GUIDELINES FOR IMPACT ASSESSMENT OF ARTIFICIAL RECHARGE STRUCTURES/SCHEMES

CENTRAL GROUND WATER BOARD
DEPARTMENT OF WATER RESOURCES, RD & GR
MINISTRY OF JAL SHAKTI

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Central Ground Water Board

FOREWORD

The importance Groundwater in sustainable management of water resources is increasing owing to continuous increase in share of groundwater to meet the water demand. The share of groundwater has increased substantially over a period of time and presently, about 65% of irrigation, 85% of rural and about 50% of urban domestic water supply is catered by Groundwater. Characterized as a hidden resource with multiple inputs and outputs acting simultaneously, there is a constraint of direct measurement in the groundwater system. However, studies of various outcome factors, many a times, would indicate the direct and indirect benefits of any interventions in groundwater systems.

Central Ground Water Board (CGWB) has conducted Brain storming sessions on artificial recharge through national seminars across the country in Nineties, before initiating the artificial recharge studies. CGWB initiated artificial recharge as experimental studies, which turned into pilot studies and then into Demonstrative studies in VIII to XI Plan Periods. Most of the studies were executed through State agencies, thereby building up their capacity and also effecting the knowledge transfer for replication. Based on the experiences, a manual on artificial recharge and technical brochures were brought out by CGWB and hosted in its website.

In deference to the water stressed conditions across the country, both Central & State Governments are dovetailing water conservation efforts of various agencies through many schemes. Artificial Recharge to groundwater projects are being implemented by State, Centre and NGOs and it is imperative that impact assessment be made of these projects.

CGWB with the domain expertise in the field of Groundwater has taken an initiative to prepare a standardized protocol to assess the impacts of artificial recharge projects. The experience of the Board in last five decades in artificial recharge experiments/projects and outcome of select studies in other parts of the World have been used to prepare the document. I am sure that the protocol will enable all the practitioners of groundwater science to bring about the standardized assessment in the country.

I wish them all the best for the future endeavours.

(G.C. Pati)

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PREFACE

Groundwater is being extracted to meet the ever increasing demand of irrigation, domestic and industrial purposes. As groundwater is taking the additional load to meet the demand, many parts of the country are becoming water stressed. Taking the cognizance of groundwater depletion in many parts of the country, both Central & State Governments are bracing up to dovetail many existing schemes towards water conservation efforts. Consequently, many artificial recharge projects are being taken up in the country to augment the precious groundwater resources.

Central Ground Water Board had taken up many such projects through VIII to XI plan period and also carried out impact assessment studies of the implemented artificial recharge projects. Based on the experiences, a manual on artificial recharge and technical brochures were brought out by CGWB and hosted in its website. In view of the many such projects being taken up across the country by different stake holders, a need was felt to prepare a standardized protocol for taking up impact assessment studies.

DrS.Suresh, Superintending Hydrogeologist, CGWB has compiled a protocol from the various reports of CGWB Regional offices and different studies across the world, which can be used as a standardized protocol for taking up impact assessment studies of Artificial Recharge projects. I am sure that the document will be found illuminating for the workers in the field of groundwater trying to assess the impacts of such artificial recharge projects.

I fondly wish that the document will be found useful by the mangers and practitioners in the field of groundwater.

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GUIDELINES FOR IMPACT ASSESSMENT OF ARTIFICIAL RECHARGE STRUCTURES/SCHEMES

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Abbreviation used in the document

m bmp	Meter below measuring point
MP	Measuring point
m agl	Meter above ground level
m amsl	Meter above mean sea level
Ha	Hectare
SMD	Soil Moisture Deficit
CD	Check Dam
RS	Recharge Shaft
RTRWH	Roof Top Rainwater Harvesting
PT	Percolation Tank
PP	Percolation Pond
DS	Desiliting
SSD	Sub Surface Dyke
SS Dev / WS Dev	Springshed Development / Watershed Development
GEC Methodology	Groundwater Estimation Methodology
GWRA	Ground Water Resources Assessment

1. SCOPE

Artificial recharge to ground water is defined as the recharge that occurs when the natural pattern of recharge is deliberately modified to increase recharge (ASCE 2001). In other words, artificial recharge to groundwater indicates the process of augmenting the recharge to groundwater exceeding the natural condition of replenishment through man-made interventions. Groundwater extraction to meet the increasing demands of fresh water has resulted in deepening of water levels and consequent impacts include drying of shallow aquifers, deepening of wells and increasing pumping costs. Augmenting recharge is normally taken up as a supply side measure to make the groundwater system sustainable. Based on the terrain conditions and availability of surplus source water, suitable artificial recharge structures are selected and designed to suit local conditions to make them effective. A preliminary assessment of groundwater system is a prerequisite for taking up any artificial recharge project, which Involves consideration of the following aspects:

1. Need for artificial recharge, defined by depth to water levels in comparison with the regional water table and declining water level trends indicating the depletion of aquifers
2. Scope of artificial recharge, defined by i) availability of surplus source water and ii) ability of the aquifer to accept the recharge
3. Benefit Cost Ratio, defining the economic viability of the project.

In view of the increasing water scarcity in parts of the country, measures for conserving/augmenting water resources are being now being taken up under many Government schemes. A realistic assessment of the impact of efforts towards conservation/augmentation is necessary for determination of the efficacy of the structures and for incorporating corrective measures wherever necessary.

Government of India has, in the recent past, been giving priority for water conservation augmentation measures and at present, several important schemes such as MGNREGS, Watershed Development programme etc. have water conservation as one of the focus areas. Ministry of Jal Shakti has been spearheading efforts for making water conservation a peoples' movement through the 'Jal Shakti Abhyan' campaign. National Water Mission (NWM) under the Ministry of Jal Shakti through its 'Water Talk' and 'Catch the Rain' campaigns have given impetus for awareness creation on the need and importance of rainwater harvesting. Experiments on artificial recharge to aquifers started in India from1980 onwards by Central and State Government Departments and individually by some NGOs in different parts of the country where early signs of overexploitation of ground water were evident. Central Ground Water Board (CGWB) undertook an experimental artificial recharge scheme during early Nineteen Eighties through injection wells around Karbatiya in Central Mehsana, Gujarat where sufficient water was available from Saraswati River during monsoon period. Brainstorming sessions on artificial recharge were organized by CGWB through national seminars across the country in the 1990's, before initiating the artificial recharge studies in the country. CGWB initiated artificial recharge as experimental studies, which turned into pilot studies and then into Demonstrative studies in VIII to XI Plan Periods. Most of the studies were executed through State implementing agencies, thereby building up their capacities and also facilitating the knowledge transfer necessary for replication of the structures elsewhere in similar hydrogeological settings. Based on the lessons learned, a manual on artificial recharge and a few technical brochures were brought out by CGWB and hosted in its website. Preliminary assessments of the impact of the schemes on the local ground water regime were also taken up by CGWB subsequently and reports published.

The manuals and impact assessment reports of CGWB are hosted in CGWB website (http://cgwb.gov.in/reportspublished.html). Based on the experience gained during implementation of the schemes and select methods for impact assessment in vogue, guide lines for carrying out Impact Assessment Studies of Artificial Recharge structures/schemes are provided in the following sections.

2. PURPOSE

Impact of artificial recharge/water conservation structures constructed for augmenting/ conserving water on the prevailing ground water regime/ environment may vary widely. Realistic assessment of impacts of these interventions are necessary to assess the efficacy and cost-effectiveness of the structures for planning future interventions Groundwater being a hidden resource and a dynamic system in which recharge and extraction take place simultaneously at multiple points, indirect indicators are often made use of to understand the impacts, in addition to the direct indicators.

The purpose of this document is to suggest broad guidelines on the methodology of impact assessment studies, so as to make a common protocol for use by the stakeholders.

3. TYPES OF ARTIFICIAL RECHARGE STRUCTURES

Artificial recharge can be categorized mostly into three categories, viz., as surface spreading, induced recharge and recharge by injection. The surface spreading methods are suited for unconfined aquifers exposed near surface without any impermeable layers between aquifer and the surface, while the induced recharge can be useful in case of availability of abundant supply of source water and additional recharge is induced by head dependent flow due to pumping and in case of confined aquifer, the recharge has to me made through injection with pressure more than the pressure within the aquifer system.

The types of artificial recharge structures depend primarily on terrain conditions. In case of water spreading methods, structures like gully plugs, nalah bunds, percolation ponds etc. can facilitate augmented infiltration, whereas in case of presence of impermeable layers between aquifer and the surface, the structure has to penetrate the impermeable layer to facilitate the movement of water into aquifer. Structures such as recharge shafts, recharge wells etc. could be the suitable in such cases. In case of recharge of confined aquifers, water may have to be injected into the aquifer system under pressure to facilitate recharge.

In India, various structures are being used for artificial recharge and are known by different names in different States as per the local practices. Different types of structures suitable for various terrain conditions and the use of different terminology for the same structures in various States have resulted in more than 25 types of artificial recharge structures (CGWB, 2020). In order to group different structures and bring in standardization, these structures have been classified into 10 groups. Further, structures which are not very common or are prevalent in specific areas have been grouped under a separate category titled 'others'. Details of grouping of various Structures for each State is given in **Annexure 1**

4. IMPACTS

The impact of any artificial recharge structure/scheme can be either direct or indirect impacts as listed below.

- Direct Impacts
    - **Rise in water level** – Arresting of Declining water level (rate/absolute Value)
    - **Increase in cropped Area** – Increase in the area cultivated with water intensive crops or with the existing cropping pattern
    - **Increase in yield of wells** – Wells sustain pumping during lean months and pumping hours reduced for the same command area
    - **Increase in pumping hours** – Longer duration of pumping or increase in number of pumping days.
    - Maintenance of water level/yield of wells/command area during years of deficit rainfall
    - **Improvement in Quality** – Improvement in ground water quality due to dilution effect (changes in concentrations of dissolved ions, individually or collectively).
- Indirect Impacts
    - Increase in vegetation cover in surrounding areas
    - Increase in non-seasonal flow in the streams/ rivers
    - Less frequent development of cracks in soil due to increased soil moisture.

The impact assessment should commence prior to initiation of construction of artificial recharge structures and should ideally continue for at least two water years after construction. The study should be inclusive of direct and indirect parameters indicating the impacts. In general, the area of influence of a single structure could be taken as 1 sq.km on the downstream side and depending on the flow direction, the impact will be pronounced. The impacts may be reflected in the changes in one or more factors mentioned above.

The use of tracers and isotopes are also in vogue to study the impacts in several countries. The tracers used for determining the movement of groundwater can also be used to infer about the recharged water. The use of tracer for impact assessment study can be grouped into two steps, viz., selection of tracer and actual study using the tracer. The selection of tracer for the study should be made on the following criteria.

- Safe to use and in concentrations high enough for accurate measurement
- Tracer/aquifer interaction such as adsorption has to be negligible.
- Tracer to be accurately quantifiable at very low concentrations

- Continuous and cost effective monitoring of the tracer concentration is required

The species include halogens (mainly fluoride and bromide), boron, zinc, EDTA (Ethane diamine tetra acetic acid), Rhodamine WT, etc. Rhodomine WT is approved for use in potable water by United States Environment Protection Agency (USEPA). However, it may produce diethylnitrosamine, a known carcinogen, in waters with high nitrite contents or may result in undesirable by-products in chlorinated water. Further, it may be adsorbed in the powdered granular materials, making it unsuitable for unconsolidated sand formation. Hence it may not useful in unconsolidated formations with high nitrate or water with free chlorine and in other cases, Rhodomine WT is a potential tracer (Rukin., N et.al., 1995).

Isotopes are elements with same atomic number and different atomic weights due the fact that they have same number of protons in the nucleus but different neutrons. Isotopes occurring naturally in the environment in varying concentration are termed as Environmental Isotopes and can be either Stable or radioactive. Isotope techniques have been extremely helpful in providing new insights into hydrological processes. The use of naturally occurring isotopes, to track the source and movements of water and solutes, to assess water budget and geochemical/mathematical models has been gaining enormous importance. Environmental isotopes, both stable (^{2}H &^{18}O) and radioactive (^{3}H &^{14}C) are generally used to study different hydrological aspects, viz., source and origin of groundwater, mechanism of groundwater salinization, source and origin of groundwater pollutants, aquifer–aquifer interconnections, surface water groundwater interconnection.

The absolute abundance ratio of isotope is not usually measured and instead the difference in the ratio of the heavy isotope to the more abundant lighter isotopes of the sample with respect to a reference is determined. The difference is expressed in δ and the δ is generally expressed in parts per thousands (‰) and written as

$$\delta (‰) = \frac{R_{sample} - R_{Standard}}{R_{Standard}} \times 1000 \qquad \text{------------} \quad 1$$

where 'R' represents the particular isotope ratio (D/H or $^{18}O/^{16}O$). The precision of measurement of the $\delta^{2}H$ is ± 1 ‰ and $\delta^{18}O$ ± 0.2 ‰. The normal range of variation of $\delta^{2}H$ and $\delta^{18}O$ in nature is approximately –200 to +100 ‰ and –30 to +10 ‰ respectively.

The variation of isotopic composition starts in hydrologic cycle itself and it is termed as isotopic fractionation. The physical and chemical processes during process of hydrologic cycle result in isotopic fractionation. The physical process includes evaporation and chemical processes are resultant of the variation in strength of the chemical bonds.

In the evaporation processes, the lighter isotopes tend to escape from the liquid phase far greater than heavier isotope, resulting in the enrichment of heavier isotopes in the evaporated water. In other words, Deuterium or Oxygen -18 gets enriched in the evaporated water.

The chemical bond in a heavy isotope will have a lower vibrational frequency than an equivalent bond with a lighter isotope and hence the bond with the heavier isotope will be stronger than that of lighter isotope resulting in enrichment.

The variation in isotopic fractionation can be expressed in terms of Temperature Effect, Amount Effect, Altitude Effect and Continental Effect. The composition of precipitation depends on the temperature at which oceanic water is evaporated into the air and even more important, the temperature of the condensation at which clouds and rain or snow is formed. The net effect is expressed in the following empirical function (Mazor, 1997).

$\delta^{18}O$ = 0.7 Ta – 13 ‰ or 0.7‰/ 0C and in a similar way δ D = 5.6 Ta – 1000 ‰ or 5.6 ‰/ 0C, where Ta is the local mean air temperature. Thus the temperature dependence on isotopic composition can to a large extent responsible for large variation in the isotopic composition of water.

The clouds as they rise up the mountains, the heavy isotopes are depleted and the residual precipitation gets isotopically lighter. It has been inferred that altitude effect is –26 ‰/100 m of altitude. This effect is not masked by temperature effect.

The isotopic composition also depends on the storm events, heavier the rain, more negative will be the δD and $\delta^{18}O$. Lower ambient temperatures cause the formation of clouds with lighter isotopic composition (temperature effect); lower temperature also causes heavier rains. Falling raindrops undergo evaporation, enriching the falling rain in heavy isotopes. The effect is less severe both when ambient temperatures are low and when the amount of rain is large. (Mazor, 1997).

The isotopic composition tends to have more negative values away from ocean, as the rain is gradually precipitated by condensation of water molecules with heavier isotopes initially and the residual moisture in the air masses becomes thus progressively becomes lighter in isotopic composition. However, this effect is often masked by temperature and altitude effects.

Thus the source of recharge from surface water system would be affected by evaporation and would show depleted values, while the water from higher reaches will have enriched values. The complication comes when the source water for recharge and the basic groundwater system is of similar isotope composition, it would be difficult to separate the recharged water. The combination of stable and radioactive isotope can be effective tools to determine the impact of artificial recharge projects. The combination of chemical characterization of source water can be successfully combined with isotope composition to substantiate the isotopic studies.

International Atomic Energy Agency (IAEA), Vienna has brought out a publication on isotope application for artificial recharge studies (IAEA-tecdoc-1723) entitled “Using isotopes for design and monitoring of artificial recharge systems”. As it is a vast subject on its own, readers are recommended to read the IAEA publication for more details.

The groundwater science, many a times works with circumstantial evidences and the impact is studied with multiple factors indicating varied responses. Hence, a holistic picture is seen by combining all the evidences to arrive at the inferences.

5. METHODOLOGY FOR IMPACT ASSESSMENT

5.1 Data Collection

The methodology should essentially describe the procedures to study the impacts, both direct and indirect, combining all available techniques. However, as a prerequisite, necessary data needs to be collected to carry out the impact assessment. If the objective of the project is to bring about change in a Block/District/State, the area of consideration for impact assessment study also would be a block/District/State as the case may be. Alternatively, the impact can also be studied for a single structure, in which case data collection is generally made within the vicinity of 1 sq.km downstream side along with area considered up to 100m on the upstream side. Thus it can be a large scale project or small scale project and the establishment of observation wells for data collection will be as per the objective. The following protocol is suggested for data collection

- Establishment of observation wells for
    - monitoring of water levels & water quality
    - changes in cropping pattern (monitoring the changes in command area of the observation well)
    - changes in yield of wells
    - Sample collection for chemical and isotope analysis
    - Identification of wells for tracer study
- Establishment of key wells in upstream side up to 100m and downstream side up to 01 km
- The information to be collected is given as Data Collection Form (Table 1)

Table 1 Data Collection Form				
1.Well No			2. Date	
3. Well Owner			4. Village	
5. Location			6. Latitude	
7. Longitude			8. Block	
9. District			10. State	
11. Depth of well (m bmp)			12. Height of Measuring Point (m agl)	
13. depth to water level (m bmp)			14. Pumping Device (Manual/Electric/Diesel/Solar)	

Table 1 Data Collection Form						
15. HP of Pump				16. Pumping Hours/day (Kharif/Rabi/Summer)	K- R- S-	
17. Pumping days (Kharif/Rabi/ Summer)	K- R- S-			18. Yield of well (Litres/Hr)		
19. Cropping Pattern						
Kharif				Rabi		
Crop	Area (Pre)	Area (Post)		Crop	Area (Pre)	Area (Post)
Summer				20.Actual Rainfall in the area after construction of project		
Crop	Area (Pre)	Area (Post)		21. Any Other information		
				1. Yield from 01 Ha for each crop pre and post implementation		

- The impacts can be summarized as given below:

Table 2 Summary of Impact Assessment			
S.No	Particulars	Pre-Project	Post Project
1	Period of Study		
2	Changes in Depth to water level (m)		
3	Changes in the WL Trend (m/Yr)		
4	Changes in Cropping intensity (%)		
5	Changes in cropped area		
6	Changes in yield of wells		

Table 2 Summary of Impact Assessment			
S.No	Particulars	Pre-Project	Post Project
7	Changes in pumping hours		
8	Changes in seasonal flow (days of flow)		
9	Changes in quantum of flow		
10	Changes in vegetative cover (Ha)		
11	Changes in Moisture condition* (Ha)		
12	Changes in water quality **		
13	Isotopic composition***		

* Changes in moisture condition can be expressed as percentage reduction in SMD or as increase in area of wetness around the structure.

** Suitable parameters may be identified to showcase the dilution effect, through analysis will be made for all basic parameters

*** The isotopic composition will indicate mixing of the recharging water, if they are different from that of the groundwater system

5.2 Method of Analysis

There is no unique method to assess the impact of artificial recharge projects, as all the impacts may or may not manifest in a project. Groundwater being a hidden resource and with multiple inlets and outlets from the system, one or more factors have to be combined to evaluate the impacts. The analyses of data for various aspects are individually discussed in succeeding sections with examples of impact assessment made in the field to showcase the importance of various factors. The agency or individuals may plan for data acquisition so that impact assessment can be made through as many factors as possible to infer the realistic assessment.

5.2.1 Water Level Analysis

The analysis of water level could be considered on the following lines.

1. **Long term water level trend**: The reversal or arresting the long term declining water trend indicates a positive impact. The change in slope of the trend line can be a measure of positive impact. The slope of the trend line prior to project implementation should be compared to slope of the trend line including the period of post implementation and the difference can indicate the impact.
2. **Absolute difference in water level:** The depth to water level of the corresponding seasons, prior and post artificial recharge project implementation can indicate the impact of artificial recharge. The absolute difference in water level can indicate the impact, considering the fact that there is no change in all other processes taking place in the location.

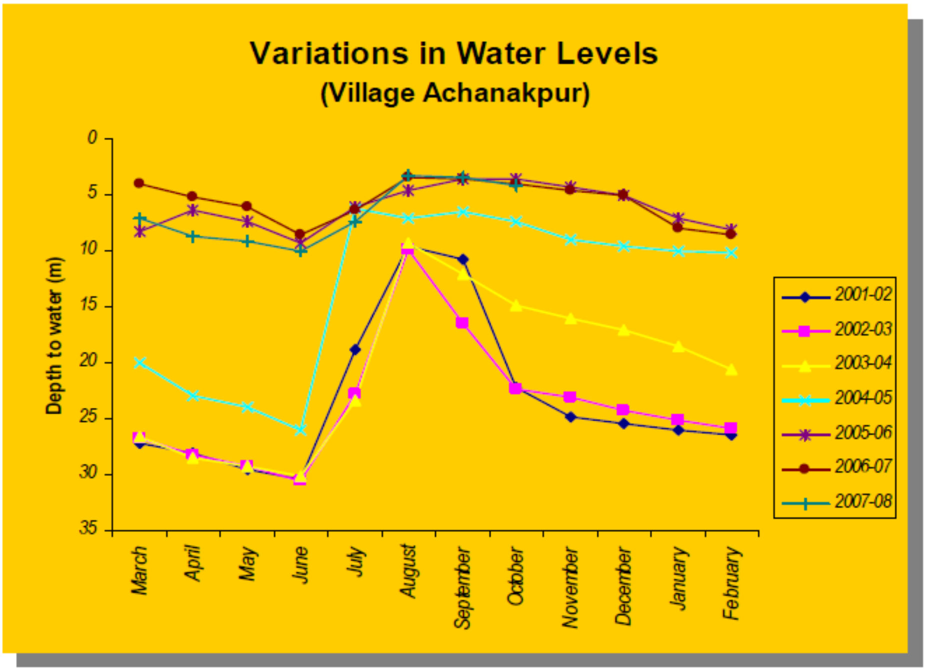


Fig.7. Monthly variations in water levels in different years in a representative observation well at Achanakpur in Guira sub-watershed

(After CGWB, 2011)

3. **Rise/Fall of water level in relation to the change in rainfall**: The post implementation period may be characterised by drought or lesser rainfall, resulting in fall in water level. In such cases, the criteria of water level may not be applicable for determining the impact.
4. **Rise/Fall of water level in relation to the increase in groundwater development:** There could be increased groundwater development consequent to implementation of artificial projects because of which the water level may not show rise. In such cases, the criteria of water level may not be applicable for determining the impact.

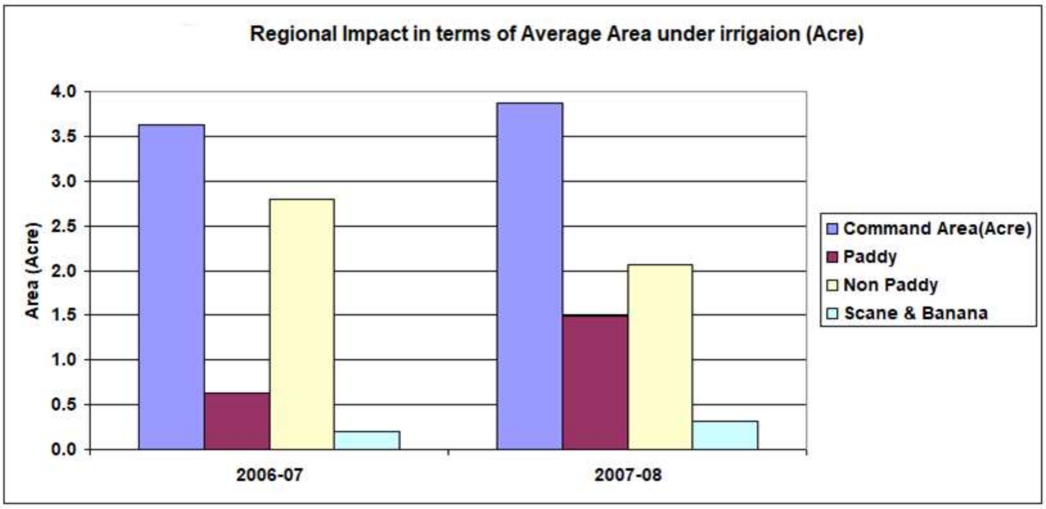
5.2.2 Cropping Pattern Analysis

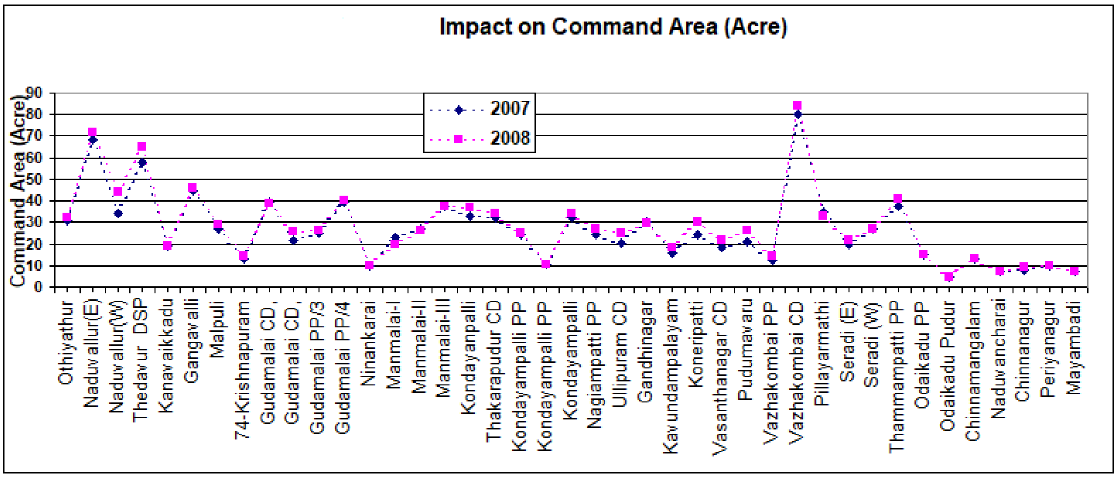
The analysis of cropping pattern could be considered on the following lines.

1. **Increase in Cropping Intensity:** An increase in the cropped area in post implementation period in reference to pre implementation period may indicate availability of additional groundwater resources due to increase in yield of wells or sustainability of wells during dry months. The increase in cropping intensity can be taken as positive impact.

Case study:

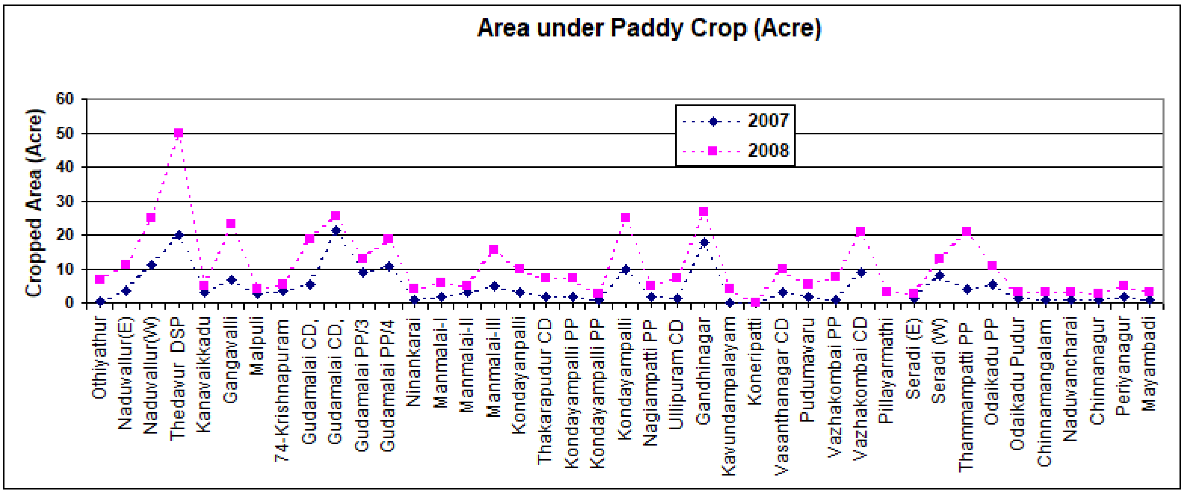
Gangavalli Block, Salem District Tamil Nadu was one of the notified blocks and had the highest groundwater development (221%) as per the computation of Dynamic resources of the State of Tamil Nadu as on 31.03.2004. A demonstrative artificial recharge project was taken up to improve the overall groundwater situation for increased productivity of crops and sustainable rural water supply. The scheme for artificial recharge was formulated with a two-pronged approach, viz., augmenting the irrigation sources and drinking water sources. The proposals include structure for augmenting water supply points and for augmenting the irrigation sources. A total of 41 structures, which include, check dams, percolation ponds, injection wells and revitalization of existing structures, etc. were constructed to augment the groundwater resources. Observation wells were established adjacent to the structures to study the impact. The assessment study showed positive impacts in terms of cropping area, well yield, water level rise etc. (Suresh & Subburaj, 2008)





(After Suresh & Subburaj, 2008)

2. **Increase in area under water intensive crops:** Farmers switching over to more water intensive crops with more returns during post implementation period indicate augmentation of groundwater resources. Thus, increase in area under water intensive crops can be taken as a positive impact.



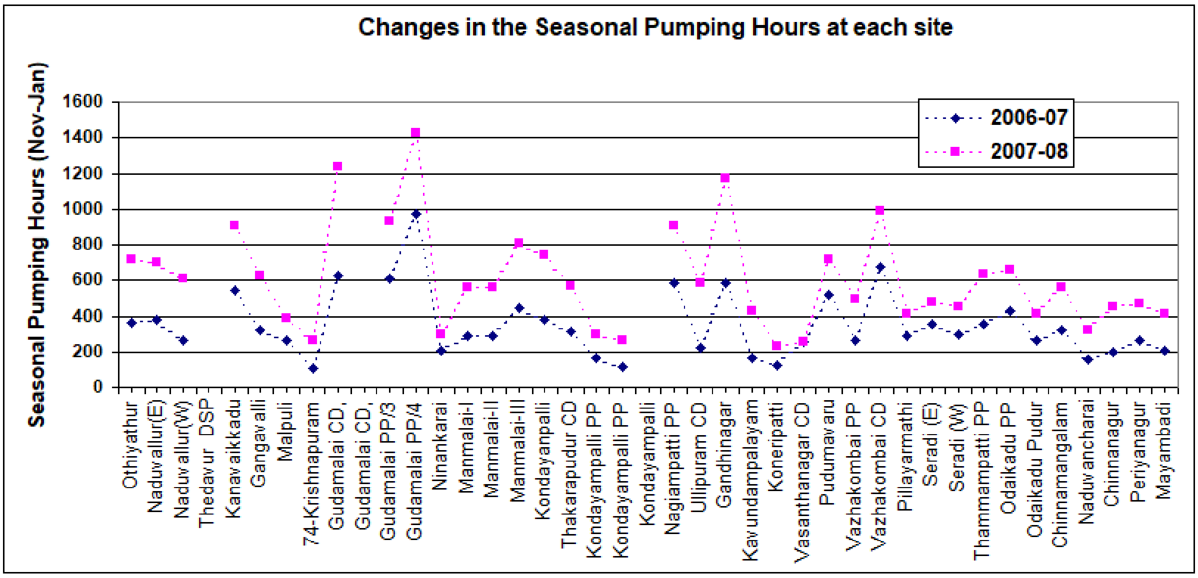
(After Suresh & Subburaj, 2008)

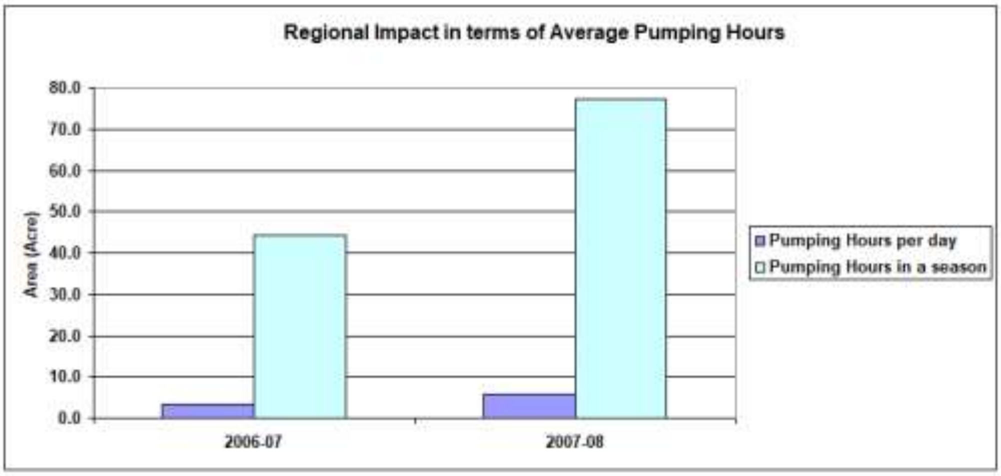
3. **Maintaining same area under cultivation in spite of reduction in rainfall:** In the post implementation period, the area may receive lesser rain fall then pre implementation period or may be reeling under drought. In such cases, if the copped area/cropping intensity remain unchanged in spite of lesser rainfall, it again indicates a positive impact.

5.2.3 Groundwater Extraction Analysis

The study of groundwater extraction in terms of well yield or pumping hours prior to implementation and post implementation can also indicate the impact of artificial recharge structures. The analysis of Groundwater Extraction can be made on following lines

1. **Increase in number of wells:** An increase in number of wells also indicate that groundwater resources have been augmented and observing the positive impact of rise in water level or increase in yield of wells, the farmers may go in for additional wells. The increase in number of wells can also be taken as an indication of positive impact.
2. **Well Yield:** The yield of the wells during post implementation period may become sustainable and have continuous flow instead of intermittent coughing of wells observed during pre-implementation period. Further, the increase in yield may also result in more cropped area or increase in cropping intensity.
3. **Pumping Hours:** The increase in yield of wells may bring in increase in pumping hours coinciding with the increase in cropped area. In case of the limitation of area available for farmers for cultivation, because of increase in yield, the farmers may be able to irrigate the same area with reduction in the pumping hours.





(After Suresh & Subburaj, 2008)

5.2.4 Water Quality Analysis

In India, artificial recharge is generally advocated for mainly good quality formation water. However, the artificial recharge can also be used to improve the water quality in case of anthropogenic contamination where in the recharged water is used to dilute the contaminated water. This may not be successful in case of contamination due to natural aquifer materials, as the augmented water also has to go through the same aquifer material and may not result in dilution. In such case, blending of poor quality water and harvested water at the surface in right proportion, before water supply can bring the water quality to the desirable limit. Thus in reference to the water quality factors, a comparison of the concentration of various ions, EC/TDS during prior and post implementation can indicate the impact of artificial recharge as dilution effect.

5.2.5 Tracer Analysis

The movement of tracer from the artificial recharge structures to groundwater system can indicate the travel path of recharge water. The non-interactive tracers can be injected into harvested water and time taken for the tracers to reach the observation wells can determine the velocity of groundwater flow. The analysis of data can provide following information

1. Velocity of groundwater flow
2. Based on the velocity, time taken for reaching farther observation well can be determined and on observing the tracer in the observation wells, area of influence of the structure can be determined.
3. In order to expedite the process of tracer reaching the distance part, tracer can be injected and distant well can be pumped to extract the tracer to study the groundwater flow and indirectly the impact of recharge.

Case study:

The State of Qatar Ministry for Municipal Affairs and Agriculture was considering artificially recharge of two carbonate aquifers in northern Qatar. A feasibility study comprising drilling and testing of boreholes and a programme of injection and re-abstraction tests were carried out at four sites. At some of these sites the only water available for injection was of similar composition to the native groundwater at the test site and Rhodamine WT fluorescent dye was used successfully to label the injected water. Analysis of data indicate different recoveries of injected water calculated from Rhodamine WT. (After Rukin., N et.al., 1995)

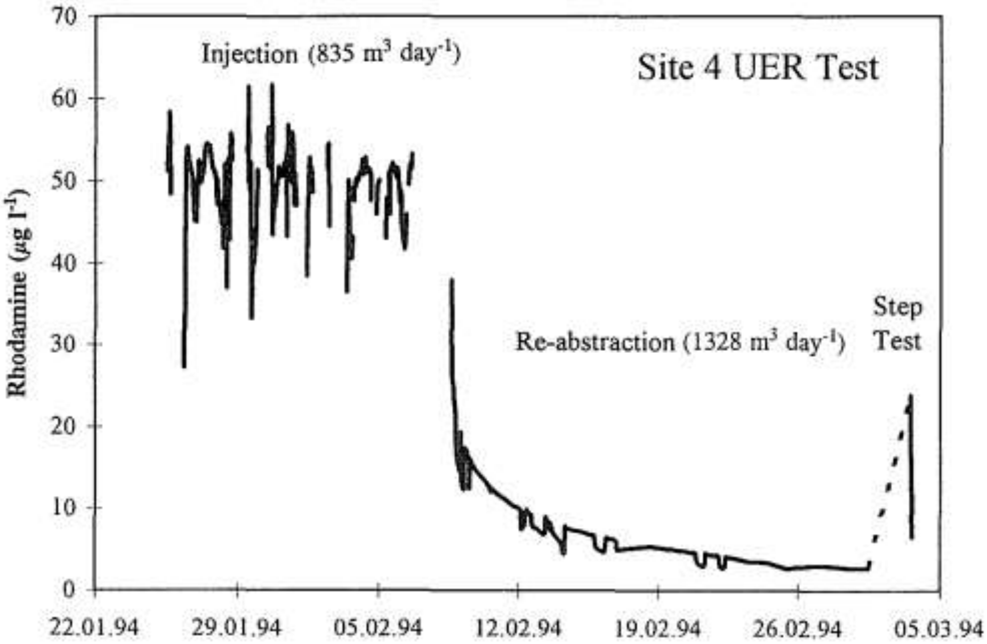


Fig. 1 Examples of Rhodamine WT concentrations during injection, re-abstraction and the final step discharge test. Injection and re-abstraction rates are noted.

5.2.6 Isotope Analysis

Stable Isotopes can be effectively employed to confirm the mixing of water from artificial recharge structures (surface storage). The surface storage will be enriched due to evaporation effect, while the groundwater will be plotting along Local Meteoric Water Line. If the groundwater sample, plots nearer to the evaporation line in post implementation project period, it indicates the impact of recharged water.

5.2.7 Water Balance Study

The water balance methodology can be used, when artificial recharge is taken as a project to improve the groundwater condition at the level of watershed or block. The principles of Groundwater Estimation Methodology (GEC) in vogue in India can be used to study the impact of artificial recharge structures. In GEC Methodology, the recharge is assessed using the water level fluctuation data and the following equation is used to compute the recharge

$$R = A * WLF * SY \qquad \text{........ 2}$$

Where,

A = Area in sq.km
WLF = Water Level Fluctuation in m
SY = Specific Yield
R = Recharge in M.Cu.m

Ground Water Resource Assessment (GWRA) provides annual recharge in the area assessed prior to artificial recharge implementation and based on the water level fluctuation monitored during post implementation period, recharge can be computed using the equation 2 and the quantum of augmented recharge can be worked out by determining the difference with the GWRA of pre implementation period.

6. PREPARATION OF REPORTS

All the methods given above, though may be ideal for impact assessment, the restriction of fund, time and logistics, it may be prudent to use the combination of one or more methods to study the impacts of artificial recharge projects. Thus the proponents may decide about the methodology for impact assessment and establish observations wells and collect the data prior to project implementation as per the pre-decided procedures for impact assessments. As there are subjectivities due to the availability of data, a generalized layout for the report is suggested for the impact assessment study of Artificial Recharge Projects.

1.0 Introduction

2.0 Background information

- 2.1 Area Details
- 2.2 Climate/Rainfall
- 2.3 Hydrogeology

3.0 Need for Artificial Recharge

4.0 Methodology adopted for Impact Assessment

5.0 Data Analysis and Inferences

6.0 Source of Data

7. REFERENCES

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Annexure -1

Grouping of AR Structures

S.No	State	CD	RS	RTRWH	PT	Gabion	DS	Injection wells	SSD	SS Dev / WS Dev	Others			
1	Andhra Pradesh	CD		RTRWH	PT									
2	Bihar	CD	RS	RTRWH	PT(H) +PT (M)		DS-tank + Revival of UWB+Mauns + Ahar Payne	Inj. Wells			CB &T(H)	GP	NB	CB & T (M)
3	Chhattisgarh		RS	RTRWH	PT						GP/CB/GS	NB/CP/KT Bhandara		
4	Delhi	CD	RS & RT		RTRWH									
5	Goa										Vented Dam			
6	Gujarat	CD		RTRWH	PT						Recharge through defunct tube wells			
7	Haryana	CD	RS	RWH							FP			
8	Himachal Pradesh	CD/ NB/CP	RS	RTRWH		Gabion	Modification of Village Pond/Tank	Inj. Well	SSD		Check dam cum SSD			
9	Jharkhand	NB/ CD/GP	RS	RTRWH area 300 to 1000 sq. m.	PT						RTRWH area more than 1000 sq. meter			
10	Karnataka	CD	RS		PT						SSD & CD Cum SSD			

Annexure -1

Grouping of AR Structures

S.No	State	CD	RS	RTRWH	PT	Gabion	DS	Injection wells	SSD	SS Dev / WS Dev	Others			
11	Kerala	CD		RTRWH	PP	GP/Gabion	0	injection wells	SSD		CB	NB	RTRWH in Commercial buildings	
12	Madhya Pradesh	CD	RS	RTRWH in Major Urban Area	PT						VP	NB/CP		
13	Maharashtra	CD	RS	RTRWH	PT						Urban Runoff Harvesting			
14	NE States	CD		RTRWH		Gabion				No. of villages with springs	NB			
15	Odisha	CD	RS		PT				SSD		NB/CB	ST conversion to PT		
16	Punjab	CD	RS	RTRWH				Injection Wells			FP			
17	Rajasthan	CD	RS		PT						FP	CAT(ha)	Tanka	Anicut

Annexure -1

Grouping of AR Structures

S.No	**State**	**CD**	**RS**	**RTRWH**	**PT**	**Gabion**	**DS**	**Injection wells**	**SSD**	**SS Dev / WS Dev**	**Others**			
18	Sikkim	CD/CD cum DW with conveyance drain/pipe		RTRWH		Gabion /Contour bund			SSD	Spring Shed Development	Rej of Lake/pond rejuvenation/excv of new pond	Rainwater harvesting in slope		
19	Tamilnadu	CD/NB	RS/ BW		PP						FP/RP	RT	RTW	
20	Telangana	CD		RTRWH	PT									
21	Uttar Pradesh	CD/NB/CP	DW/ TW/ RS	RTRWH(area in sqkm)	PT						Pond			
22	Uttarakhand	CD		RTRWH	PT						Chalkhal	CT		
23	West Bengal	Check dam		RTRWH (Munc/Cor.) + RTRWH (Cen.Town)	PT in CT & MC	Gabion /Contour bund		injection wells	Sub-Surface Dyke		REET with RS	DW Recharge		
24	UT-Andaman & Nicobar Islands	Check dam		RTRWH	PT	Gabion /Contour bund			SSD	Springshed Dev with CAT and Micro- WS Mgt	REET with RS			
25	UT-Chandigarh		RS											
26	UT-DNH	CD		RTRWH	PT						Urban Runoff Harvesting			

Annexure -1

Grouping of AR Structures

S.No	**State**	**CD**	**RS**	**RTRWH**	**PT**	**Gabion**	**DS**	**Injection wells**	**SSD**	**SS Dev / WS Dev**	**Others**			
27	UT-Daman & Diu			RTRWH										
28	UT- Jammu & Kashmir			RTRWH		Gabion/ NB/SS Bhandara				Diversion of flows from Perennial Nalas/Springs	Rev & Res. Pond	Artificial Glaciers		
29	UT-Lakshadweep			RTRWH										
30	UT-Puducherry	CD/NB	RS/BW		PP						FP/RP	RT	RTW	
31	UT-Ladhak					Gabion				SS Development		Artificial Glaciers		

CONTRIBUTORS' page

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