantitative surveys were conducted in Nekpur and Meyar (Figure 6). The land holding of landowners in the quantitative interviews ranged from 0.65 to over 32 ha. It was done to estimate the willingness of villagers to adopt new technology and mapping of technological change happening in agriculture. In addition, we tried to understand the vulnerabilities being faced by the farming community. In addition, we drew from participant observations and have done extensive photo documentation of the study sites. Observational methods were extremely useful to understand the local context and the everyday lives of farmers and other groups in the villages. We have conducted multiple visits of the houses, farms, common public places in the selected villages, and the office premises of local administration for collecting the primary data.

Figure 6: (a) Socio-economic survey work and (b) life history interview with elder villagers (with farmers of age more than 50)

4.3 Secondary data collection

Rainfall data of South Bihar for the last seven decades (1958-2018) were collected from the Indian Meteorological Department, India Water Portal, Rainfall Statistics of India (Kaur and Purohit 2015).

Socio-economic data at the household level of the two villages, i.e., Nekpur and Meyar were collected from Census 2011, Government of India. We focused on aspects such as the size of the working population, household size, gender, literacy, housing, sanitation, assets, drinking and irrigation facilities.

The following flow chart (Figure 7) presents the overall data collection process and steps involved in the installation of the ASR system at selected sites. The process started with initial survey and community mobilization, which eventually led to the development and installation of ASR systems at suitable locations for effective recharge and possible recovery of recharged water by the farmer.

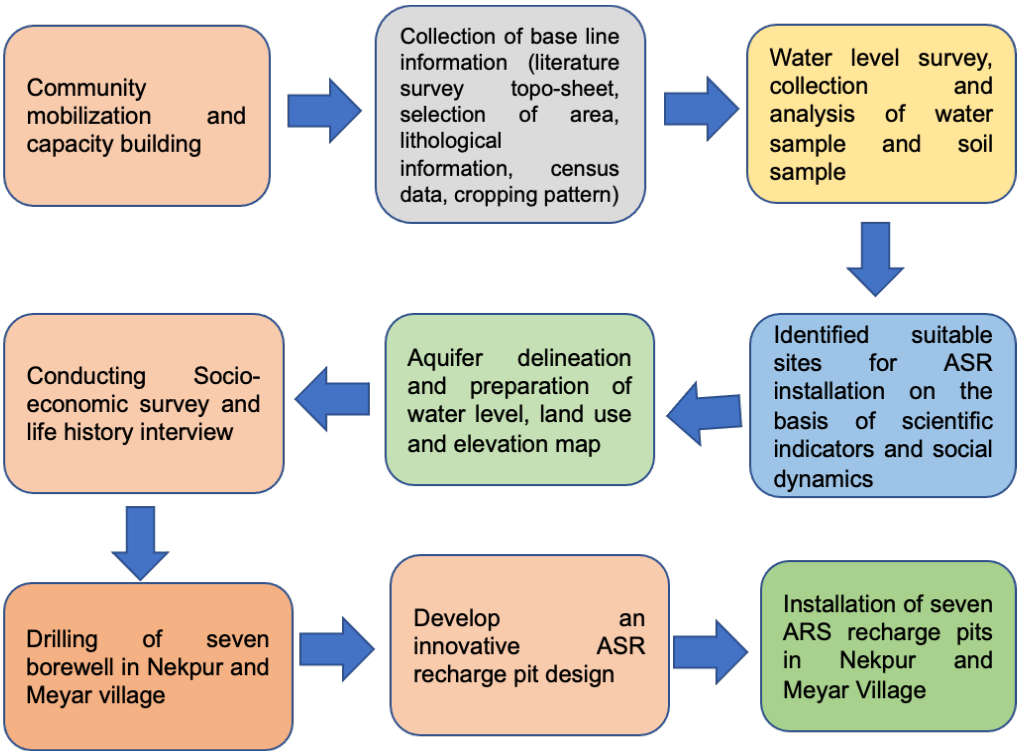


Figure 7: Process of ASR installation plan

5 Achievements against Activities and Outputs/milestones

Objective 1: To study the rate of infiltration, the quantity of storage/recovery and transmissivity processes of contamination associated with aquifer storage and recovery (ASR)

no.	activity	outputs/ milestones	completion date	comments
1.1	Background studies - Training - Cross-learning - Literature review - Laboratory experiments	- project team oriented and trained in MAR - learnt from other similar projects, e.g., *Bhungroo* and MARVI - reviewed the implementation of ASR in India - identified parameters for site selection - conducted an inception workshop - identified project sites - set up column experiments	Jul 2019	Online course of MAR, conducted by the International Centre of Excellence in Water Resources Management (ICE WaRM) and Australian Water School, facilitated by ACIAR Key persons from Naireeta Consultants and MARVI visited Rajgir Draft manuscript under preparation and review Identification of, and assessment methods for, critical parameters such as elevation, source of recharge water, rainfall, land use pattern, lithology Infrastructure constraints, social acceptability and adaptation and availability of electricity connection near ASR site Identified sites in two villages along a defined social and environmental gradient Data analysis continuing (delayed due to COVID restrictions on the use of laboratory) but this is being supplemented by theoretical calculation of total recharge which will be verified by automatic discharge reading by the installed flowmeter at each site after the next monsoon season.
1.2	Baseline assessment - Secondary data-based - Primary data-based	- environmental variability assessment (e.g., rainfall across seasons/ years) - landscape and aquifer assessment (e.g., mapping of elevation/ land use/ water level/ aquifer) for project sites	Feb 2020	Draft publications: Verma, P.; Sharma, P.; Verma, A.; Sharma, A.; Bandyopadhyay, S. 2021. An integrated site selection model for aquifer storage and recovery. J. Hydrol. (in Review)

no.	activity	outputs/ milestones	completion date	comments
		- guidelines for ASR site-selection - soil analysis (depth-wise) - socio-economic assessment		
1.3	Field Interventions - ASR installation - Community participation	- 7 recharge pits, and recharge bore-wells, were constructed - the lead farmer model was used to ensure clarity in ownership, stakes, and contractual obligations in operation and maintenance - design innovations were encouraged through a process of co-creation	Sept 2020	Seven recharge pits were constructed at the sites of newly constructed bore wells to allow recharge of filtered water. The cost of ASR system for a farmer of this region would be about A$ 4,000 however constructing a recharge pit alone with the available defunct borewell would only occur about A$ 800. The recharge pits were indigenously designed and aimed at reducing costs significantly compared to the existing models of water recharge pits. These recharge pits were designed to measure the volume of water recharge and water recovery via the new bore wells. The complete installation of ASR couldn't be completed before the monsoon season of 2020 due to COVID restrictions and heavy rainfall (flash flood situation) during the ASR construction. Each recharge pit was owned by a group of four to five farmers. Each of them had legally accepted the terms of management and proportionate use of recharge pits based on their relative contribution in operating costs.

PC = partner country, A = Australia

Objective 2: To assess the effectiveness of the recharge pits (as part of ASR) technologies for conjunctive use in the agriculture sector in South Bihar

no.	activity	outputs/ milestones	completion date	comments
2.1	Background Studies	Analysis of secondary data and academic literature for formulating conceptual frameworks and scope of ASR for augmentation of	Sept 2020	The recharge pits were installed to carry groundwater recharge functions as well as allow recovery of water for irrigation. Based on the depth and dimension of filter materials used in the recharge pit, the total recharge volume for each ASR was estimated. It was approximately 10.5 x 10^7 L per season when it was submerged for about 30

no.	activity	outputs/ milestones	completion date	comments
		groundwater and reduction of water- logging during intense rainfall		days (detail calculation is included in the Appendix). The proportion of recovered water are expected to vary in both villages. Since, the fractured aquifer in Nekpur village was completely dry so the loss of recharged water may be less but the recovery efficiency may be relatively less for the alluvial aquifer of Meyar village. This will have a direct impact on irrigation. It may be expected that the farmers can get sufficient irrigation supply in the months of peak summer (March to June end) in the study area. The complete installation of ASR couldn't be completed before the monsoon season of 2020 due to COVID restrictions and heavy rainfall (flash flood situation) during the ASR construction. Recharge pits would recharge the deeper aquifers which have capacity to hold water for much longer periods in comparison to shallow aquifers. It would also help to manage the flood water during the rainy season that will have helped farmers to grow crops during waterlogging periods which is generally inundated for two to three months.
2.2	Baseline Assessment	Understanding environmental changes and agrarian changes at local level - scope of ASR installation and potential adoption of the technology by farmers	Dec 2020	Changes in cropping pattern and crop production was analysed Increase in the quantity of water stored in aquifers would help the farmers for the second or third crop in a year. Recharge pits will allow the farmers to utilize additional 3 months in farming, it may be expected that the farm income for an average farmer will increase by 25-30%. As recharge pits would make the irrigation much more reliable, one should expect the farm yield to fluctuate much less by mitigating the effects of rainfall uncertainties increasingly induced by climate change.
2.3	Interventions	Finalization of ASR design and farmer led model for ASR adoption among farmers	April 2020	Villagers accepted the urgency of the groundwater recharge, as more borewells will deplete the water table further. Showed interest to adopt the ASR technology for failed borewells as well as new or existing borewells. This may save the cost (upto 70 %) of drilling a new borewell for an ASR. Farmers are experiencing the groundwater shortage, and the depth of the new borewells are increasing. The average depth of the new borewell in the Nekpur and Meyar villages were

no.	activity	outputs/ milestones	completion date	comments
				observed as 120 m and 50 m in 2019 and 150m and 60 in 2020 respectively. During the socio-economic survey, farmers expressed their concern about the groundwater depletion and expressed their willingness to pay for the groundwater recharge pits.

PC = partner country, A = Australia

Objective 3: To estimate user satisfaction, economic benefits, social acceptance and opportunities for the spread of recharge technologies through government schemes and market-based mechanisms

no.	activity	outputs/ milestones	completion date	comments
3.1	Background Studies	Analysis of secondary data and academic literature for understanding technology adoption	Jun 2020	Localized solutions were required for addressing water stress and augmenting irrigation infrastructure.
3.2	Baseline Assessment	Focus group discussions with villagers, personal interview with farmers, and socio-economic survey was conducted to understand social acceptance, economic benefits and potential adoption of technology	Oct 2020	All the above experiences and observations made during focus group discussions and personal interviews strongly suggest the wider need and social acceptance of the proposed technology which promises water availability. The villagers' suggestion about challenges caused by running water was considered and suitable change was made into the ASRA pit design to prevent the filtration chamber from choking with mud and soil impurities.
3.3	Interventions	Entrepreneur Farmer Led Model - Problem and Benefit Sharing at local level Revival of defunct borewells as ASR systems	Dec 2020	Groundwater monitoring and potential estimation are very important for groundwater development by the State and Central Groundwater Organization to support the construction of wells through the appropriation of funding. A groundwater monitoring system can generate basic data for the evaluation of the hydrologic system. This kind of generated data to improve accessibility for academics, non-governmental (NGOs), and government agencies. The villagers including the partner farmers in ASRA project were made aware about the role of collective oversight, periodical maintenance of recharge pits and need for wide adoption of such technology for sustainable irrigation. The artificial groundwater recharge areas are planned to be investigated in detail where water levels are declining.

no.	activity	outputs/ milestones	completion date	comments
		Creation of user's group for monitoring and information sharing among users		The extraction reduction is very significant for physical response capable of arresting the decline in the water level. It can be understood as limiting the physical capability to extract water. To increase efficiency improvements for reducing water demand without reducing the service provided. It can generate real water saving for reallocating available water.

PC = partner country, A = Australia

6 Key Results and Discussion

Initially, large-scale regional data on climate, topography, and aquifer characteristics were analysed using geospatial domain in GIS to develop the first order of confidence in initiating the ASR project. This initial knowledge (i.e., geospatial data analysis) formed the basis for site visits (i.e., selection of two villages in this study) and conversations with the local community, usually in public places such as the local temples, community halls/spaces, and agricultural centres. The initial conversations generally covered local demography, social structure, economic activities, and other lived experience (i.e., collected through group discussions). Subsequent conversations focused on specific farmers in different landholding categories to understand cropping patterns, irrigation issues, and external interventions through individual surveys of shortlisted farmers and village officials. Most of the farmers were not only familiar with borewell construction but were also concerned about the investment risks.

The idea of ASR application was an instant cause for excitement among the farmers who realised its benefits in reducing risks and obtaining significant control over groundwater irrigation. Local knowledge provided a comprehensive understanding of the current land use, soil characteristics, cropping pattern and water use, and a focused understanding of the groundwater hydrology, aquifer characteristics, and possible site locations. Finally, the broad participation of the village community was replaced with a focused conversation with identified farmers on the various terms and conditions for participating in the project. Eventually, contracts were drawn up specifying the beneficiary contributions and sharing of benefits.

The twelve parameters, explained in table 2, were used to make decisions regarding not only the location of the specific sites but also the amount of water available at the site for recharge, the appropriate depth of borewells and design of the filtration unit (recharge pit). It is evident that the hybrid, but integrated model for site selection covering both scientific and social science data collected from secondary and primary sources enable the implementers for ASR to be more successful. This pioneering study attempted to identify the process and the parameters necessary to select sites that might be suitable for the construction of ASR. The study recognises the potential for rapid scaling-up of ASR interventions in the region through private and public investments and, therefore, has carefully integrated several water qualities measures in a structured manner (Bandyopadhyay et al., 2021).

Table 2. List of 12 essential parameters considered for ASR site selection conceptual model

Indicators	**Water availability (seasonal/sudden)**	**Aquifer storage potential**	**Land suitability**
Geomorphological assessment	Rainfall patterns, Surface elevation	Groundwater depth .	Land-use pattern
Field and lab-based assessment	Runoff generated, Water quality (Surface & Groundwater)	Aquifer characteristics	Soil characteristics
Field-based socio-economic surveys	Local knowledge (on surface water bodies)	Local knowledge (on aquifers and recharge potential)	Landholding and willingness to participate, Infrastructural considerations

Indicators	**Water availability (seasonal/sudden)**	**Aquifer storage potential**	**Land suitability**
Critical decisions	Amount of recharge	Depth to storage	Design of filtration unit

Following the developed methodologies, Nekpur and Meyar villages of Nalanda district in South Bihar region of India were selected for the ASR pits installation. Figure 8 indicates that 92% of the 362 mm average annual precipitation in the selected area occurs during the rainy season, i.e., June, July, August, and September. The amount of rainfall, in the context of other climatic factors (such as temperature, wind speed), is insufficient for supporting the *rabi* (winter) crop, which is dependent on groundwater extraction. Therefore, the possibility of aquifer storage and its utilisation through ASR installations was a perfect solution for this region.

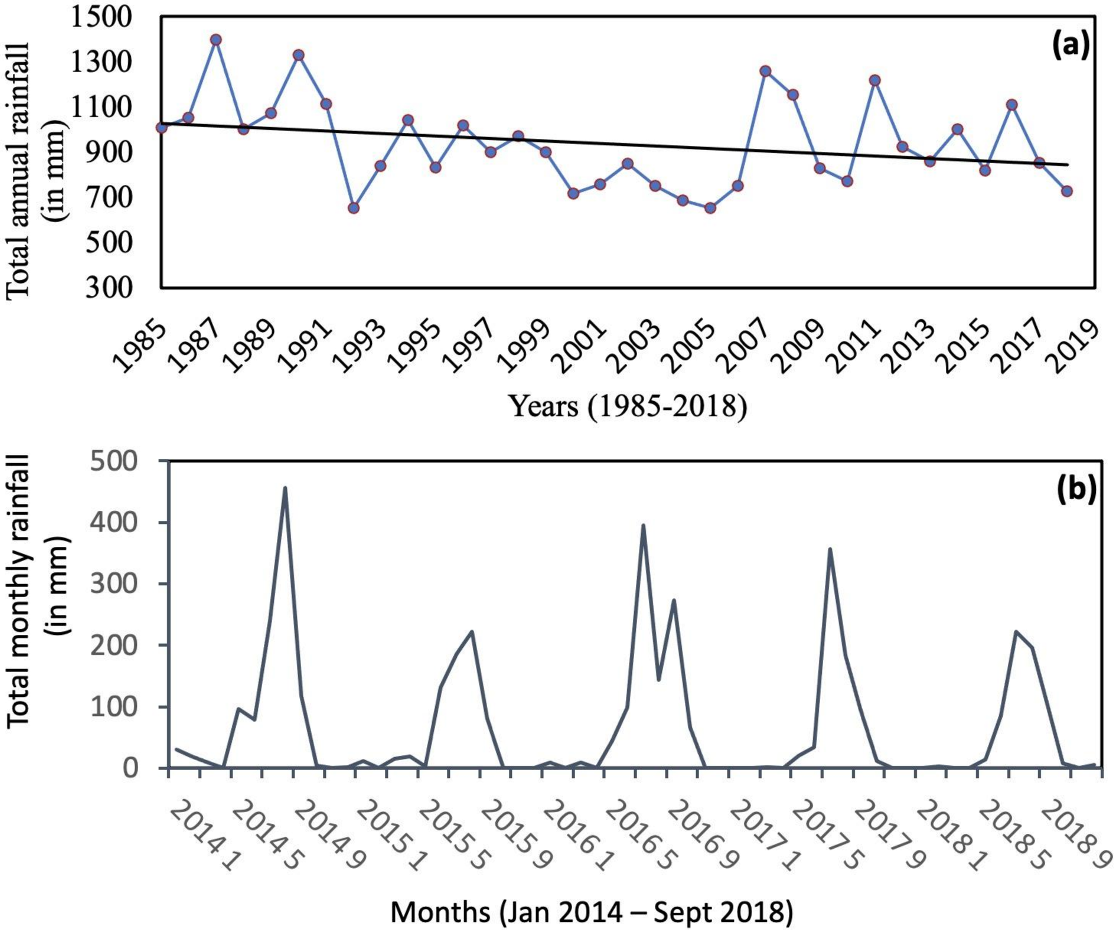


Figure 8: (a) Annual average and (b) monthly average rainfall of Rajgir, Nalanda, Bihar, Source: Kaur and Purohit 2015.

The land use and elevation of the proposed ASR site were critical factors in the movement and collection of surface water because areas of higher comparative elevation generate runoff and decrease the rate of infiltration. Bhuiyan (2010) had suggested that groundwater recharge can be more effective in areas with comparatively lower elevation. According to the surface elevation maps for both the villages, Nekpur revealed a higher variation in the elevation than Meyar village. Surface elevation in Nekpur village ranged between 67-80 m, while in Meyar it was 64-69 m only (Figure 9). In both the villages, the surface elevation is lowest at the *ahar* that are created in low-lying areas to collect the runoff water. The installation of ASR was more suited for areas with lower elevation (indicated in dark green colour in figure 9) as compared to areas with a higher elevation that was characterised by more significant surface runoff and lesser retention.

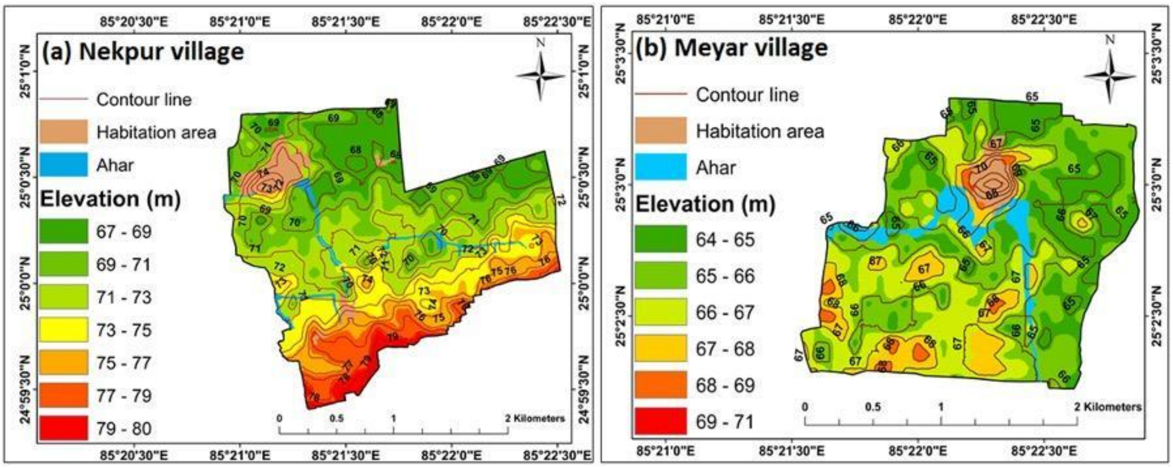


Figure 9: Elevation map for (a) Nekpur and (b) Meyar village

The proximity of the proposed ASR sites to the existing source water provided an opportunity for gravity flow, minimising their installation and operation costs. A minimum distance of source water from the ASR should be the least expensive due to transportation costs. However, in both the selected villages in the current study, the recharge water source (*ahar*) was within 100 m of the proposed ASR locations.

About 92 % of the total land area is cultivable in both the villages (Figure 10). This ASR project aims to provide irrigation water for agriculture and create an opportunity for farmers of the region to raise their incomes from agriculture and other economic activities through assured irrigation from the reuse of water stored beneath the surface. So, agricultural lands near the *ahar*s in both villages were appropriate for this project.

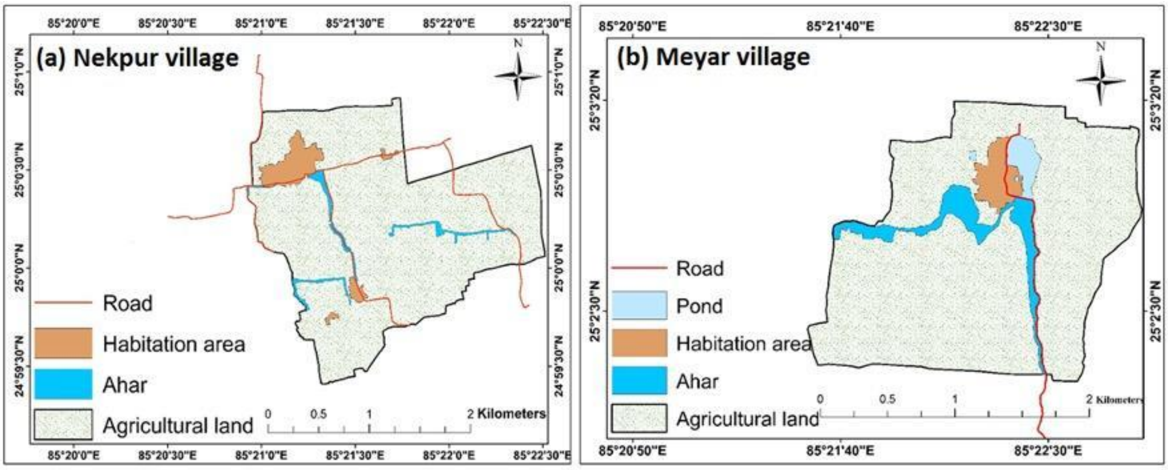


Figure 10: Land use map for (a) Nekpur and (b) Meyar village

The depth of groundwater levels was mapped to assess the water storage capacity and appropriate depth of water injection. The groundwater table should be sufficiently deep in an unconfined aquifer so that adequate storage space in the vadose zone is available to accommodate the recharged water. Zare and Koch (2014) postulated that artificial recharge should not be considered for depths to groundwater tables less than 3 to 4 m, as it may cause additional water-logging, leading to economic, and environmental losses, often affecting human health because of increase in salinity.

During the pre-monsoon season in Nekpur village, the depth to water level ranges from 2 m below the ground surface only at the southeastern and northwestern side of the village to a maximum of 20 m below ground surface at the northern part of the village near the habitation area (Figure 11a). In Meyar village the depth to water level ranges from 3.7 m below the ground surface at the northwestern side of the village to a maximum of 10 m below the ground surface at the southern part of the village (Figure 11b).

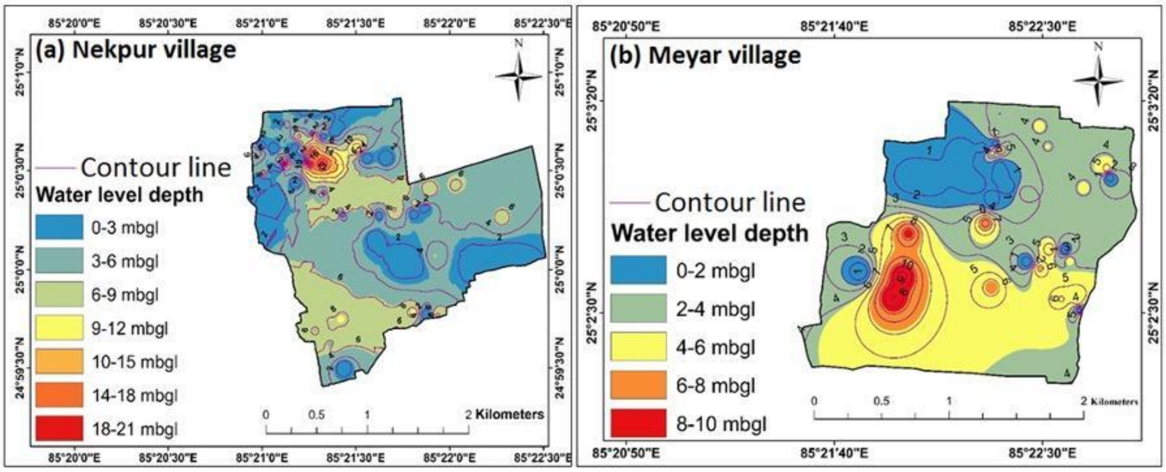


Figure 11: Depth to water level map for (a) Nekpur and (b) Meyar village

During 2019–2020 in Nekpur and Meyar village, groundwater levels were also analyzed to understand the seasonal water level variations. Most of the dug-wells and shallow borewells of the region dried up during the winters, seriously affecting the rabi crop and even domestic water supplies. This is clearly evident from the seasonal variation of groundwater level in one of the piloted village in this study (Figure 12). The figure indicates a sharp decrease in groundwater level measured in a number of open dug wells and deep borewells. For the selected year of this study, the groundwater level is the nearest to the ground surface in the month of October due to late rainfall in September 2019 in this region (Figure 12). For Nekpur, groundwater was shallower in the agricultural area after the monsoon season, implying that any additional recharge may not be feasible even after fulfilling all the site selection criteria discussed in the previous section. It was, therefore, important to further explore the complete aquifer characteristics through detailed lithological investigation to find out the exact recharge locations for ASR. For Meyar village, groundwater was sufficiently deep even after the monsoon season indicating that the aquifer should accept the proposed amount of recharge. The exact depth location of recharge is further understood using lithological investigations discussed in the following paragraph.

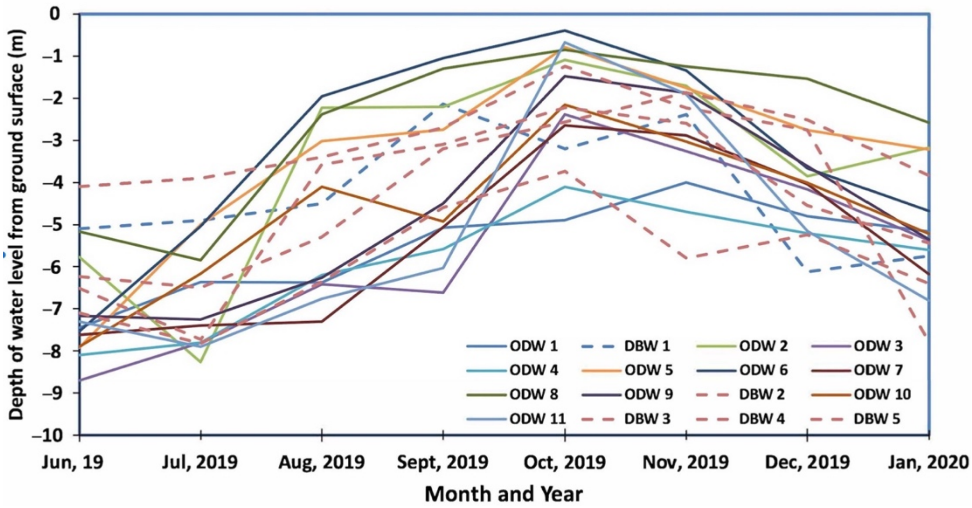


Figure 12: Seasonal groundwater fluctuations in Nekpur village for 10 ODW (open dug well) and 5 DBW (deep borewell) for year 2019

The lithological details of Nekpur and Meyar villages are shown in figure 13. In Nekpur, the thickness of the sand, clay and weathered rock is thinner and ranges from 0 to 33.5 m, while the bedrock starts from 33.5 m. In this area, groundwater also gets emptied quickly from the upper aquifer (up to 33.5 m depth) after the first irrigation event due to the absence of thick sand layers. Besides, the groundwater table was very shallow in Nekpur just after the monsoon (as mentioned in the previous paragraph) suggesting that the bedrock with fractures (below 33.5 m depth) could be considered for aquifer recharge.

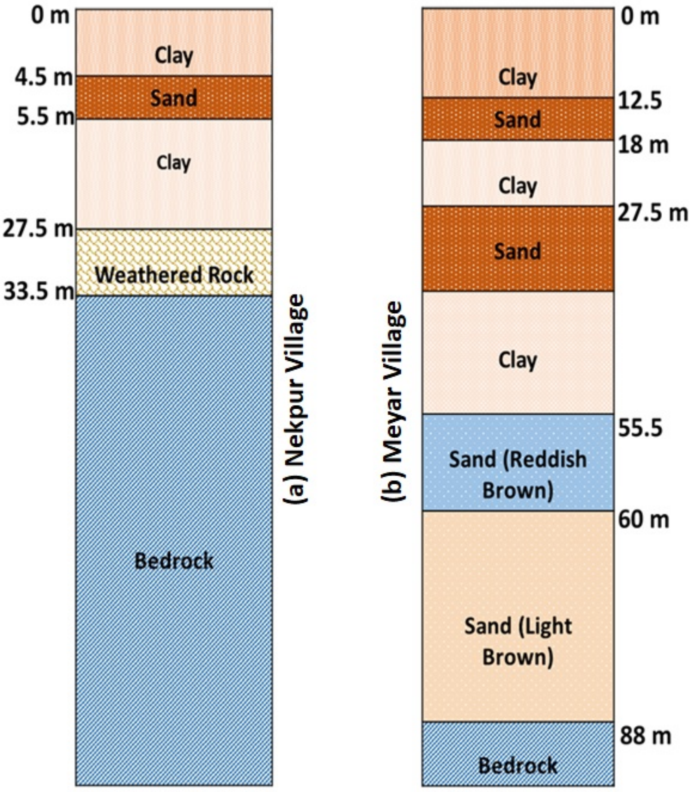


Figure 13: Lithological detail of (a) Nekpur and (b) Meyar village

In Meyar, the thickness of the sand and clay layers are thinner and range from 0 to 27.5 m, while below that there is one thick layer of sand ranging from 27.5 to 39.5 m, which is followed by a thick clay layer (about 15 m thick). However, the aquifer thickness in Meyar ranges from 55 to 88 m and was more appropriate for the water injection and storage in ASR. The data on aquifer properties were obtained from sieve size analysis of the collected soil samples during borewell drilling at both the villages. To further understand the capacity of recharge volume, pumping tests and flowing fluid electrical conductivity (FFEC) logging are proposed to estimate the actual transmissivity of the conductive aquifers after harvesting of wheat crop in April-May 2021.

In addition to the quantity of groundwater recharge, the quality of the injected water and the final groundwater quality are critical. Several groundwater samples from the existing groundwater wells were collected from both villages as part of the ASR site selection criteria. Most of them were well within the prescribed drinking water limits (Table 3). The quality of the proposed recharged water in the *ahars* of Nekpur and Meyar villages were also monitored and critically analysed (Table 3). As per the WHO guidelines for irrigation water quality, all the parameters were within the permissible limit, for drinking water quality, TDS, TH, Mg^{2+}, Nitrate, and Chloride were slightly high for some of the wells in both villages. The pH of *ahar* water was also high so it is important to monitor the groundwater quality changes of the surroundings after the proposed recharge. It should be noted that the surface water samples from the *ahars* were collected in October 2019 allowing the suspended sediments to settle over several days. The actual TDS and TS in fresh runoff water proposed for the recharge could be relatively higher. In order to overcome the high doses of suspended sediments, a temporary settling tank was added to the design of the recharge pit at each ASR site.

Table 3: Water quality parameters for groundwater and surface water (*ahar*)

Location	Well type	Well depth (m)	Latitude	Longitude	pH	EC (µS/cm)	TDS (ppm)	DO (ppm)	TH (ppm)	Ca2+ (ppm)	Mg2+ (ppm)	Sulfate (ppm)	Nitrate (ppm)	Chloride (ppm)	TS (ppm)	TOC (ppm)	TN (ppm)
Nekpur village																	
N1	ODW	<10	85.36	25.01	8.1	703.7	284.4	8.9	200	25.63	33.03	0.22	270.13	25.99	0.382	8.2	121.4
N2	ODW	<10	85.37	25.00	8.5	756.7	306.8	8	234	22.42	43.24	0.01	88.63	37.99	0.352	7.4	12.5
N3	DBW	108	85.36	25.00	7.4	526.1	214.2	3.2	184	44.04	17.97	-0.43	10.98	45.99	0.252	5.6	1
N4	SBW (HDP)	21	85.36	25.00	7.8	624.6	262.4	4.27	220	53.65	20.89	-0.66	70.08	59.98	0.358	5.1	10
N5	ODW	<10	85.36	25.00	7.7	1363	**553.6**	4.52	494	36.84	97.65	5.22	196.28	285.91	0.978	13	35.7
N6	ODW	<10	85.36	25.01	8.3	825.7	334.7	7.9	186	41.64	19.92	2.44	113.61	43.99	0.662	12.1	17.1
N7	DBW	115	85.37	25.01	7.4	786.3	322.9	10.1	290	24.02	55.87	-0.22	44.25	59.98	0.326	11	5.6
N8	ODW	<10	85.36	25.01	8.2	326.1	132.8	7	80	23.22	5.34	1.37	25.79	83.97	0.032	5.4	4
N9	DBW (HDP)	27	85.36	25.01	7.9	1902	831.7	3.1	276	24.82	51.98	50.68	18.35	339.89	2.002	14.5	1
N10	DBW (HDP)	31	85.35	25.01	7.5	2070	801.7	6.7	362	28.83	70.44	22.18	261.87	449.86	1.508	16.4	75.4
N11	SBW (HDP)	<10	85.35	25.01	7.6	2040	821.8	5.8	344	38.44	60.24	31.81	73.01	479.85	1.76	12.4	9.8
N12	DBW (HDP)	29	85.35	25.01	7.1	4320	1764	9	1034	84.08	200.15	44.14	286.65	99.97	3.29	17.3	394.3
N13	ODW	<10	85.35	25.01	7.7	809.2	328	4.51	212	33.63	31.09	5.70	140.47	79.98	0.452	9	22.6
Ahar 1			25.00	85.36	9.6	382.9	155.3	13..8	70	20.02	4.86	4.61	10.93	89.97	0.165	6.886	3.482
Ahar 2			26.01	85.36	9.1	199.8	81.09	10.14	0	NA	NA	1.46	34.59	63.98	0.4105	12.86	4.402
Ahar 3			25.00	85.36	9.2	287.3	116.5	11.4	50	16.02	2.43	1.55	10.80	69.98	0.1215	7.07	2.25
Meyar village																	
M1	DBW	83	25.05	85.38	7.5	771.8	313.6	6.7	272	40.84	41.29	10.02	243.00	159.95	0.438	4.68	50.58
M2	DBW	50	25.05	85.37	8.3	2281	887.1	6.2	216	20.82	39.84	39.77	85.34	669.79	1.638	9	9.05
M3	DBW (HDP)	50	25.05	85.37	7.7	3931	1600	4.4	380	25.63	76.76	46.03	357.76	959.70	2.636	7.73	1986
M4	DBW (HDP)	50	25.05	85.37	7.6	2742	1120	4.3	436	33.63	85.50	40.94	284.19	449.86	1.712	5.14	291.4
M5	DBW (HDP)	50	25.05	85.37	7.7	1589	646	3.6	258	38.44	39.35	31.61	266.47	267.92	0.976	11	87.13
M6	DBW	50	25.05	85.37	7.7	1135	458	4.7	230	41.64	30.61	4.81	78.64	163.95	0.15	5.7	6.84
M7	DBW	76	25.05	85.37	7.6	997.8	401.3	3.9	320	36.04	55.87	6.44	58.19	157.95	0.556	9.31	8.43
Ahar			25.04	85.37	9.3	883.1	356	9.18	82	20.02	7.77	17.50	17.66	205.94	0.6065	11.83	4.187

Although the surface water quality proposed for aquifer recharge was within the acceptable limits at the selected sites in this study, it is crucial to be extra cautious even while recharging in the agricultural zone for irrigation purposes. A recharge pit was designed for the ASR systems at all the locations with four layers of filtration mechanisms, as shown in figure 14. It is planned to test the efficiency of the filling materials used in the recharge pit through the ongoing column transport experiments with the original recharge water collected from the *ahar*. The first layer consists of coarse sand for removing the mixed clay or other dissolved matter, the second layer consists of activated charcoal for reducing the dissolved salt, and similar compounds, while the third and fourth layers consist of gravel and broken puffed bricks respectively to allow smooth injection of recharged water. As a precautionary measure, a control valve was attached for the emergency closure of recharge water in the event of contamination or repair of the recharge pit. A flow meter was installed at the entry point of the borewell for estimation of total recharge volume for proper groundwater balance estimation of the region. The cost of ASR system for a farmer of this region would be about A$ 4,000 however constructing a recharge pit alone with the available defunct borewell would only occur about A$ 800.

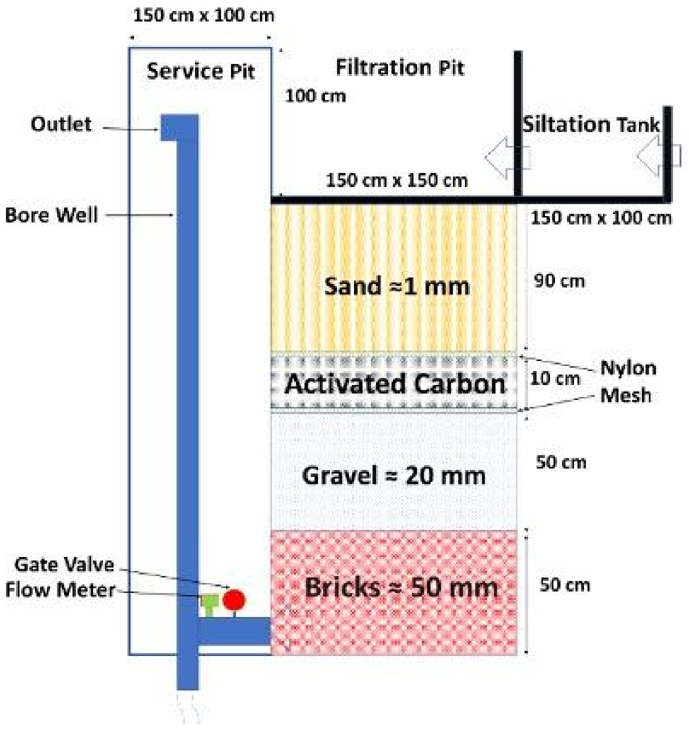


Figure 14: Design and specification of aquifer recharge pits

From a socio-economic point of view, a survey of households and community mobilisation with farmers and villagers was performed in this study on water needs, flood issues, willingness to participate and availability of land before the implementation of the ASR technology in both the villages. Within Nekpur and Meyar, there has been a consistent rise in demand for water in irrigation and domestic use on the back of rising per capita consumption, expansion of economic activities such as a bigger basket of crops in agriculture, poultry, dairy farming, etc. It was stressed in the survey whether ASR was needed in the selected sites to boost dry-season farming. Villagers informed that they have limited access to water in summer seasons. At the same time, they face flooding of their farmlands during monsoon seasons due to erratic rainfall patterns. The villagers showed a willingness to work together with this initiative. Based on the knowledge shared by the farmers, a decision was taken to go for recharging of deep aquifers in Nekpur and shallow aquifer recharge in Meyar (which was also complimented by the lithological logs shown in figure 13). The shallow aquifers of Nekpur got easily recharged through the *ahars* and open wells during the early monsoon and thus presents little opportunity for further recharge. The upper aquifers in Meyar were thick as compared to Nekpur, and it took longer to get recharged.

While the accessibility of lands can be an obstruction to the successful implementation of such community-based projects, the willingness of landowners to participate in the project facilitated the process. Project team approached the farmers in both the villages to know their interest in allowing the installation of ASR systems in their land. However, after meeting with farmers regarding ASR installation, it was found that only large, medium and semi-medium level farmers showed their willingness to participate in this project. These categories of farmers actively pursue farming throughout the year and are capable of making private investment for agricultural purposes. These farmers were interested in having the ASR installed to secure the irrigation of their farmlands in the time of low rains and expansion of agriculture in terms of the number of crop cycles and crop varieties for commercial purposes. They readily agreed to provide the land for ASR installation. They also agreed for sharing the recovered water from ASR wells with neighbouring farmers and agreed for maintenance of the recharge pit. The project team also approached small and marginal farmers for the same, but they did not show interest in the ASR project. The reason for their unwillingness was on account of the loss of potential farming land due to recharge pits and not having enough capacity for making additional economic investment for agricultural purposes. Some of the plots held by medium size farmers were unsuitable as they were far from the *ahar* area and had no direct road connection. Lack of road connectivity could have created hurdles in carrying the equipment to these plots for research related observations.

Proximity to roads or access to the ASR wells was a criterion for site selection in order to reduce travel time and effort for the local communities. Proximity to roads logistically supports the installation of the ASR project, as heavy equipment may be needed to be deployed close to the sites (Owusu et al., 2017). In this study, proximity to roads was considered adequate if a metal road was within 1 km. Electric power was considered to be available if a connection to the grid was possible within 0.5 km. of the proposed site. Affordable, reliable, and quality power supply was also essential for the installation and operation of a pump required to recover water stored in the aquifer.

Some large farmers were also not interested in sacrificing a patch of land of farming for recharge pits and have not put their trust on this novel technology. They probably did not see any potential benefits from ASR in the beginning. The farmers were selected for ASR installation whose land was near the *ahar* area that lies near the road and beyond the habitation zone in both the villages. The landowners of flood-prone lands were consulted, and they offered suitable land for the implementation of ASR projects in both the villages.

Suitable sites for the installation of ASR in both the selected villages were identified by also considering rainfall, the slope and elevation of the land, availability of water for recharge, groundwater depth, aquifer characteristics, quality of source water, and land use pattern. It was found that scientific, as well as social factors play an important role in site selection for ASR installation. Based on overall analysis, three locations in Nekpur village and four locations in Meyar village were identified as the most suitable sites for the ASR installations (figure 15). All these sites were located near the *ahars.*

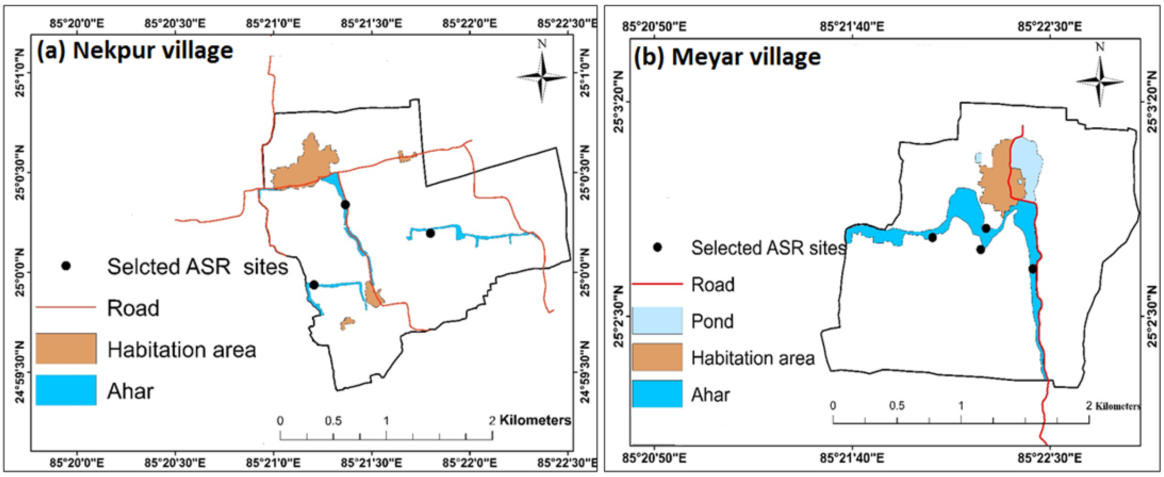


Figure 15: Suggested suitable sites (in black spheres) for ASR project for (a) Nekpur and (b) Meyar village

To understand the cropping pattern, water usages, livelihood pattern of the farming community, farmers' concern about groundwater depletion and their willingness to adopt groundwater recharge techniques such as ASR, a socio-economic survey was conducted during the period 2019-20 in the Nekpur and Meyar. During the survey, we have collected the information regarding the agricultural practices in various cropping seasons (*kharif* - July to October, *rabi* - October to March, and *zaid* season - March to June), cost of production, market support, income through agricultural activity, and willingness to pay for ASR systems.

Depending on the cropping pattern, the farmers who own the uplands are able to cultivate two crops, such as paddy in *kharif* season and wheat, maize, onion, and other vegetables in the *rabi* season. Whereas, farmers in the low-lying areas are able to cultivate only pulses such as gram, green gram, lentil, mustard. Due to water shortage in *zaid* season (March to July), farmers are unable to grow any crops during this season. Agricultural production in Bihar depends on the rains received during the monsoon season. Nalanda District receives moderate rainfall during the monsoon season (July-September), but figure 8 shows a decreasing trend of the annual as well as seasonal rainfall over the years.

The farming community largely depends on the groundwater for irrigation. Due to groundwater depletion, farmers are investing money in deeper borewells. During the survey, we observed that farmers borrow money from various sources to go for deep borewells, between the 2019 and 2020, number of new borewells were increased by 20%, and more farmers were planning to get new deep borewells in their farm land. Due to lack of recharge facilities, the groundwater levels in the Meyar and Nekpur decreased to 30 m and 61 m respectively. As per the CGWB, Nalanda district shows a decreasing trend of groundwater over the years (Figure 16).

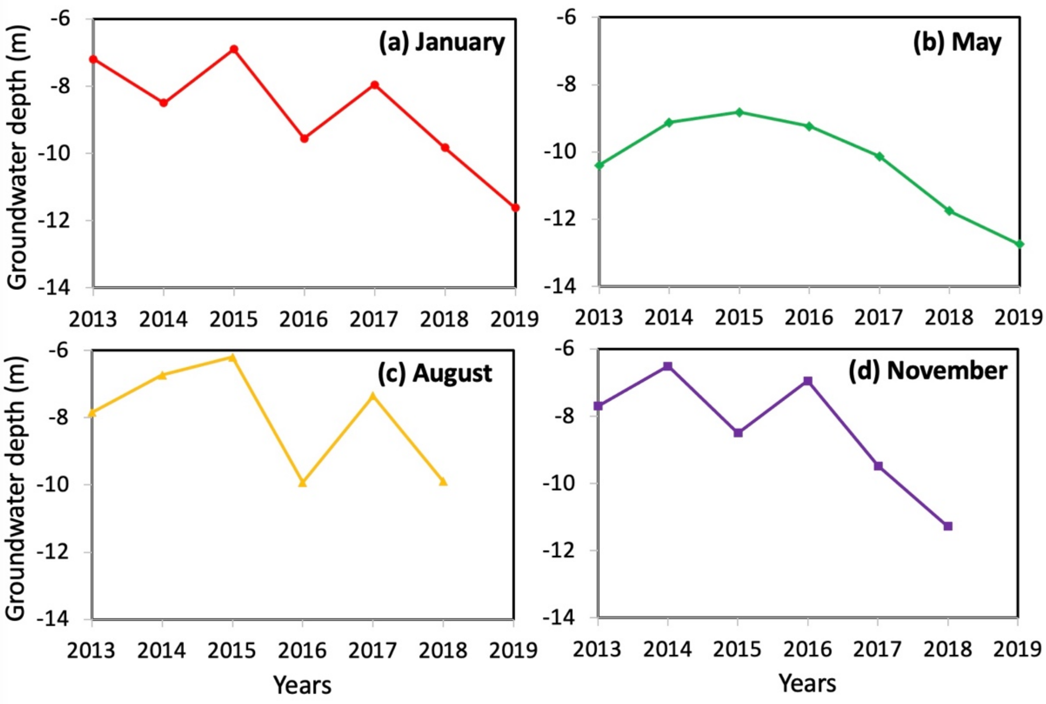


Figure 16: Groundwater below the ground level (bgl) in Nalanda district: (a) Groundwater level in January, (b) Groundwater level in May, (c) Groundwater level in August and (d) Groundwater level in November. Source: Compilation from various reports of CGWB (Groundwater year books 2015, 16, 17, 18, 19).

Farmers having land in the uplands, cultivate two crops per year, paddy in *kharif* season, and wheat in the *rabi* season. Table 4 and 5 provides the cost-revenue of the agricultural production in Nekpur and Meyar villages. These farmers receive a crop yield of 50-75 quintals/ha (100 kgs/ha), and cost of production of the *kharif* crop is A$ 796/ha - 841/ha and *rabi* crop is A$ 729/ha -A$ 775/ha. The slight cost variation is due to the amount of labour employed in the cropping season. Considering the market price of paddy and wheat, the expected revenue from paddy is in the range of A$ 1850/ha - A$ 2057/ha and A$ 1959/ha - A$ 2286/ha for wheat. Considering the two crops, the farmers who own the uplands could earn an income A$ 2284/ha to A$ 2727/ha to (after deducting cost). Whereas, farmers who own land in low-lying areas cultivate pulses, considering the yield, cost of production and revenue, these farmers earn A$ 915/ha to A$ 980/ha (Table 4 and 5).

Table 4: Farming income by season - Nekpur Village

Land	**Season**	**Crop**	**Yield (kg/ha)**	**Price/100 kg (A$)**	**Cost/ha (A$)**	**Revenue/ha (A$)**	**Benefit/ha (A$)**
Upland	*Kharif* (June -October)	Paddy	5000-7500	28-32	796	1850	1054
Upland	*Rabi* (October-March)	Wheat, Maize, and Vegetables	5000-7500	30-34	729	1959	1230
Low lying area/*ahar*	*Rabi* (October-March)	Pulses, Mustard	1000-1500	97-115	435	1350	915

Table 5: Farming income by season - Meyar Village

Land	**Season**	**Crop**	**Yield (kg/ha)**	**Price/100 kg (A$)**	**Cost/ha (A$)**	**Revenue/ha (A$)**	**Benefit/ha (A$)**
Upland	*Kharif* (June -Oct)	Paddy	6200-7500	28-32	841	2057	1216
Upland	*Rabi* (Oct-March)	Wheat, Maize, and Vegetables	6200-8600	30-34	775	2286	1511
Low lying area/*ahar*	*Rabi* (Oct-March)	Pulses, Mustard	1000-1500	97-115	435	1415	980

During our interactions with farmers, we observed that few farmers who have deep borewells able to retrieve small amounts of groundwater during the dry months, these farmers are able to receive an additional crop (green gram/vegetable) during this season. Depending on the soil and availability of groundwater, the farmers who cultivate green gram receive a minimum income of A$ 871 and maximum A$ 900/ha. Farmers who grow vegetables, depending on vegetables, they receive farm income in the range of A$ 2612/ha to A$ 4354/ha. During the socio-economic survey, farmers were asked about their willingness to pay for getting the water during the dry season. A majority of the respondents expressed their concern about the water availability in the *zaid* season. About 60% of the respondents expressed their willingness to contribute a maximum of A$ 881 to repair the defunct/failed borewells and adopt ASR structure. Given the cost of a new borewell (approximately A$ 2644), farmers who do not have deep borewell, have expressed to contribute some amount to repair neighbour's defunct borewell.

Based on these findings, we propose the "entrepreneurial farmers-led model". The critical elements of this model include (i) a multi-disciplinary approach to site selection in which scientific assessments can be integrated with socio-economic insights, (ii) system will be initially adopted by entrepreneurial farmers who agree to invest and share benefits, and (iii) co-designing the recharge pit using locally available material and ease of maintenance. While a strong knowledge input from scientific literature ensures credibility and confidence necessary for the technical feasibility of ASR, the flexibility of a participatory approach allows the farmers to creatively engage with the design and governance aspects of recharge pits.

Our model is expected to provide implementation flexibility within an overarching technical framework that integrates water quality concerns. The implementation flexibility is derived from the distributed nature of the model, where entrepreneurial lead farmers serve neighbourhood user groups—the "problem shed" for groundwater use [Woodhouse and Muller, 2017]. At scale, these operational units could either be supported by a specialised technical support entity from outside, or some of these operating units could graduate into local water enterprises. In any case, the available local expertise on aquifer management will expand to serve rural communities. We expect the increasing water stress, the rising environmental subjectivity of selected entrepreneurial farmers, and willingness to address their local concerns will act as the precursor for higher uptake of the model.

It is interesting to note that instead of favouring the construction of new ASR structures, the farmers were more interested in converting "failed borewells" into ASR installations. Not all failed borewells were suitable for conversion, mainly due to residual debris and natural collapse. However, given the relatively large proportion of failed borewells in the region, many can be effectively converted into recharge pits with limited financial investment. The idea of "reviving" the failed borewells as possible ASR system emerged from the participatory discussions being promoted during the study period since it may require to construct only the filtration unit (i.e., recharge pit) but no borewell.

The scaling up of ASR will also require significant policy support. The state regulatory apparatus for water resources needs to be integrated and streamlined to adopt a holistic approach to water governance, promoting conjunctive management of surface and groundwater resources, and integrated services across the water use sectors. The opportunities for Bihar are significant. The *Jal-Jivan-Hariyali* mission of the state government is attempting an integrated approach to water resources management and environmental well-being. Under this mission, the state government is constructing both surface-based and groundwater-based water recharge structures. However, the mission's top-down model leaves little space for meaningful participation of local stakeholders, jeopardising both the effectiveness and efficiency of the program. Evidence of several semi-functional to dysfunctional water-harvesting structures built on the principle of direct recharge of groundwater aquifers during the last year abound in the study area. The state agencies can initially adopt our design at institutional level for augmenting aquifers in selected parts of Bihar. The government agencies/institutions can promote the design aspects and overall information about this project through agricultural fairs and other mediums.

The entrepreneurial farmer-led model builds local accountability, creates avenues for private investments, and opens up the space for continued innovation in technology and management while also committing to resource distribution justice and environmental sustainability. However, the model emerging from our pilot study needs further analysis; even though the initial findings are promising, the long-term viability of such projects and real adoptions can only be measured in the coming months once we leave the site after completing the ongoing pilot project. We hope this piece provokes the wider academic community to engage with the idea of farmers-led models for the adoption of recharge pits.

7 Impacts

7.1 Scientific impacts – now and in 5 years

An innovative design model for ASR with a gravity driven recharge pit and a novel site selection method were two major scientific impacts from this study.

The ASR design was developed with the consultation of the villagers with the motive of recharge sustainability and maintenance by the villagers. Locally available materials were used in the construction of the recharge pit. The recharge pits were developed according to local conditions such as high waterlogging conditions, mud and silt loads, and easily available replacement materials for the safety and long-lasting of the structure. Recharge pits are generally prone to clogging and require high maintenance cost, eventually failure of the recharge unit. This pit may be cleaned by simply flushing the pit from the top or bottom. There is a flowmeter attached to the borewell for the measurement of total volume of water recharged and an option to stop the water storage process for research or during an emergency, which is generally not available in traditional recharge pits. This design may be adopted by the scientific community for studying the mechanism of gravity driven groundwater recharge structures.

The site selection method for the low-cost gravity driven ASR structure was developed based on the technical as well as socio-economic factors which may be adopted for the ASR site selection in other parts of India and outside India. Database was created for water level, water quality, groundwater usage, farming practices etc. which will be useful for the next 5 years and beyond for long-term monitoring for the water level and quality changes during ASR operations. In the long-term, development of recharge pits has opened the plethora of research options such as potential of climate resilience, groundwater sustainability, risk assessment, etc. to be carried out for the benefit of farming communities of similar agroclimatic regions with the adoption of such low-cost gravity driven ASR systems.

7.2 Capacity impacts – now and in 5 years

The ASRA project involved four diverse project coordinators, four research fellows, a lab assistant, a contractor, and seven partner farmers, for all of them ASR system planning and development was a great learning experience. All learn various interdisciplinary knowledge and skills during the execution of the project. All research fellows got hands-on experience of project management, report preparation, tender documentation with national standards, procurement in government e-market and also in local and national markets, organizing events and meeting at various levels, etc. which would benefit them in future projects. Junior research fellows got skilled in groundwater and soil sample collection, water quality estimation, water level mapping, various socio-economic surveying etc. which provided them PhD positions and one of them will carry forward this work for next few years at Nalanda University. Partner farmers, contractors, and local masons got experience in constructing ASR systems and it would provide job and business opportunities to them to construct such systems as many farmers are willing to upgrade their (defunct) borewells with recharge pits in future. ASR system's installation will be studied for its environmental and socio-economic impacts by PhD scholars and master's students at Nalanda University. The contacts developed with villagers, will help the university students to carry out their research works in these villages for next several years.

7.3 Community impacts – now and in 5 years

Economic impacts

This project has impacted on reliable irrigation supply, employment duration for farmers, and ultimately the increase in income through agricultural activities for current drought/flash flood situations and for long-term in the region.

During the socio-economic quantitative surveys and qualitative surveys done with households, it became clear that they are unable to grow the first and third crop within a cycle season during the months of April to October (summer and monsoon in India) in the water logging areas. The cultivators actively express their desire to have a reliable irrigation source as well as to solve the issue of water logging. It is expected that functional recharge pit would store the excess water in aquifers solving the water logging and ASR systems will supply sustainable irrigation in the months of summer. Therefore, they are able to grow a more diverse set of crops in an agriculture cycle. This has a direct impact on the duration of employment of inputs needed in farming activity. The stored excess water stored in the aquifer will lead to rise in income from agriculture to a significant level. That is, if the additional crops are relatively labour intensive then it may provide farm labour an incremental period of employment. Otherwise, there will be relative incremental use of capital in cultivation of additional crops. Reliable irrigation sources are bound to make agriculture more resilient in environmental terms and as a result will enhance the economic viability in the coming years.

Social impacts

This project tried to resolve the water stress created in the local community due to water scarcity for irrigation and domestic purposes. Fetching drinking water from long distances has been emerging as a big concern for women and children belonging from marginalised communities. This project aimed to recharge the aquifers, which would eventually lead to reduction in water stress in dry seasons. We tried to train and encourage farmers to take collective action for maintenance of recharge pit of the ASR. The project in addition, sensitized the University community to work and design more projects which would contribute to the betterment and empowerment of the local community.

The ASR systems are well equipped to alleviate water logging during heavy rains and flash floods. The farmers will use recharged water for irrigation, there should be slower rate of groundwater depletion and consequently can meet the demand for drinking water throughout the year. This should result in lower burden on women and children who are often tasked to fetch water from places outside their home. The qualitative study during the survey revealed the ongoing forced sacrifices made in daily routines and cropping possibilities by small and marginal farmer families due to water scarcity in the months of April to June. The increased availability of water due to ASR should do away with those dire implications. The consumption of water and energy for irrigation under the ASR model should be more efficient through peer monitoring and formal electricity connection. The villagers should become amenable to collective action with respect to irrigation. The joint ownership of recharge pits, if proved successful, can become the go to way for adoption of new technology among farmers and other villagers. This joint ownership gives them the opportunity to cut costs and gain benefits through rule-based sharing. The current model is initially likely to be adopted more by large and medium level active farmers. However, in the longer run, we expect adoption possibilities even at community, village and institutional level.

Environmental impacts

The project has significant environmental impact for short- and long-run. The developed and implemented ASR systems are aimed to provide appropriate measures for the available groundwater resources in terms of their quantity and quality. It further reduces the risk of sudden flood situations by surface water recharge.

Due to the development of ASR systems in these villages, significant volume of groundwater recharge is expected. According to the surface and groundwater qualities studies, groundwater quality is expected to be improved through dilution or mixing, physical and chemical processes as reported in various studies (Vanderzalm et al. 2010; Sultana et al. 2014). As expected, there will be additional water storage, the rate of groundwater depletion will be lower and hence farmers would not be forced to dig deeper borewells. Accordingly, carbon emission will be constant because electricity consumption due to pumping will be constant in coming years. However, to achieve such reliable irrigation water supply through ASR borewells, the demand for irrigation water needs to be manage sustainably. Apart from these benefits, there may be chances of contamination of groundwater due to storage of oxygen rich water in the aquifers which may create some geogenic minerals released through the interaction with available oxygen (Vanderzalm et al, 2011; Maliva 2020). This aspect requires further research.

The interactions of project teams with villagers at different levels and multiple occasions and mobilizations of farmers and other villagers led to a healthy debate among the village communities on finding the ways to address the water stress. The role of local and global factors in exacerbating the water stress and emerging environmental vulnerabilities were debated and this shaped the emerging environmental discourse at the village level. The rise of environmental subjectivity among selected members of the community may lead them to find appropriate solutions at the local level. In the longer term, with increase in climate uncertainty, selected farmers may emerge as the champion of the ASR system. Farmer to farmer (peer communication) sharing of knowledge is identified and acknowledged as a major source of communication which shapes diffusion of technologies and different agrarian practices in rural India. We believe this model will be widely communicated among the local farmers through peer communication, once the farmers will realize the potential of the ASR system for recharge and recovery of water after using the system for a few years.

8 Communication and Dissemination Activities

For wider dissemination of research findings and policy advocacy, we have created a website (https://asranu.wixsite.com/asra), where we have listed all the major works carried out by the team. We will keep updating the website and will post the articles and other outputs which will emerge from the ASRA project. In addition, the findings of the study were widely reported in local and national media (both in Hindi and English). We believe the wider dissemination through mass media will create the ambient environment for generating awareness and possible uptake of the technology among farmers and other relevant groups. In addition, the specific materials generated for communication are listed below:

Reports

- Sharma, P. 2021. Implementation of Aquifer storage and recovery for sustainable agriculture workshop report. ACIAR Project WAC 2018 211. February 25-26, 2021.
- Sharma, P. 2019. Aquifer storage and recovery for sustainable agriculture (ASRA) workshop report. ACIAR Project WAC 2018 211. November 15-16, 2019.
- Sharma, P. 2019. Aquifer characterization, Artificial recharge and reuse of suddenly available water in South Bihar annual report July, 2019.
- Sharma, P. 2020. Aquifer characterization, Artificial recharge and reuse of suddenly available water in South Bihar annual report. ACIAR Project WAC 2018 211. July, 2020.

Conference and presentations

- Sharma, P. 2021. An integrated site selection model for aquifer storage and recovery, Indian National Chapter of International Association of Hydrogeologists.
- Sharma, P. 2021. An integrated site selection model for aquifer storage and recovery. Workshop on Implementation of Aquifer storage and recovery for sustainable agriculture held at Nalanda University, Bihar, and 25th February, 2021.
- Sharma, A. 2021. Climatic Variability and Environmental Change in South Bihar, India: Towards an Integrated View, Workshop on Implementation of Aquifer storage and recovery for sustainable agriculture held at Nalanda University, Bihar, and 25th February, 2021
- Bandyopadhyay, S. 2021. Potential for Aquifer Storage and Recovery (ASR) in South Bihar, India, Workshop on Implementation of Aquifer storage and recovery for sustainable agriculture held at Nalanda University, Bihar, and 25th February, 2021
- Dhavala, K. 2021. Enhancing Farmers income through ASR technology, Workshop on Implementation of Aquifer storage and recovery for sustainable agriculture held at Nalanda University, Bihar, and 25th February, 2021
- Verma, P., Sharma, P. et. al. 2020. Integrating top-down and bottom-up perspectives for site selection for aquifer storage and recharge. Fall Meeting, AGU Fall Meeting, San Francisco, CA, H163-0013.
- Sharma, P. et. al. 2019. Artificial recharge and reuse of suddenly available water in South Bihar, India. Fall Meeting, AGU Fall Meeting, San Francisco, CA, H11L-1659.
- Sharma, A. 2019. Trajectories of Agrarian Change in South Bihar: Agricultural Modernisation, Vulnerabilities and Environmental Risks. Workshop on Aquifer storage and recovery for sustainable agriculture held at RICC, Bihar, and 15th November, 2019.
- Sharma, P. 2019. Aquifer Characterization and Mapping for ASR in South Bihar, Workshop on Aquifer storage and recovery for sustainable agriculture held at RICC, Bihar, 15th November, 2019

- Bandyopadhyay, S. 2019. Aquifer Storage and Recovery for Sustainable Agriculture (ASRA), Workshop on Aquifer storage and recovery for sustainable agriculture held at RICC, Bihar, and 15th November, 2019
- Dhavala, K. 2019. Economic Analysis of ASR, Workshop on Aquifer storage and recovery for sustainable agriculture held at RICC, Bihar, and 15th November, 2019.

Internal workshop

- ACIAR Project WAC 2018 211, Workshop on Aquifer storage and recovery for sustainable agriculture, School of ecology and Environment studies, Nalanda University, Bihar, and 15th-16th November, 2019.
- ACIAR Project WAC 2018 211, Workshop on Implementation of Aquifer storage and recovery for sustainable agriculture, School of ecology and Environment studies, Nalanda University, Bihar 25th-26th February, 2021.

Field days/ created ideas

Farmer's field day was held on 15th November, 2019 and 25th February, 2021. A team of experts visited the sites and interacted with farmers and end-users of ASR pits. On both occasions around 100 farmers participated in the event and they were made aware of the objectives of ASRA project and its wide potential in solving water scarcity.

Several group discussions with farmers were held in 2019, 2020, 2021 at Nekpur and Meyar village regarding recharge pit design, site selection for ASR, water issues and cropping pattern.

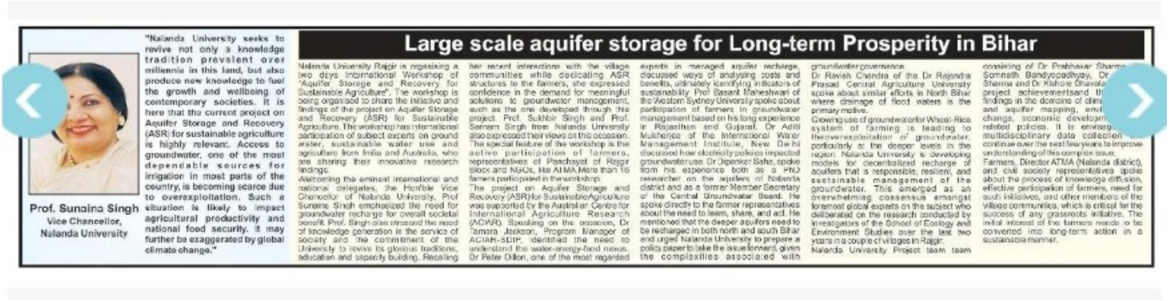
Field day held on 10th February, 2021 to inaugurate the constructed ASR recharge pits in both the villages by Hon'ble Vice Chancellor of Nalanda University wherein ACIAR project was presented to more than 500 farmers. It is also worth noting that some of the farmers threw light on the water shortage issues in their villages for both drinking and irrigation due to increased usage and erratic rainfall. They spoke about supporting this technique for water management and using it in a sustainable way. They expressed gratitude that a university like Nalanda is located near to their village and started this project in their villages. They promised after getting results from this project they will promote such kind of water management strategies willingly and they will create awareness among the people to extend it at a larger scale.

For the benefit of the general public and as part of mass awareness, the ASRA team has also created a fully functional website, i.e., https://asranu.wixsite.com/asra. The website has the information related to the field intervention, updates about ASRA workshop and external expert visits, contact information about the project team members, etc.

A WhatsApp group has also been formed comprising the partner farmers, non-partner farmers, project team and contractor to allow for smooth cooperation related to functioning of ASRA pits.

Coverage in media

Activities related to the project have also been able to get featured in the nationally reputed daily newspapers like The Hindu, The Times of India, Telegraph, Prabhat Khabar, Dainik Bhaskar, Dainik Jagran and Hindustan. The newspapers talked about the ASRA pits as a large-scale potential solution for water scarcity and well-being of farmers in Bihar.



Large scale aquifer storage for Long-term Prosperity in Bihar

Prof. Sunaina Singh
Vice Chancellor,
Nalanda University

"Nalanda University seeks to revive not only a knowledge tradition prevalent over millennia in this land, but also produce new knowledge to fuel the growth and wellbeing of contemporary societies. It is here that the current project on Aquifer Storage and Recovery (ASR) for sustainable agriculture is highly relevant. Access to groundwater, one of the most dependable sources for irrigation in most parts of the country, is becoming scarce due to overexploitation. Such a situation is likely to impact agricultural productivity and national food security. It may further be exaggerated by global climate change."

Nalanda University Rajgir is organising a two days International Workshop of "Aquifer Storage and Recovery for Sustainable Agriculture". The workshop is being organised to share the initiative and findings of the project on Aquifer Storage and Recovery (ASR) for Sustainable Agriculture. The workshop has international participation of subject experts on ground water, sustainable water use and agriculture from India and Australia, who are sharing their innovative research findings.

Welcoming the eminent international and national delegates, the Hon'ble Vice Chancellor of Nalanda University, Prof Sunaina Singh emphasized the need for groundwater recharge for overall societal benefit. Prof. Singh also stressed the need of knowledge generation in the service of society and the commitment of the University to revive its glorious traditions, education and capacity building. Recalling her recent interactions with the village communities while dedicating ASR structures to the farmers, she expressed confidence in the demand for meaningful solutions to groundwater management, such as the one developed through this project. Prof. Sukhbir Singh and Prof. Sonam Singh from Nalanda University also expressed their views on this occasion. The special feature of the workshop is the active participation of farmers, representatives of Panchayat of Rajgir Block and NGOs, like ATMA. More than 15 farmers participated in the workshop.

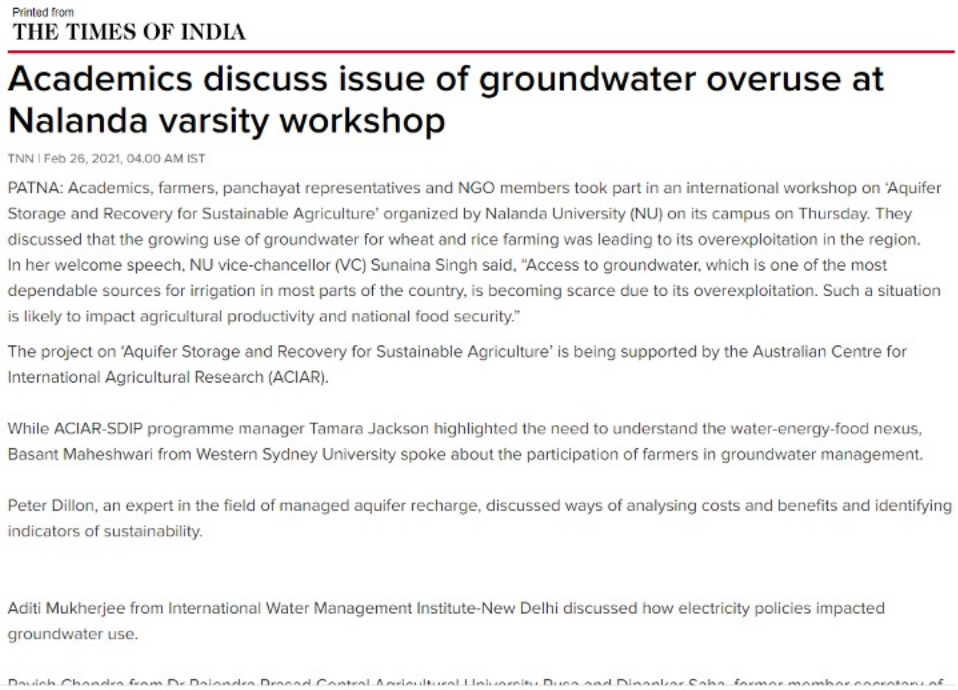
The project on Aquifer Storage and Recovery (ASR) for Sustainable Agriculture was supported by the Australian Centre for International Agriculture Research (ACIAR). Speaking on the occasion, Dr Tamara Jackson, Program Manager of ACIAR-SDIP, identified the need to understand the water-energy-food nexus. Dr Peter Dillon, one of the most regarded experts in managed aquifer recharge, discussed ways of analysing costs and benefits, ultimately identifying indicators of sustainability. Prof Basant Maheshwari of the Western Sydney University spoke about participation of farmers in groundwater management based on his long experience in Rajasthan and Gujarat. Dr Aditi Mukherjee of the International Water Management Institute, New Delhi discussed how electricity policies impacted groundwater use. Dr Dipanker Saha, spoke from his experience both as a PhD researcher on the aquifers of Nalanda district and as a former Member Secretary of the Central Groundwater Board. He spoke directly to the farmer representatives about the need to learn, share, and act. He mentioned that the deeper aquifers need to be recharged in both north and south Bihar and urged Nalanda University to prepare a policy paper to take the issue forward, given the complexities associated with groundwater governance.

Dr Ravish Chandra of the Dr Rajendra Prasad Central Agriculture University spoke about similar efforts in North Bihar where drainage of flood waters is the primary motive.

Growing use of groundwater for Wheat-Rice system of farming is leading to the overexploitation of groundwater, particularly at the deeper levels in the region. Nalanda University is developing models for decentralized recharge of aquifers that is responsible, resilient, and sustainable management of the groundwater. This emerged as an overwhelming consensus amongst foremost global experts on the subject who deliberated on the research conducted by investigators of the School of Ecology and Environment Studies over the last two years in a couple of villages in Rajgir.

Nalanda University Project team team consisting of Dr Prabhakar Sharm [illegible] Somnath Bandyopadhyay, Dr [illegible] Sharma and Dr Kishore Dhavala [illegible] project achievementsand th [illegible] findings in the domains of clim [illegible] and aquifer mapping, envi [illegible] change, economic developm [illegible] related policies. It is envisag [illegible] multidisciplinary data collection [illegible] continue over the next few years to improve understanding of this complex issue.

Farmers, Director ATMA (Nalanda district), and civil society representatives spoke about the process of knowledge diffusion, effective participation of farmers, need for such initiatives, and other members of the village communities, which is critical for the success of any grassroots initiative. The initial interest of the farmers needs to be converted into long-term action in a sustainable manner.



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THE TIMES OF INDIA

Academics discuss issue of groundwater overuse at Nalanda varsity workshop

TNN | Feb 26, 2021, 04.00 AM IST

PATNA: Academics, farmers, panchayat representatives and NGO members took part in an international workshop on 'Aquifer Storage and Recovery for Sustainable Agriculture' organized by Nalanda University (NU) on its campus on Thursday. They discussed that the growing use of groundwater for wheat and rice farming was leading to its overexploitation in the region.
In her welcome speech, NU vice-chancellor (VC) Sunaina Singh said, "Access to groundwater, which is one of the most dependable sources for irrigation in most parts of the country, is becoming scarce due to its overexploitation. Such a situation is likely to impact agricultural productivity and national food security."

The project on 'Aquifer Storage and Recovery for Sustainable Agriculture' is being supported by the Australian Centre for International Agricultural Research (ACIAR).

While ACIAR-SDIP programme manager Tamara Jackson highlighted the need to understand the water-energy-food nexus, Basant Maheshwari from Western Sydney University spoke about the participation of farmers in groundwater management.

Peter Dillon, an expert in the field of managed aquifer recharge, discussed ways of analysing costs and benefits and identifying indicators of sustainability.

Aditi Mukherjee from International Water Management Institute-New Delhi discussed how electricity policies impacted groundwater use.

Ravish Chandra from Dr Rajendra Prasad Central Agricultural University Pusa and Dipankar Saha, former member secretary of

Nalanda Contributes growth and well-being of farmers in Bihar

On 10th February, the Vice Chancellor Prof. Sunaina Singh inaugurated seven aquifer storage and recovery pits created by Nalanda University in the villages of Meyar and Nekpur. This project is funded by the Australian Centre for International Agriculture Research (ACIAR). The recharge pits were created for the farmers as the winter advances, the ground water level depletes leading to water scarcity and crop failure in this region.

The innovative research was developed by Ecology and Environment Studies experts on water management in the last two years, was translated into seven aquifer storage and recovery pits. Due to this innovative method and mechanism, the water levels increased from 30 feet to 15 feet. Prof. Singh highlighted how education and knowledge should translate into well-being of the community. She encouraged University faculty to pursue researches on Climate Change, Natural Calamity, Flood Control Systems, etc. which would be significant for the lives of the people.

She also spoke about keeping Hon'ble Prime Minister vision of *Sabka Sath Sabka Vikas*, research with a view to create a water bank for the community by the Nalanda University. The concerned villagers attended in a big number and appreciated the Vice Chancellor's initiative and applauded such efforts towards their community. The farmers mentioned about chemicals and fertilizers removal by the recharge pits constructed at the village and may also improve the water scarcity problems.

This project is a model of Aquifer Storage and Recovery (ASR) technology using flood waters to provide an opportunity for farmers to raise their income. A model for implementation, including awareness, local capacity and chain of facilities, will be available in a manual to ensure the sustainability of the technology and wider adoption in the region in areas with similar hydrological characteristics.

The state of Bihar is especially vulnerable to floods and droughts, often leading to significant disruption in agriculture – the mainstay of people's life and property. South Bihar has the potential to emerge as one of the major agricultural hubs of eastern India. During the winter, crops like wheat are particularly at risk due to depletion of groundwater [illegible] has emerged as a major sou [illegible] recent years particu [illegible] erratic monsoonal [illegible] irrigation sourc [illegible] challenges for s [illegible] South Bihar. AS [illegible] innovative su [illegible] intensification of [illegible] creating an undergr [illegible] resilience to climat [illegible] incomes from agricu [illegible] activities.

The pilot project in Rajgirh as demonstrated the feasibility of ASR in both hard rock and deep alluvial aquifers, the prominent aquifer types in the marginal alluvial plains of South Bihar and elsewhere. Successful implementation of ASR in these two villages can augment usable water resources for agriculture during the winter cropping season. More importantly, ASR can adapt to local circumstances and challenges under changing climatic conditions.

The project team led by Dr. Prabhakar Sharma was present on the occasion. Faculty members, officials, and the students from the University participated in the program.

THE TIMES OF INDIA, PATNA
FRIDAY, FEBRUARY 26, 2021 4

Academics discuss issue of groundwater overuse at Nalanda varsity workshop

Times News Network

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Peter Dillon, an expert in the field of managed aquifer recharge, discussed ways of analysing costs and benefits and identifying indicators of sustainability.

Aditi Mukherjee from International Water Management Institute-New Delhi discussed how electricity policies impacted groundwater use.

The two-day workshop will conclude on Friday.

9 Conclusions and Recommendations

9.1 Conclusions

Aquifer storage and recovery system has been established as an effective technology to replenish depleted groundwater tables and support sustainable intensification of agriculture. Adoption of ASR helps in building resilience to climate change and raise incomes from agriculture and allied activities. Reliable irrigation sources are one of the key challenges for sustainable agriculture in South Bihar. Seasonal water availability determines the cropping pattern in South Bihar because agriculture in the region is mainly rainfed.

The project activities and outcomes are concluded as follows:

- Detailed surveys have been performed to identify locations for ASR installations in South Bihar. Two villages (Nekpur and Meyar), situated within Rajgir block in Nalanda District have been chosen for ASR projects after geospatial analysis, the collected information from local villagers about water shortage, and the physical inspection of various sites of water logging.
- Seven suitable sites were identified in Nekpur and Meyar village in South Bihar based on scientific indicators (i.e., rainfall, elevation, soil and aquifer characteristics, surface and groundwater quality) and social dynamics (tacit knowledge, land ownership, willingness to participate). On the basis of these factors, three locations in Nekpur village and four locations in Meyar village have been chosen as the most suitable sites for ASR.
- The geophysical and geochemical characterization of the target aquifer at the installation sites were completed. Consequently, the construction of seven borewells with their respective recharge pits were completed in September 2020 at the selected sites in both the villages which were selected based on a chosen set of parameters. The installation of ASR couldn’t be completed before the monsoon season of 2020 due to COVID restrictions and heavy rainfall (flash flood situation) during recharge pit construction for ASR.
- Focus group discussion and personal interview with farmers revealed their willingness to adopt and operate the new ASR systems. Seven entrepreneurial farmers (EFs) were identified in the two villages who formally agreed to own and operate the new ASR structures. The EFs were typically large and medium level active farmers (holding more than 2 hectares of land) with deep bore-wells whose primary source of family income was agriculture, were keen to protect and augment their farm incomes through assured irrigation.
- Overall, the project has demonstrated the feasibility of ASR in both hard rock and deep alluvial aquifers, the prominent aquifer types in the marginal alluvial plains of South Bihar and elsewhere.
- A successful spread of ASR in South Bihar can augment usable water resources for agriculture during the winter cropping season. More importantly, ASR can adapt to local circumstances and challenges under changing climatic conditions.

9.2 Recommendations

Groundwater management is a challenging task in India because of the growing water demand for irrigation, domestic, industrial, and ecosystem restoration and growing uncertainties caused by global climate change. ASR promises to be an effective process in overcoming the periodic limitations in water resources available for use. ASR can provide an opportunity to farmers of the region to raise their incomes from agriculture and other economic activities during the dry season through reuse of water collected during the flood periods and stored beneath the ground surface.

India's development depends on its groundwater resources, which is marred by inefficient practices. Different groundwater policies and reform choices at the federal, state, and local levels are required for sustainable planning and management. The following recommendation is advanced to ensure aquifer storage and recovery for India, which is being documented in a policy briefs:

- expand the understanding of artificial recharge of aquifers and conjunctive use of surface and groundwaters as integral to water resources management practices;
- promote best practices for the use of surface water during wet periods and groundwater during dry periods for conjunctive use;
- create a regional database of hydrogeological and socio-economic conditions of the region to facilitate best practices for conjunctive use, such as through ASR techniques;
- integrate recharge pits, with proper filtration mechanism using locally available material, in the design of ASR systems, coupled with systems for periodic monitoring of water quality;
- provide easily accessible knowledge of groundwater databases and assistance to individuals and small groups of entrepreneurial farmers for adoption of ASR systems;
- adopt a holistic regional water management approach that integrates, and promotes, local solutions (such as ASR systems) while building resilience through large-scale, inter-basin infrastructure.

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10.2 List of publications produced by project

Published paper

Bandyopadhyay, S.; Sharma, A.; Sahoo, S.; Dhavala, K.; Sharma, P. 2021. Potential for aquifer storage and recovery (ASR) in South Bihar, India. Sustainability 13: 3502.

In the process of publication

Verma, P.; Sharma, P.; Verma, A.; Sharma, A.; Bandyopadhyay, S. 2021. An integrated site selection model for aquifer storage and recovery. J. Hydrol. (in Review)

Sharma, A.; Sahoo, S.; Sharma, P. Bandyopadhyay, S. 2021. Climatic variability and environmental change in South Bihar, India: towards an integrated view. (In preparation)

Bandyopadhyay, S.; Sharma, A.; Dhavala, K.; Sharma, P. 2021. Why is Aquifer Storage and Recovery (ASR) important for Sustainable Groundwater Management in India? Policy paper (In preparation).

Sharma, P; Bandyopadhyay, S.; Sharma, A.; Dhavala, K. 2021. Review of aquifer storage and recovery for groundwater sustainability opportunities and challenges. (In preparation)

Sharma, P.; Verma, P.; Verma, A. 2021. Role of hydrogeochemical investigation before and after the installation of ASR. (In preparation)

Sharma, P.; Kumar, R.; Abhishek, K. 2021. Effectiveness of filter materials used in ASR for removal of nitrate and phosphate leached from agricultural runoff. (In preparation).

Sharma, P.; Verma, A. 2021. Simulation of ASR capacity with the long-term impact on groundwater quantity and quality changes. (In preparation)

Dhavala K.; Bandyopadhyay, S. 2021. Enhancing Farmers' income through ASR technologies (In preparation)

Dhavala K.; Bandyopadhyay, S. 2021. Willingness to pay of the farmers to adopt ASR technology: A comparative analysis of ex-ante and ex-post of ASR structure implementation in the piloted villages (In preparation)

11 Appendixes

1. Video documentary from the project is included.

2. Estimation for total filtration with the help of hydraulic conductivity

Hydraulic conductivity of coarse sand:

Assuming, D_{10} = 0.5 mm, g= 9.8 m/s, viscosity of water V=$1.2\text{x}10^{-6}$ m^2/s, C_{KC} is an empirical coefficient equal to 1/180 [dimensionless], porosity n = 0.36

Using Kozeny-Carmen Formula

$$K_{KC} = C_{KC}\frac{g}{\nu}\frac{n^3}{(1-n)^2}D_{10}^2$$

After substituting all values, we get

K= $1.29\text{x}10^{-3}$ m/s

Using Darcy's law for flow rate

Q = -KA(dh/dl)

A = 1.5 x 1.5 m^2, dh = 2 m, dl = 1 m

For K = 1.29 $\text{x}10^{-3}$ m/s

After substituting all values, we get

Q=$5.805\text{x}10^{-3}$ m/s

For 1 day, Q=501.5 m^3 or Q= 501,500 liters

For 30 days, Q=15045 m^3 or Q= 15,045,000 liters for one ASRA system

For 30 days, Q=105315 m^3 or Q= 105,315,000 liters for seven ASRA system