



Technologies for Sustainable Groundwater Management

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Preface

About 98% of liquid freshwater in the earth occurs as groundwater, and hence it is the most valuable freshwater resource. Because of its several inherent qualities as well as the relative ease and flexibility with which it can be tapped, it has become most reliable and very important source of water supplies in all climatic regions including both urban and rural areas of developed and developing countries. It is estimated that groundwater provides about 50% of the current global domestic water supply, 40% of the industrial supply, and 20% of water use in irrigated agriculture. However, overexploitation and continued mismanagement of groundwater resources to supply ever increasing demand of water has led to water shortages, increased pollution and degraded ecosystems worldwide. Hence the key concern is how to maintain a long term sustainable yield from the aquifer in the face of impending climate change and socio-economic factors.

In spite of favourable national scenario on the availability of groundwater, several areas of our country are facing water scarcity due to intensive groundwater exploitation. The experiences in the field of water management in India have shown that unbalanced use and mismanagement of water resources have either lowered groundwater levels or caused waterlogging and salinity in different parts of the country. Excessive groundwater exploitation has led to alarming decline in groundwater levels in several parts of the country such as Tamil Nadu, Gujarat, Rajasthan, Punjab and Haryana. In recent studies, the analysis of GRACE satellite data revealed that the groundwater reserves in the states of Rajasthan, Punjab and Haryana are being depleted at a very alarming rate. The depletion of groundwater resources has increased the cost of pumping, caused seawater intrusion in coastal areas and has raised questions about sustainable groundwater supply as well as environmental sustainability. Therefore, efficient and judicious utilization of groundwater resources is essential as a part of sustainable water management strategy.

The All India Coordinated Research Project on Irrigation Water Management has been working to address the research issues related to irrigation water management in 25 Centers distributed all over the country. Out of them, 9 Research Centres located at Ludhiana, Udaipur, Junagarh, Rahuri, Coimbatore, Pantnagar, Jabalpur, Raipur and Pusa are specifically working on research issues related to groundwater management. An effort has been made to compile the technologies developed on groundwater management by the concerned Centers of AICRP on Irrigation Water Management and publish them in the form of a bulletin. We hope that the bulletin will be useful for agricultural and water resources researchers, planners and other stakeholders of the country.

Authors

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Use of Abandoned Wells for Artificial Groundwater Recharge

Relevance: It is observed during heavy rainstorms that there is lot of runoff generated from the fields which not only damages the crops but significant volumes of water also get wasted. So there is a dire need to conserve this excess rainfall in the agricultural fields by harvesting rainfall for groundwater recharge. In agricultural fields, a number of pumping wells have gone dry due to lowering of groundwater and therefore abandoned well structures are found in the fields. Therefore, efforts were made to artificially recharge groundwater using surplus canal water/ agricultural runoff through these abandoned wells.

Description of technology: Near the abandoned well, a pit is dug so that most of silt coming along the excess runoff settles inside the pit and overflow from the pit is diverted into the well. The design diameter of the pit is 3.8 m and depth of pit is 3 m. The pit is conical in shape and bottom diameter is 0.9 m. The pit is filled with broken bricks which can be acquired from the dismantled old constructions. Also this pit is lined with flexi sheets so that walls of the pit remain intact. The observation wells have been installed to monitor the water table depth and water quality.

Output and scalability: A recharge rate upto 7.5 lit/sec was observed in the abandoned dugwells in Punjab. The EC varied from 0.26 to 0.67 dS/m for samples in abandoned dry wells. The RSC values were within permissible limits for pre-monsoon, monsoon and post-monsoon season. The pH varied from 6.76 to 8.46. The microbiological / insecticide / pesticide contamination were also found below determination limit. It was concluded that the abandoned wells can be used for groundwater recharge using surplus runoff from agricultural field as well as surplus canal water. This technology may be adopted for water recharge wherever the good quality agricultural field runoff or surplus canal water is available in good amount.



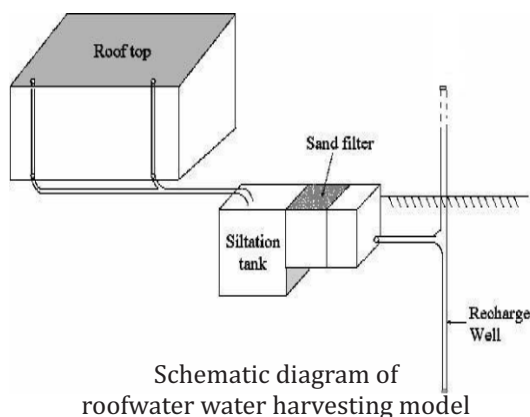
View of artificial groundwater recharge through abandoned wells

Rooftop Water Harvesting for Groundwater Recharge

Relevance : Due to overexploitation, groundwater level is fast declining in different states of India like Punjab, Haryana, Rajasthan, Tamil Nadu and western UP. Groundwater depletion is more in urban areas due to higher population concentration and more domestic consumption by groundwater withdrawal. Therefore, there is urgent need to recharge the groundwater aquifer in urban areas from the rainwater from rooftops. There are about 1.4 million residential houses in urban areas and 2.6 million houses in rural areas of Punjab. Assuming average covered area of each house to be 100 m^2 about 140 million m^3 of rainwater can be harvested for groundwater recharge each year based upon average rainfall condition of each district.

Description of technology : Rooftop rainwater harvesting is the technique through which rainwater is captured from the roof catchments and stored in reservoirs. Harvested rainwater can be stored in sub-surface ground water reservoir by adopting artificial recharge techniques. This will not only improve the quality of groundwater but also check the declining of water table problem to some extent. In the developed technology, the harvested roofwater is conveyed to the filtration chamber through a pipeline. In the chamber, filtration of harvested water is done horizontally through gravel placed between two sheets of wire meshes. In case of clogging of the filter, the wire mesh sheet can be removed and the gravel can be cleaned.

Output and scalability : More than 100 rooftop rainwater harvesting structures at different locations in the State of Punjab have been constructed. Nine structures are installed in Jain Colony alone in Hoshiarpur. The decline of groundwater level has been considerably checked due to the rooftop rainwater harvesting structures. The technology can be used at all places and slowly it is becoming mandatory in all residential buildings in most of the states.

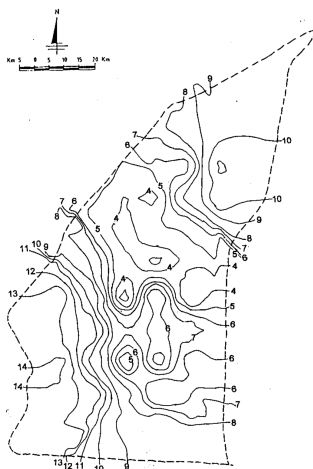


Regional Water Balance for Sustainable Water Management

Relevance : The State of Punjab is facing the problems of declining groundwater table and deterioration of groundwater quality and there are indications that the water availability would soon emerge as a limiting factor even to sustain the present production levels unless remedial measures are undertaken immediately. Numerical groundwater models can be useful in such scenarios as they can simulate groundwater flow scenarios under different management options and thereby help in taking corrective measures for sustainable water resources management.

Description of technology : Digital computer model based on finite difference approach were adopted to South western Punjab and Sirhind Canal tract. Regional water balance studies were undertaken to estimate the water resources. Groundwater management models were prepared and simulated by varying cropping pattern/area under crops so that there is no depletion in groundwater resources of Punjab state. MODFLOW as standard groundwater model was found useful and efficient in such modelling studies.

Output and scalability : A simulation–optimization model for Sirhind Canal tract of Punjab was developed and it was found that after reducing paddy area, the area falling under deep groundwater table conditions diminished. The area under water table depth range of 10-15 m reduced from 48.4 to 47.4, 46.4, 44.1 and 41.6 per cent when paddy was diversified by 5, 10, 20 and 30 per cent respectively. Maximum use of canal water and groundwater pumpage as per irrigation requirement depending upon the quality of groundwater to meet 90 per cent ET demand was the best management strategy for long-term management of rising water table in the southwest Punjab. The modelling methodology being generic in nature, is also useful for other regions of the country.




Predicted water table depth after five year under best management strategy in South-west Punjab

Decision Support System for Estimation of Pumping Energy Requirements

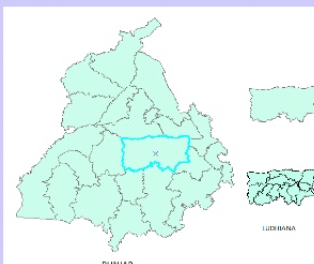
Relevance : Most of the farmers are facing problem for selection of pump sets and its components because of lack of knowledge about pumping system. This leads to ineffective use of pumps to irrigate their fields. Wrong selection of pump sets and its components may lead to failure of the system. If the pump performance specifications are not matched with site operating conditions, it leads to consequences that affect safety, reliability, capital costs, operational costs etc.

Description of technology : A Decision Support System (DSS) was developed under 'PHP' server side scripting language which provides the information of groundwater behaviour and energy requirement for pumping set at micro level in time and space. This helped for proper selection of pumping sets. A Spatial Decision Support System was developed for assessing the pumping energy requirement of irrigation pumpsets.

Output and scalability : The DSS provides information on water table depth, trend of rise/fall of water table and horsepower requirement of the submersible pump set and advice on the specifications of the accessories / components required for installation of tubewells based on the cropping pattern and location. This DSS can be used for other irrigation commands even outside the state of Punjab.


**WEB BASED DECISION SUPPORT SYSTEM
FOR ASSESSING PUMPING ENERGY REQUIREMENT
USING GEOGRAPHICAL INFORMATION SYSTEM (G.I.S.)**

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**The total Discharge Required = 14.56 ltr/sec. The total Hp Required = 18.92 hp
Farmer should select motor available in the market close to total hp required**

Optimum Spacing Between Tubewells

Relevance : It has been observed that farmers install their tubewells quite closely which results in interference of radius of influence of wells. This results in decreased discharge of both the tubewells. The criteria of spacing until now have been based largely on experience and tradition. Proper spacing between two tubewells can be obtained only when there is a clear and concise understanding of the theoretical relationships between the various variables viz., the permeability of the soil, transmissibility, storage coefficient, radius of influence of the well etc.

Description of technology : To overcome this problem, theoretical relationships for finding the spacing between wells for non leaky and leaky aquifers were developed for different conditions assuming steady state relationship. A simple nomograph was developed to find out the effect of mutual interference of wells and their discharges. A mathematical expression to compute the optimum spacing between two wells was evolved. A study was conducted to determine the radius of influence of shallow tubewells for different pumping rate and different pumping hours. The effect of mutual interference was also studied under steady state conditions. The study revealed that for 10 hours of continuous pumping the increase in radius of influence was 47 % when discharge increased from 10 to 25 lps, whereas for 18 hours of continuous pumping the increase was 80 %.

Output and scalability : The spacing between shallow and deep tubewells depends on the type of the aquifer i.e. leaky or non-leaky confined or unconfined aquifer. Not only type of the aquifer is sufficient to note but also it is necessary to find the amount of leakage occurring into or out of the aquifer. In non leaky confined aquifer at 15% interference, the value of the optimum spacing for case (i) i.e. when deep well is fully penetrating and shallow well is partially penetrating comes out to be 530 meters and for case (ii) i.e. when both wells are partially penetrating, it is 500 meters. For leaky confined aquifer, the value of the spacing between deep and shallow wells obtained was 152 meters for case (i) and 157 meters for case (ii). Results of optimum spacing between wells have helped the farmers of the state/region to space their tubewells at optimum distances so as to avoid mutual interference of wells resulting in higher well discharge.

Detection and Removal of Harmful Gases in Well Pits

Relevance : The problem of accumulation of harmful gases has been found in well pits after the onset of monsoon period. When a person goes into these pits for repair and maintenance of pump sets, he feels difficulty in respiration and become unconscious after few minutes and may die if he remains in pit for longer time. The analyses of air samples show the presence of more carbon dioxide, increase in nitrogen and decrease in oxygen contents.

Description of technology : A simple technology for detection and removal of harmful gases in well pits was recommended. A lighted kerosene lamp is lowered inside the pit before entering the pit. If it blows out, it indicates the presence of harmful gases below that point. There are several methods to remove these harmful gases. One can use any of the following methods:

- (i) The harmful gas can be disposed off quickly by using air blower connected with a flexible pipe. The blower is placed on the ground surface while the flexible pipe goes down the pit up to bottom. When fresh air is blown into the pit, the harmful gas is pushed out. It may take about 10-20 min to dispose off the gas for a pit of 18 m depth.
- (ii) The gas can be removed by lowering a table fan up to bottom of the pit. It takes about 30 min to push the gas out to well pit of 9 m depth.
- (iii) In case of shallow pits, farmer may lower an umbrella to the bottom of the pit. When the umbrella is raised and emptied outside the pit, the gas is removed. The raising and lowering will have to be done till the well is completely free of gas. This operation takes about an hour. One can also use the jute bag in place of umbrella.
- (iv) In case of belt driven pump sets, run the pump idle. The gas will be agitated and will come out of pit. For tube well pit up to 6 meter depth, it takes only 10 min and up to 12 m depth, it takes about 30 minutes for cleaning pit from gas.
- (v) Pour lime solution in the pit. It neutralizes the carbon dioxide gas. For an average diameter of pit (about 1.75 m), use 1 kg of lime for every meter depth of gas column in the pit.

Plastering of walls may reduce the entry of harmful gases but may not prevent it fully. After using the above measures, one should re-test the presence of gas with kerosene lamp before going in the pit for repair etc.

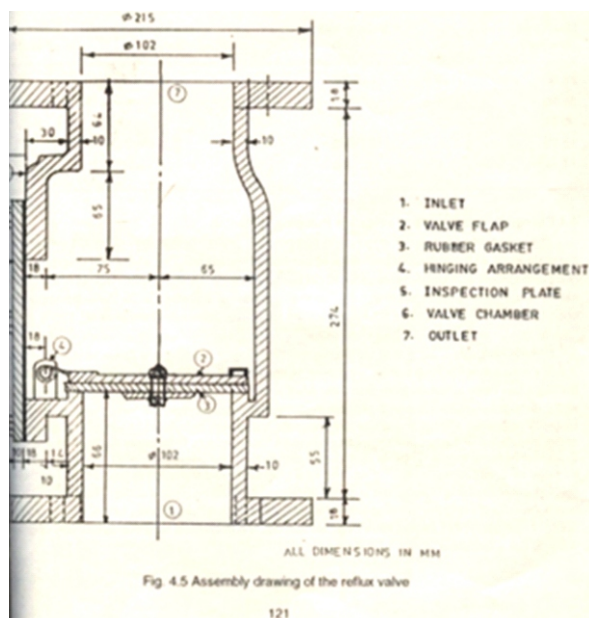
Output and scalability : The technology has been well adopted by the farmers and extension agencies of the state. Because of this, many farmers have been saved from the harmful effects of accumulated gases in well pits. It was because of this recommendation that the Govt. of Punjab included this as a cause of paying compensation to the affected farmers.

Development of Efficient Reflux Valve

Relevance : Reflux valve is also called as non return valve or check valve. This valve is installed when flow is required to proceed in one direction only. Reflux valves available in the market caused excessive head loss due to friction as their valve do not open fully to give full rate of flow. Hence, there was a need to develop an efficient reflux valve.

Description of technology : The relationship between the velocity head and head loss due to reflux valve for different weights of the valve were developed. It was found that the optimum weight of valve flap should be 550 gm. The shape of valve chamber was varied by varying the taper angle on the delivery side of the reflux valve; and the diameter of the chamber housing of the valve was reduced uniformly to 10 cm diameter.

Output and scalability : Studies on the evaluation of six commercially available reflux valves of 100 mm size showed that frictional coefficient varied from 0.32 to 2.15 with an average value of $K = 0.94$. The performance test in terms of head loss of the PAU reflux valve was obtained by varying the discharge rates and velocity heads. The value of frictional coefficient K was 0.25. This valve was well adopted by two manufacturers of the state who got ISI mark on their product and got good response from the private and government agencies.



Schematic diagram and view of reflux valve

Improving Operational Efficiency of Agricultural Pump Sets

Relevance: There is large scale exploitation of groundwater for irrigation purposes in the state of Punjab which is evident from the fact that the number of tubewells has increased from 0.192 million in 1970 to 1.405 million in 2015. The situation is similar in states like Haryana, Rajasthan and Western UP. A survey was conducted to assess the efficiency of centrifugal pump sets and to identify the common factors that are responsible for low efficiency of agricultural pump sets. There is a dire need to identify the factors responsible for reduction in efficiency of agricultural pump sets and their remedial measures.

Description of technology: Field studies and lab studies were conducted and technologies were developed to improve efficiency of electric and diesel pump sets for conservation of energy in pumping system. Based on the studies, it was recommended that for agricultural purposes, suction lift range should be specified by the manufacturer so that the farmer installs a centrifugal pump at a depth falling in the specified range from ground level and the motor should be designed in such a way that these operate satisfactorily under wide range of voltage. A 5 BHP diesel engine while running at 4, 3 and 2 BHP consumes 5-46 per cent extra fuel /BHP/hr in comparison to engine running at full load. Also, the engines were running at a temperature of 30 – 35°C and not at optimum water jacket temperature resulting in 8 per cent of more fuel consumption.

Output and scalability: Based on the studies to evaluate the operational efficiency of electrical pumpsets, the Punjab State Electricity Board implemented a number of recommendations, a few of which are given below:

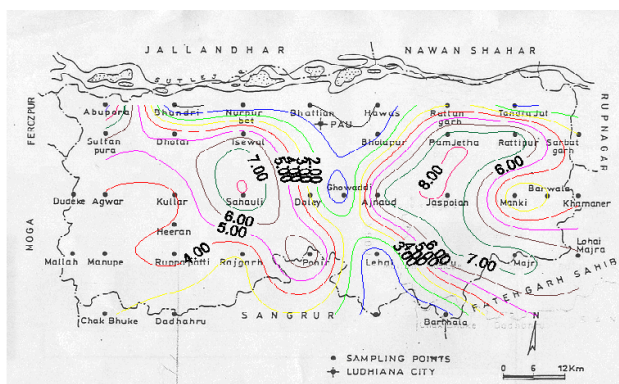
- The PSEB made appropriate changes in their demand notice for release of new power connections for tubewells, according to which the farmer must install an ISI mark monoblock pump set only.
- The Punjab Government created the posts of Assistant Engineers at the district level for improving the efficiency of electric driven pump sets with a view to save energy.
- Factors responsible for low efficiency of diesel operated pump sets were identified and Punjab Agro Industries Corporation ensured while sanctioning loans to the farmers that the recommended rectifications were included and adopted by the farmers in this connection. This resulted in enormous fuel savings and increased the operating efficiency of such pump sets

Groundwater Pollution due to Nitrogenous Fertilizers

Relevance : In Punjab state, the quality of water resources is getting degraded with increasing use of fertilizers especially the nitrogenous fertilizers and agro-chemicals. Since the crop utilizes only 25-70 % of the total nitrogenous fertilizer, rest of it either remains in the soil or is lost from the soil plant system. It is therefore apprehended that a significant amount of applied fertilizer moves as Nitrate-N into the deeper soil layers and ultimately joins the groundwater. Due to harmful effects of high $\text{NO}_3\text{-N}$ concentration, the concern for large scale groundwater pollution from non point source pollution has grown in recent years. This requires an assessment of groundwater vulnerability which aims at predicting the areas which are more likely than others to become contaminated as a result of activities at or near the land surface.

Description of technology : A square grid of 6 km \times 6 km was superimposed on the map of Ludhiana district. The pre- and post-monsoon ground samples were collected from thirty five points spread over the district of Ludhiana and analyzed for $\text{NO}_3\text{-N}$. Also, to understand depthwise movement of agrochemicals, 15 observation wells were installed at different depths i.e. 0.5, 1, 2, 3, 4, 5, 10, 20, 30, 40, 50, 60, 70, 80 and 90/92 feet in a circular pattern from the ground surface and leachate was collected for analysis. Total cumulative nitrogen loss on 95 days after sowing was calculated as 32.3 and 29.6 % at 60 and 90 cm depth below the ground surface respectively whereas predicted leaching loss was calculated to be 30.7 and 27 % at corresponding depths below the ground surface.

Output and scalability : The results revealed that none of the samples had $\text{NO}_3\text{-N}$ more than the permissible limit of 10 mg/l posing no immediate threat of groundwater contamination due to N fertilization under paddy-wheat rotation. The result of work on groundwater pollution due to excessive use of fertilizers and agro chemicals was accepted by the State Directorate of Agriculture. The Department through its well spread network of officers and field level workers have conveyed the message to farming community to desist from using more than the recommended doses of fertilizers and agro chemicals.



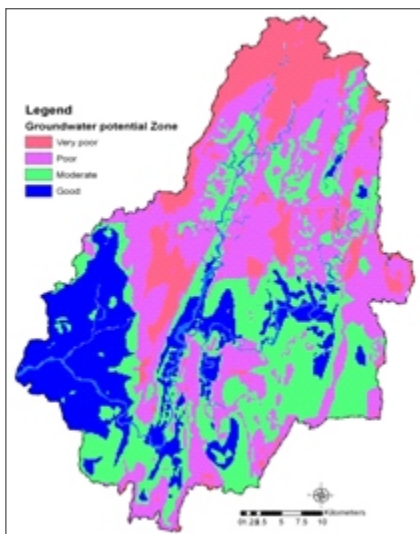
Nitrate N contours of groundwater for Ludhiana district (pre-monsoon)

Groundwater Potential Zones in Wakal River Basin, Rajasthan

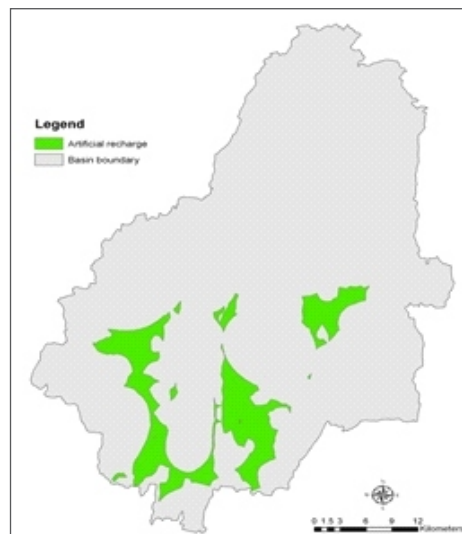
Relevance : The Wakal River basin is one of the important river basin of Southern Rajasthan and Khedbrahma block of Gujarat as it is draining to Sabarmati basin. The area of the basin is 1914.32 km². A scientific study to determine aquifer parameters through pumping test and to delineate groundwater potential/ sustainable artificial recharge zones in the Wakal river basin was conducted.

Description of technology : Overall 10 pumping tests were conducted in three rock formation of Quartzite, Phyllite & Schist and Cal Schist & Gneiss based on systematic square grid pattern. The observed pumping test data were analyzed by using Papadopulos-Cooper method valid for large diameter wells. Classical curve-matching technique was applied for estimation of storage coefficient and transmissivity of the aquifer. Thematic layers on geomorphology, drainage, soil, land use, net recharge, topographic elevation, groundwater fluctuation and transmissivity were assigned suitable relative weights and then integrated using ILWIS software for estimation of groundwater potential zones.

Output and scalability : The groundwater potential map of the river basin revealed four distinct zones representing 'good' (382.94 km², 20%), 'moderate' (596.61 km², 31.2%), 'poor' 654.48 km², 34.2% and 'very poor' (280.29 km², 14.6%) groundwater potential in the area. 174.39 km² area in the river basin is favourable for artificial recharge, and it contributes only 9.2 per cent of the total area. The transmissivity and specific yield map of the basin was recommended to Water Resources Department/ Ground Water Department of Govt. of Rajasthan for further planning and ensuring sustainable groundwater management in the state.



Groundwater potential zone map of Wakal river basin



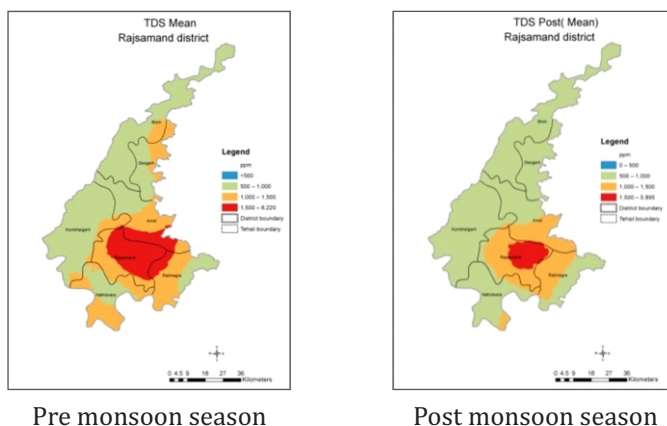
Map showing zones favourable for artificial groundwater recharge

Suitability of Groundwater Quality for Irrigation

Relevance: Normal irrigation water generally has no adverse effect on soil properties. However, irrigation with poor quality water containing high concentration of cations and anions may adversely affect the properties of soil by increasing salt content and exchangeable sodium of soil solution. The salt composition of irrigation water will lead to development of salinity and alkalinity in soil. The suitability of water for irrigation is determined by the amount and kind of salts present. With poor water quality, various soil and cropping problems can be expected to develop.

Description of technology : As the water resources are depleting and deteriorating day by day, there is a need for assessment of groundwater quality. Hence, an attempt was made to evaluate spatio-temporal variability of groundwater quality of Rajsamand district of Rajasthan and to prepare groundwater quality map of the district. The whole Rajsamand district was divided into 6 km × 6 km square grids and from each grid one open dug well was selected randomly. The locations of wells were recorded with the help of global positioning system (GPS). Groundwater levels were measured periodically and 128 groundwater samples were collected for analysis.

Output and scalability : The seasonal variation in TDS of groundwater in the study area has been depicted in the figure. This clearly indicated that the total dissolved solids of groundwater decreased to a great extent in post monsoon season as compared to pre monsoon seasons. This may be due to dilution effect of rainwater recharge. The higher average value of EC (upto 12.82 dS/m) in pre monsoon season in groundwater was due to enrichment of salts because of evaporation effect and due to deeper groundwater levels in the pre-monsoon. The decrease in salinity (by 3.58 dS/m) of groundwater in post monsoon season was due to dilution through good quality rainwater. The information on the water quality will be highly useful for the selection of the crops for particular block, distribution of seed minikits, management and methodology of application of fertilizers, drinking water supply etc. in the whole district.



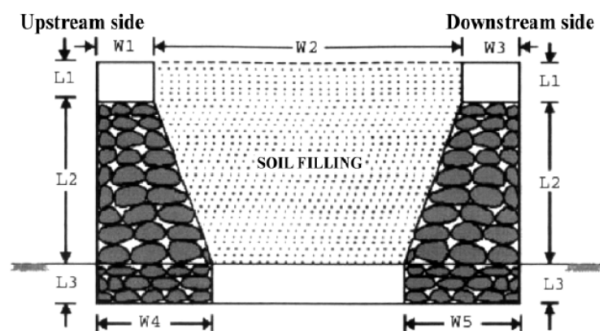
Variations in TDS of groundwater of Rajsamand in pre and post monsoon seasons

Low Cost Rainwater Harvesting Structures for Groundwater Recharge in Semi-arid Regions

Relevance : Water scarcity and depletion of groundwater levels are among the major problems in Rajasthan. During May-June every year, most of the wells become dry due to decline in groundwater levels. In hard-rock areas of Rajasthan, cost-effective and feasible methods for artificial groundwater recharging have not been identified. Artificial recharge of groundwater seems to be an appropriate solution under the present situation. The masonry water harvesting structures constructed in the region are cost intensive and difficult for the rural community to afford it.

Description of technology : The low cost dry stone masonry pond is made in the small vallies by constructing dry stone masonry walls and in between two walls, soil/murum is filled. The thickness of the dry stone wall is generally kept at 0.50 m. The filled soil is compacted well in different layers using water. It is very effective structure and can be constructed by the community themselves because of less technical skill required in the construction. In the design, all major aspects likes peak rate of runoff, height, volume of storage, provision of spillway and stability were taken into consideration. The low cost rainwater harvesting structure is cost effective and about six times cheaper than the masonry structures. It is most suitable to harvest the rainwater upto catchment area of 50 ha and also for augmenting the groundwater table of the well located in the downstream area through continuous recharging.

Output and scalability : The study on impact assessment of designed structure was carried out during 2012-2014 and the results of the study revealed that the average recharge rate of pond was 7.6 cm/day and net volume of recharge was 6132 m³/year. This technology has been widely disseminated and Govt. of Rajasthan is executing it in MGNREGA and watersheds projects for groundwater recharging. This technology is widely adopted by various Govt. and NGO's for groundwater augmentation and more than 250 such structures has been constructed in the southern Rajasthan.



Cross section of low cost structure



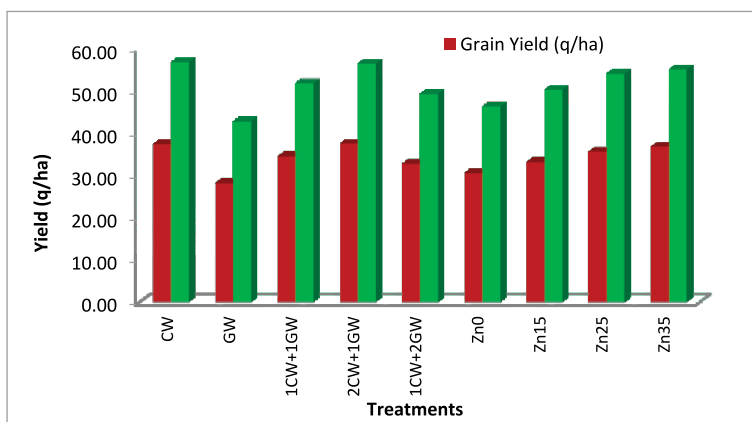
Low cost rainwater harvesting structure

Conjunctive Use of Canal water and Marginally Saline Groundwater for Wheat Cultivation

Relevance : The Haroti region of South-Eastern Rajasthan is bestowed with poor quality groundwater. This region has canal water but the supply of canal water is not sufficient especially to the tailenders. This area is quite calcareous and zinc deficient. Hence, there is possibility for use of marginally saline groundwater and zinc for crop production. Keeping the above facts in view, the research work was carried out to find out the appropriate level of conjunction of available water resources, i.e. poor quality groundwater and canal water to maximize the production with saving of good quality canal water.

Description of technology : In this study, total 20 treatment combinations comprising of five levels of conjunction of irrigation water and four levels of zinc sulphate were tested and the treatment combinations were allocated randomly to different plots. The treatments were replicated four times in randomized block design. The treatments of irrigation were: I1=All irrigation with canal water, I2=All irrigation with groundwater, I3=One irrigation with canal water followed by one irrigation with groundwater, I4=Two irrigation with canal water followed by one irrigation with groundwater and I5=One irrigation with canal water followed by two irrigation with groundwater. The zinc sulphate treatments were Zn0=Control, Zn15= 15 kg zinc sulphate, Zn25=25 kg zinc sulphate and Zn35=35 kg zinc sulphate.

Output and scalability : The observation of responses of biological yield (grain and straw yield) and soil health (EC, pH and organic carbon content) parameters showed that with the I4 irrigation (two irrigations with canal water followed by one irrigation with saline groundwater), one can achieve as good production as in canal water irrigation (I1) on sustainable basis. Saving of 33 % good quality water without any economic yield reduction and soil health deterioration is possible. By adopting conjunctive use of water in cyclic fashion for wheat cultivation in Bundi district, the area of mustard or chickpea or coriander can be doubled with the existing water resources for irrigation.



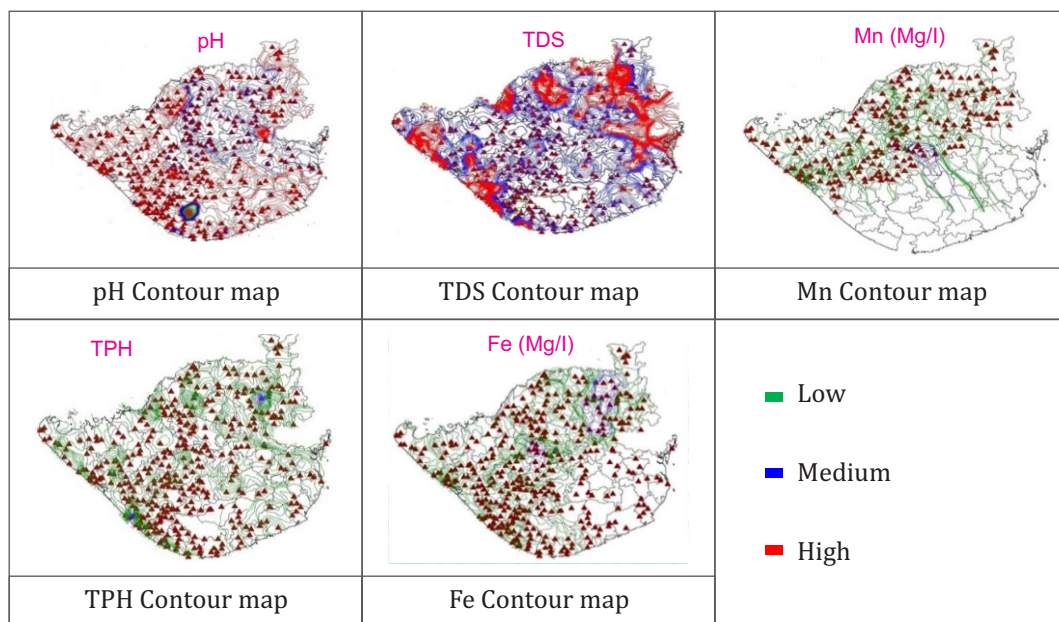
Grain yield in different conjunctive use and zinc treatments

Suitability of Groundwater Quality for Drip Irrigation

Relevance : The Gujarat state has 1600 km of seacoast, among which Saurashtra has 1100 km. These coastal belt area is having sandy and lime aquifer which is dominant in calcium element. This underground aquifer has an effect on groundwater quality dissolving precipitated material like carbonate, bicarbonate, chloride and sulphate of calcium, magnesium, sodium and iron which is responsible for dripper clogging. Water containing significant amounts of these minerals and having a pH greater than seven has the potential for clogging of drippers.

Description of technology : The contour maps of groundwater quality parameters like EC, TDS, pH, Ca, Mg, Na, Fe, Mn, carbonate, bicarbonate, chloride, sulphate, Nitrate-Nitrogen and water hardness based on groundwater sample analysis of 391 wells in 73 talukas of 11 Districts of Saurashtra region during rabi season of 2012 and 2013 were prepared which can be used for estimation of suitability of the water for the drip irrigation operation. The groundwater quality maps were proposed under GIS environment for each district of the region which can be useful to decide the suitability of groundwater for the drip irrigation, fertigation and maintenance schedules of the system.

Output and scalability : The pH of the groundwater was observed higher (more than 7) in all districts of the Saurashtra region. The maximum ground water samples (99.14 %) were found in category of scale forming but non corrosive class. Based on the EC, SAR and RSC of the groundwater, 56.24, 18.4, 6.64 and 18.68 per cent samples were found under categories of good water, saline water, high SAR saline water and alkali water class, respectively.



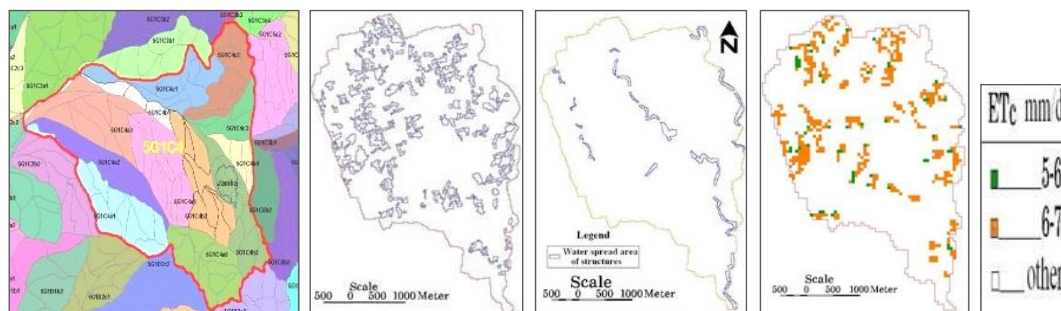
Groundwater quality in Saurashtra region of Gujarat

Groundwater Recharge Estimation Using RS and GIS

Relevance : The Government of Gujarat has implemented the scheme known as “Sardar Jal Sanchay Abhiyan” to construct water harvesting structures on small rivers/streams with people's participation. By reducing the runoff and enhancing the water stagnation time, these structures are increasing the groundwater recharge. However, there is not yet a scientific assessment of the water harvesting and artificial groundwater recharge from these structures and their impact in the region. Attempts were made to quantify groundwater recharge and crop water requirement in selected watershed of Saurashtra region using remote sensing (RS) and geographical information system (GIS).

Description of technology : The satellite image of IRS 1D, PAN + LISS III merged data, and IRS P6 of sensor LISS III was used for assessing the groundwater recharge through water harvesting structures and crop water requirements using remote sensing and GIS technologies. Water spread area was delineated using the RS and GIS technique and from the duration of water stagnation, recharge was estimated by empirical methods. The area under different crops was mapped using the geospatial techniques and based on the weather data and crop coefficients, crop water requirement was calculated.

Output and scalability : Remote sensing and GIS techniques identified 49 water harvesting structures and estimated groundwater recharge from these structures as 150.37 ha m. The total groundwater recharge through rainfall, water harvesting structures and return flow of irrigation water in the study area was estimated as 407.12 ha m. which was verified with water table fluctuation method and was found less than the total recharge estimated through rainfall and recharge from storage structures. This indicated groundwater outflow from the micro-watershed. Gross irrigation requirement of wheat crop grown in 187 ha area estimated using remote sensing data was found 119.12 ha m for year 2006-07. The cost of storage capacity created by water harvesting structures was found to be Rs.1.49 per m³ of storage. The estimated benefit-cost ratio was found to be 1.53 for growing wheat crop using the groundwater recharge by water harvesting structures.



Micro-watersheds
of the study area

Area under
wheat crop

Location of water
harvesting structures

ETc maps for wheat using
KcSAVI on Jan, 2007

Seawater Intrusion Impacts on the Groundwater Quality

Relevance: Gujarat state lies in western peninsular region with 1600km of seacoast. Along this sea coast, 9 districts, 14 Tehsils and 1,500 villages are affected by seawater ingress. Over the last 35 years, with the advent of diesel pumps and the electric motors, there has been a rapid increase in the number of wells and tubewells along the Gujarat coast line. The over withdrawal of groundwater has decreased the groundwater level which has led to seawater intrusion. Prolonged use of this water for irrigation has led to decline in soil health and fertility which caused social unrest in coastal area.

Description of technology: The groundwater quality parameters viz, EC, pH, Ca, Mg, Na, K, CO_3 , HCO_3 , Cl, SAR, ESP, SAR, RSC, RSBC, SSP, TDS, total hardness, LSI, sodium hazard, potential salinity, permeability index, were measured for the coastal belt area at various distance of 5, 10, 15 and 20km from seacoast during, before and after monsoon period. Evaluation of the quality of irrigation water namely: salinity hazard, sodium hazard, salt index, alkalinity hazard, permeability hazard and specific ion toxicity hazards was done. The mathematical models relating rainfall and groundwater EC were developed for the scientific communities/line departments of state/central governments/NGOs. The information is also useful for the selection of cropping pattern and irrigation water management strategies by the farmers.

Regression model between rainfall and electrical conductivity

SN	Coastal belt region	Best fit model	R ²
1	0-5 km	$\text{ECPM} = 0.6364(\text{EC}_{\text{bm}}) - 0.00166(\text{RF}) + 2.9495$	0.83
2	5-10km	$\text{ECPM} = 0.6965(\text{EC}_{\text{bm}}) - 0.000359(\text{RF}) + 1.2837$	0.64
3	10-15km	$\text{ECPM} = 0.4171(\text{EC}_{\text{bm}}) - 0.000267(\text{RF}) + 1.5592$	0.64
4	15-20km	$\text{ECPM} = -0.3577(\text{EC}_{\text{bm}}) - 0.0000683(\text{RF}) + 1.8636$	0.82

EC_{bm} and EC_{pm} are the groundwater EC(dS/m) during pre and post monsoon, RF=monsoon rainfall(mm)

Output and scalability: The EC of the coastal belt at 0-5km and 15-20km from sea coast were 7.23 and 1.28 dS/m respectively. The groundwater had pH above 7.0 which increased with increase in distance from seacoast. The SAR values of groundwater at 0-5km from coast during both the pre-monsoon and post-monsoon periods were found close to critical limit of 10. The seawater intrusion in area at 0-5 km from coast affected the SAR values of groundwater. The sodium ratio was affected up to 15 km. The seawater intrusion effect was noticed at 0-15 km from seacoast as per permeability index. The groundwater SSP was less affected by seawater ingress in nearby area of sea coast. The MAR ratio was found nearly 0.50 indicating good quality of irrigation water. The higher Kelli's ratio of groundwater in vicinity of seacoast indicated the doubtful categories of water quality. The harmful effect of chloride concentration was noticed up to 15 km which indicates that the water cannot be used for sprinkler irrigation. The total hardness indicated not harmful in context to plugging potential of drip irrigation. The CO_3^{2-} and HCO_3^- content of groundwater increased with increase of distance from sea coast.

Artificial Groundwater Recharge Through Percolation Tanks

Relevance : Augmenting the groundwater is essential in order to obtain more water for irrigation by creating artificial structures for groundwater recharge. The construction of percolation tanks has been undertaken by the Maharashtra State since 1964 and by now there are more than 21000 percolation tanks in the State. The efficacy and feasibility of these structures is more in hard rock formation where the rocks are highly fractured and weathered. The State of Maharashtra is covered (82%) mostly by Deccan Basalt (hard rock) area. Hence to know the irrigation potential of the percolation tanks, it is necessary to quantify the ground water recharge through these structures and assess the area of influence in the downstream regime of the tank.

Description of technology : Three percolation tanks were selected for quantifying the groundwater recharge and assessing the area of influence (distribution) of groundwater recharge in the downstream region of the tank. These are: Shingave percolation tank; Pimpalgaon Ujjaini percolation tank-I and Pimpalgaon Ujjaini percolation tank-II. The data viz. stage storage relationship, number of wells in the command area of percolation tanks, distance of each well from the percolation tanks, water levels in the wells were collected. These data were analyzed for assessing the area of influence (distribution) of groundwater recharge in the downstream region of the percolation tank and to quantify the groundwater recharge through the tank. The groundwater recharge as a result of construction of the percolation tank was worked out taking into consideration all the components of flood routing.

Output and scalability : The influence of Shingave percolation tank with maximum storage capacity of 52.5 ha-m was found in the range of 194 to 1514 m during the period 1993 to 2005. It was found that the total recharge from the Shingave percolation tank during 1993-2005 ranged from 1.27 cm/day to 6.0 cm/day. The influence of percolation tank no. I at Pimpalgaon Ujjaini of the maximum storage capacity 69.6 ha-m was in the range of 400 m to 979 m during the period 2000-2005. The average distance of influence up to which the tank storage influences the well water levels was 654 m. The influence of percolation tank no. II at Pimpalgaon Ujjaini of the maximum storage capacity 21.6 ha-m was found in the range of 219 to 1013 m during the period 2001-2006. The average distance of influence up to which the tank storage influences the well water levels was 655 m.



View of the percolation tanks

Artificial Groundwater Recharge through Borewells

Relevance : The State of Maharashtra belongs to water scarce region. Large area (82 %) of Maharashtra is occupied by hard rock (Deccan basalt) and because of variations in their basic characteristics, physiography and variability in the rainfall, there are limitations on the occurrence of ground water. In most parts of the state, the water table is declining day by day as the natural groundwater recharge is less than the pumping from open wells and tubewells. Therefore, there is a need for artificial groundwater recharge for sustainable groundwater management.

Description of technology : The AICRP on Irrigation Water Management, MPKV, Rahuri has developed four layer filter for the artificial groundwater recharge through bore wells. The runoff water is first filtered through the filter chamber and then diverted to the borewell for artificial recharge of groundwater. The four layer filter is recommended for recharge of bore wells to obtain better filtration efficiency as given below.

Specifications of four layer filter

Filter layer No.	Filter layer thickness (top to bottom)	Filter material and its size
1	25 cm	Brick flakes (24 to 28 mm)
2	25 cm	Sand grade I (0.6 to 2.0 mm)
3	25 cm	Angular gravel grade I (9.5 to 15.5 mm)
4	25 cm	Pea gravel grade I (20 to 24 mm)

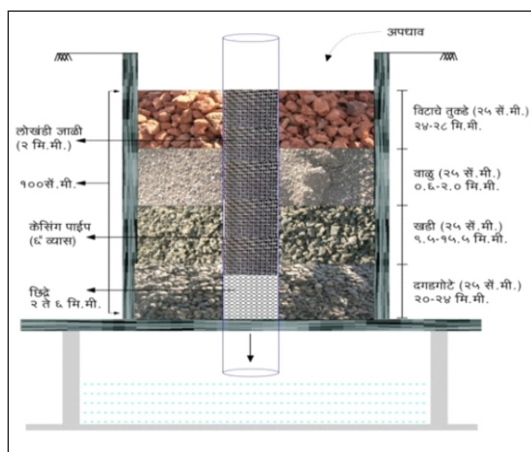


Diagram of filter chamber

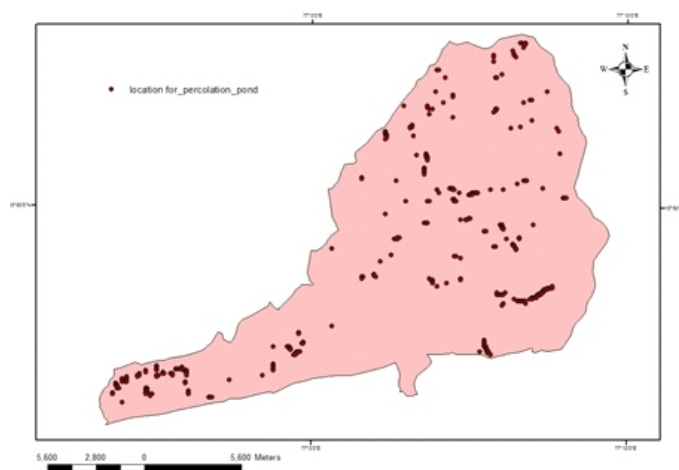
Output and scalability : There are approximately 21 lakh wells in the Maharashtra. The artificial groundwater recharge technology has been tested and validated in the laboratory and on farmers' field. Based on the success of the developed technology, the Government of Maharashtra has sanctioned Special Rashtriya Krishi Vikas Yojana entitled "Enhancement of ground water recharge through open and bore wells" amounting to Rs.1.39 corers. Under this project, the four layer filter technology will be installed on the open and bore wells of nearly 400 farmers of different districts of the State.

Potential Groundwater Recharge Zone and Site Specific Recharge Structures

Relevance: Excessive groundwater exploitation has led to alarming decrease in groundwater level in several parts of the country. Hence, there is a need to identify regions where site-specific groundwater recharge methods can be adopted to augment the water supply. The purpose of this study was to delineate the potential recharge zone in the hard rock regions using RS and GIS and to suggest the site specific recharge structures at favorable zones so as to improve the groundwater status of the watershed and prevent the wells from drying.

Description of technology: The study was carried out in Koraiyar watershed of Tamil Nadu. Thematic maps such as geology, geomorphology, land use/land cover, soil and slope map were prepared using Remote Sensing and GIS. Detailed characteristics of each theme were studied in accordance with their response to artificial recharge process. Ranking and weightage were applied for suitable site selection for artificial recharge process, and weighted overlay analysis was carried out. From the recharge zone map, it was found that moderate zone had the maximum areal extent of 261 km². Based on the criteria given by IMSD (Integrated mission for sustainable development-Section 3.9.1), suitable locations were identified for constructing check dams and percolation ponds using RS and GIS

Output and scalability: Planning of artificial recharge of groundwater and suggesting specific recharge structures are equally important for any augmenting process of groundwater. The suitable zones for the artificial recharge and site specific RWH structures i.e. check dam and percolation pond that can be constructed in the watershed was identified and suggested based on the groundwater potential of the area.



Location map for constructing percolation pond in the study area

Artificial Groundwater Recharge through Borewells in Percolation Tanks

Relevance : Alarming levels of groundwater abstraction has resulted in the declining of water table in many parts of the state of Tamil Nadu. These problems are very acute in those areas underlain by hard rocks, since the hard rock aquifers have limited water storage capacity. The general measure to sustain the groundwater depletion is the construction of percolation ponds. But the recharge through percolation ponds is very slow. Hence there is need for accelerated groundwater recharge in hard rock area to increase the rate of recharge and also to reduce the evaporation losses.

Description of technology : Artificial recharge through recharge well in percolation pond was taken up by way of allowing the runoff water to pass through silt detention tank, water collection tank cum treatment chamber and shaft with filtering chamber. Silt detention tank is a pit excavated to retain the boulders and sediments that is carried away by the runoff water from the catchment. The silt is deposited in the pit and the boulders are also trapped in the tank and thereon the silt free water flows to the water collection tank and treatment chamber. The size of tank is 5m × 3m × 2m. The tank is separated into four chambers filled with boulders, gravels, coarse sand and fine sand separated by grill and mesh. The runoff water get filtered through this and then the filtered water is allowed to pass through the bore well. A bore well of 6 ½" diameter is dug to a depth of 100m. Surrounding the bore well, a 5 m diameter circular pit is excavated with the bore well as its centre to a depth of 4.5 m. The length of casing pipe is 12m. The pit is filled with filtering media viz., fine sand, coarse sand, fine jelly, hard jelly and boulders for further filtration.

Output and Scalability : Recharge well technique was adopted to increase the



View of recharge borewell within percolation tank

effectiveness of percolation ponds, wherein recharge well is constructed in the middle of the percolation pond with filters to increase the recharge rate. It was found that recharge due to recharge bore well during the north-east monsoon was 23% which was about 6% increase from the maximum recharge due to the percolation pond. Recommendations were passed on to the agriculture department and accordingly recharge bore well technologies was introduced by the department in various blocks of Tamil Nadu.

Design and Development of Pantnagar Propeller Pump

Relevance : Several types of pumps are available for lifting irrigation water under different conditions of head and discharge. Propeller pump is best suited for efficient handling of large quantities of water against low heads such as lifting of water from rivers, canals, ponds or open wells with shallow water table. It has relatively high discharge capacity and high efficiency, compared to other pumps for lifting water against low heads ranging from one to four meters. Propeller pumps have not become popular in India in irrigation practice due to high prices. In such a situation the farmers use the centrifugal pump which, because of low efficiency, requires high energy input and works at low heads. Keeping the above points in view, a new low cost design of propeller pump, named as “Pantnagar Propeller Pump” was developed.

Description of technology : The Pantnagar propeller pump was developed which has a capacity of 45 to 65 lps. It is suitable for lifting of water from rivers, canals, ponds or open wells with shallow water table. It has relatively high discharge capacity and high efficiency compared to other pumps for lifting water against low heads ranging from one to four meters. The design features are as given below.

- Casing: The casing is tapered from 22.5 cm in the lower most portion to 30 cm at the end of tapered length.
- Propeller: 3-vane propeller of 22 cm diameter made of aluminum.
- Diffuser: It has 7 vanes with its diameters tapering from 22.5 to 30 cm. The hub diameter is 13.5 cm and the length of the diffuser is 45 cm. It is provided with two ball bearings.

Output and scalability : The pump performed best at a speed of 1440 rpm. The efficiency of the pump at this speed varied from 65 to 40 percent at a static head of 1.0 to 2.5 meter. The discharge ranged from 30 to 65 lps and horse power ranged from 2.3 to 3.2 hp respectively.



Propeller



Diffusor



Pantnagar propeller

Design and Development of Pantnagar Foot Valve

Relevance : Studies on the hydraulic evaluation of commercially available foot valves conducted at different places have shown that these foot valves offer excessive head loss due to friction. Keeping this in view, a new design of foot valve named as 'Pantnagar foot valve' was developed. The foot valve was designed and developed for a 10 cm diameter suction pipe

Description of Technology: Pantnagar Foot valve consisted of a casing cum strainer and a valve system.

(i) Casing cum strainer: A 15 cm diameter pipe of 25 cm length with a plate welded in the bottom was used as casing cum strainer. Continuous slots were made on the circumference as well at the bottom at one cm spacing. 25 slots of 1 cm width and 7 cm length were made on the circumference. Similarly, slots of 1 cm width at one cm radial spacing were made in the bottom plate. The perforated area was 3 times the cross sectional area of suction pipe of 10 cm diameter. A ring was welded inside the pipe just above the perforated portion to provide a proper seat to the valve. A reducer of 15 cm × 10 cm was provided on the casing to connect the valve with the suction pipe.

(ii) Valve system :The valve system consists of the following components: (1) leather washer, (2) lower plate, (3) upper plate, (4) hinge and (5) connecting plate. A leather washer of 3 to 4 mm thickness and 12.5 cm diameter was used. Cast iron circular plates of 3 to 4 cm thickness were put on the lower and upper sides of the washer. The lower plate was 9 cm in diameter and the upper plate was 10 cm in diameter. All the three components were tightened by nuts and bolts in the centre. The upper plate was provided a free hinge with a connecting plate of 3 mm width, 2 mm thickness and 7.5 cm in length. The connecting plate was provided with holes at two points to fix it with nuts and bolts with the casing wall. The valve rested on the internal ring when the pump was not in operation. It opened vertically almost full when the pump was in operation.

Output and scalability : The comparison of hydraulic performance of Pantnagar foot valve with commercially available foot valves, used in the region showed that the Pantnagar foot valve reduces the head loss and saves energy to a greater extent. The capacity of the pump with Pantnagar foot valve increased by 6.3 lps compared with the capacity of the pump with commercial foot valve. The Pantnagar foot valve was found 4 to 8 times more efficient than the commercial foot valves at these discharge rates.



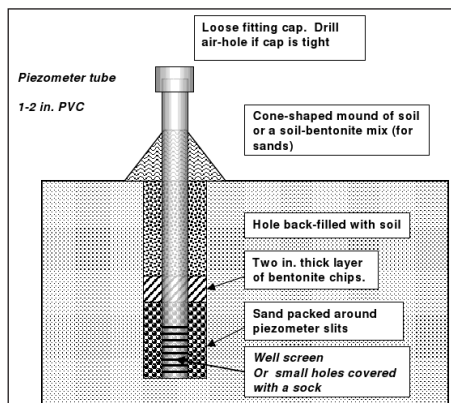
View of Pantnagar foot valve

Irrigation Induced Recharge for Shallow Water Table Regions

Relevance : Several techniques have been developed to investigate the availability of groundwater and to quantitatively assess its utilisable potential. The application of the budgeting technique to groundwater reservoir is easy to visualize. Recharge due to irrigation water is one of the major parameters in the estimation of ground water potentials. This parameter is affected by soil properties, depth of water table and other conditions. Though, a number of average values are being used for recharge due to irrigation in different parts of the country, these may not be applicable in every condition. The Tarai region (Humid) is having a unique shallow water table and soil condition. Therefore, it is important to estimate recharge due to irrigation in these region to estimate utilisable ground water potentials.

Description of technology : The experimental study was conducted for two crop seasons at Crop Research Center of G.B. Pant University, Pantnagar to establish recharge from irrigation. The 20 observation points were established using 20 augur holes at 50m x 50m grid spacing covering approximately 250m x 200m area. The water table depth was observed for two crops season i.e from December 2009 to May 2010 and from December 2010 to May 2011 at fortnightly interval as well as before and after irrigation applied.

Output and scalability : The maximum average increase of water table in experimental field during experiment was 29 cm and minimum variation was 5.55 cm for two crop seasons i.e, 2009-10 and 2010-11. Average percentage of recharge due to irrigation was estimated as 18.14% in shallow water table condition of humid region. This value may be used to estimate recharge due to irrigation component while computing net groundwater recharge potential in shallow water table condition.



Views of observation wells

Rejuvenation of Natural Springs

Relevance : Drying up of natural springs are major problem in hilly regions of Uttarakhand state. This problem is due to deforestation, grazing and trampling by livestock, erosion of top fertile soil, forest fires and development activities. These activities have reduced the infiltration rate and thus created the failure of natural spring. This has plunged mountain residents to severe water shortage for drinking water. In Uttarakhand, out of total 16000 villages, 8800 villages have been placed under water scarce villages. There is a challenge how to increase the water retention in the fragile watersheds to augment a sustainable discharge. Efforts were made through continuous monitoring of hydrological situations for recharging the drying springs.

Description of technology : Three natural springs (two perennial and one seasonal) located at different locations in Tehri Garhwal district of Uttarakhand, were selected to study their hydrological trend and engineering treatment measures were tried to rejuvenate the springs for their sustainability. Due to steep sloping catchments area of the springs, a major quantity of rainfall water was going as runoff. Therefore, to increase the infiltration opportunity time of this rainfall water, staggered and continuous contour trenches were made according to the feasibility of the geographical area.

Output and scalability : The variation in discharge of Hill Campus spring and Ambar II spring for different years showed that the maximum weekly discharge increased over the years due to the interventions. The effect of engineering treatments like contour trenches and ditches constructed in the upper catchments increased the discharge every year. During first year, the spring discharge of Hill Campus spring increased by 22.64 per cent, and again by 38.95 per cent in the next year. The developed technology can be applied in different regions of Uttarakhand and other hill states to rejuvenate natural springs.



Engineering treatments : ditches and contour trenches

Development of Chain Pump

Relevance : Diesel and electric operated pumps consume energy and sometimes not affordable by poor farmers. Hand or paddle operated pumps which do not involve any running costs are preferred by poor farmers. For farmers having water source at shallow depth, these pumps are quite effective.

Description of technology : An improved chain pump capable of providing water supply of 7146 lph (hand operated) and 9516 lph (pedal operated) was developed, fabricated, demonstrated and popularized in tribal areas of Kundam (M.P). This is a low lift pump and lifts water from 3.5 m deep. It is suitable for water lifts from Nalas, open wells and from one field to another field. Development and comparison of 76 mm, 63 mm, and 51 mm chain pumps was done. The overall performance of 51 mm chain pump was found to be the best. It can be continuously operated for 50 minutes and lifts water upto 3.2 m head. It consists of earthen pots mounted over the Persian wheel. The earthen pots of 3 liters capacity, 21 cm height and 10 cm mouth opening delivered 6344 lph at 3 m head. It was tested and modified for proper work rest ratio to minimize the fatigue to operator.

Output and scalability : The discharge of the pedal operated pump was about 46% more than the hand operated set. Pedal operated set required a little more rest period for normalization to operator after 30 min of operation. It resulted in 20% reduction in unit cost of irrigation. 51 mm diameter inlet pipe was found capable of discharging 42 lph more water than bigger sizes, and also offers more working hours per day. It can be continuously operated for 2 hrs and can irrigate 0.41 ha.cm/day of 8 hrs.



View of Chain Pump

Development of Fishing Tools for Recovery of Dropped Items in Tubewell

Relevance: With the increase in population of tubewells, a number of problems associated with tubewells are increasing at an alarming rate. As a result, farmers are not getting full advantage of their available water resource, crops suffer badly and many times the tube well becomes useless. Dropping of submersible pump and assembly, sand pumping, reduction of discharge, rupture of PVC casing etc are the common problems encountered in the farmer's fields. Out of the above, dropping of pump and other things is the most common. The process of taking out the dropped item from the tube well is called fishing.

Description of technology: The process of fishing tools that has been developed is described as follows:

Detector: This is a cone shaped tool made of MS funnel fitted with two rods in the bottom crossing each other. Battery compound is used to get the impression of the part fallen in the tube well. This helps to decide the appropriate tool to be lowered for recovery.

Cable cutter: Generally the cable also drops along with pump which generally is wrapped around the pump. The cable cutter is a cylindrical tool having sharp edges and cut at 45 degree at its lower end.

Cable puller: This tool has hooks which is used to pull the cable.

Inner threaded pipe puller: This tool is having inner thread in its lower part and used to pull dropped pipe having outer threads open.

Outer threaded pipe puller: This tool is having outer thread in its lower part and used to pull dropped pipe having socket in upper portion.

Motor puller: This tool is used to pull the motor.

Output and scalability: These fishing tools for tubewells have been used at various locations successfully. They have been well accepted by farmers, drillers and village level workers, and can be used at other regions also.



Fishing tools for tube wells

Rectification of Farm Pumping Units for Saving Electricity

Relevance: Rectification performed over pumping units improves operating efficiency. The working efficiency of pump sets at farmers fields in Jabalpur and Narsinghpur districts of Madhya Pradesh was surveyed with a view to optimize their efficiency. From the survey, it was found that 62 percent pumps are operating at an average efficiency lower than 30 percent. The causes generally observed for poor efficiency were (i) excessive suction lift (ii) loose foundation and (iii) poor maintenance of pumps. The results are indicative of wastage of electricity in pumping units.

Description of technology: Field studies were carried out at about 160 locations of two districts, Jabalpur & Narsingpur of MP for ten years. Energy used, operating conditions, output delivered, quality of pumps, installation & maintenance of pumping units were observed, recorded and analyzed in the light of efficiency of energy utilization. Guidelines were issued in form of leaflets for pump selection, installation, operation and maintenance and distributed to about 10,000 farmers at various occasions. "Sinchai Margdarshika" was published to save not only energy but also to save and use water resource which is becoming scanty day by day.

Output and scalability: Analysis of cause and improvement thereby showed the way to improve the performance of pumps by 5 to 14 percent. This saved 77 to 2688 units of electricity per year per pump. Appropriate remedial measures like mounting pumps on a rigid platform, cleaning of suction and delivery pipes, stopping leakage from joints, change of foot valve, and regular maintenance of the unit were suggested and executed in the farmers' field.



Loose foundation of the pump at farmers field



Firm foundation of the pump-rectified by the centre

Recharge Through Haveli Fields

Relevance: Havelis can be a good source of groundwater recharge. Water is stored in Haveli fields in rainy season and allowed to percolate in the field itself. Remaining water is let out after rainy season and residual moisture is utilized for rabi cultivation. Recharge of groundwater shall be fruitful to make these resources sustainable. Rejuvenation of Haveli fields is advocated at local, regional, and state level platforms. As a need of time and traditionally tested solution, the government of M.P. has started making Khet Talab similar to Haveli in each of the block and districts. This conservation and recharge of groundwater shall be fruitful to make these resources sustainable.

Description of technology: Satellite data with IRS-ID PAN Sensor was used to identify the Haveli areas in Patan block near Jabalpur. It was found that 73,424 ha were under Haveli during the year 2002-03, which is about 11 percent of total area under the study. An estimated spread of Haveli in Narsinghpur district was 1, 91,778 ha in the year 1986-87 and in Jabalpur district it was 2,78,624 ha. The total area was estimated to have been reduced to 1,38,422 ha in the year 1999-2000. The following steps were involved for estimation of recharge through Haveli fields.

- Characterization and mapping
- Evaluation – water Balancing
- Improvement and multiple uses for WP like singhara cultivation
- Water quality
- Additional recharge through recharge shaft and filter for direct recharge
- Status of Haveli fields and future prospects

Output and scalability: It was found through field observations during three consecutive years that each Haveli field contributes 4 to 6 mm/day for 40-60 days in the rainy season. This results into 40 to 60 cm percolation from the entire Haveli track which is mainly responsible for rich groundwater reservoir in the black soil regions of central Narmada Valley. Haveli can convert 40% of runoff into groundwater recharge over an area of about 7.5 lakh ha in Kymore Plateau and Satpura Hill region. Advices on rejuvenating Haveli fields in Kymore plateau and Satpura Hills is being considered for realization of quantum of recharge and harvesting of excess runoff from fallow fields during Kharif season.



Groundwater recharge through Haveli fields

Conjunctive Use of Surface Water and Groundwater

Relevance : Unbalanced use and mismanagement of water resources have either lowered groundwater levels or caused waterlogging and salinity in different parts of the country. Particularly in the canal-dominated regions of North India, there has been increase in groundwater levels due to seepage from the canals leading to the problems of waterlogging and salinity in many canal commands of the country. Excessive groundwater exploitation on the other hand has led to alarming decrease in groundwater levels in several parts of the country. Therefore, there is a need for conjunctive use of surface water and groundwater.

Description of technology : Water balance of the Khulri minor in the command area of Rani Awantibai Sagar was estimated considering cropping pattern, rainfall, surface runoff, seepage from canal and water table gradient. Model so developed was compared with observed water table fluctuations during monsoon and non-monsoon period. The rising trend was arrested through conjunctive use of groundwater and canal water, and shift in cropping pattern, i.e. partial replacement of paddy by soybean. Studies showed two shallow water table zones, Gangai-Barkhera and Changaona. The study was aimed to extend the approach of conjunctive use planned for the entire command area of Patan Branch Canal System in order to arrest groundwater table rise in shallow water table zones. The average rise of water level in canal irrigated area was 23 cm per year whereas average depletion in well-irrigated area was 10 cm/year. The case of rise in water table after introduction of canal (average 30 cm /year) was mainly due to high seepage rate ($2.35 \text{ m}^3/\text{million m}^2$ against the design value of $2.2 \text{ m}^3/\text{million m}^2$), non-utilization of groundwater, Haveli system of cultivation and paddy crop.

Output and scalability : The model revealed that 60 per cent of canal water and 40 per cent use of groundwater in the area will keep water table within the safe limit. 60:40 ratio of surface and ground water use is found a good media to maintain dynamic equilibrium at a safe depth of 1.5 m from ground surface. This is applicable for command areas having black soils specifically in Bargi Command, Tawa Command, Chambal Command in central India.



View of the canal

Treatment of Sewage Water Through Soil Aquifer

Relevance: It has become essential to use sewage wastewaters not only for augmenting the depleting water supply but also for protecting the environment. Use of sewage water as irrigation water has been successful in vegetables and forage. Sewage contains a number of nutrients including nitrogen, phosphorous, potassium and other micro elements required by the crop and landscape. Application of this sewage water after proper treatment considerably reduces the investment on nutrients.

Description of technology: A technology was developed for treatment of sewage by 'Soil Aquifer Treatment (SAT)'. Soils having varying percentage of sand, silt and clay can be used as filtration media for the treatment of sewage. Three cycles of loading sewage on soil for 10 days and then left for next 10 days can reduce levels of suspended solids, BOD, COD, nitrogen, turbidity and other trace elements appreciably and can be brought within safe limit for irrigation. Soil column depth of 110 cm to 140 cm provided acceptable renovation efficiency after treatment as per the physical and chemical analysis. Efficiency of SAT was tested under layered soil columns. Six layered soil column with clay loam soil of 300 mm, 450 mm and 600 mm depth amended with 15% sand and 30% sand in 500 mm layer were tested. Loamy sand of 200 mm was used as homogenous soil column. Outflow of a municipal sewer was taken as source sewage. Loading was carried out of water continuously for 14 days with a constant head of 10 cm in the entire column

Output and scalability: Based on efficiency of removal of toxic contents in the treated water, clay loam layer of 450 mm and 600 mm depth were ranked equal and superior than other layers. Percolation rate was found maximum in 300 mm layer amended with 30% sand. Looking to higher capacity of percolation and better treatment effacing homogeneous soil layer, loamy sand was found best to be used for SAT.



View of soil aquifer treatment plant

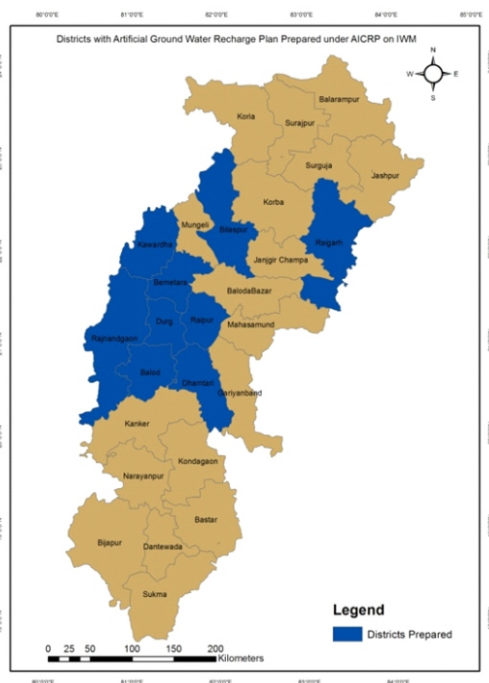
Groundwater Recharge Planning for Critical and Semi-critical Districts of Chhattisgarh using RS and GIS

Relevance: Artificial recharge aims at augmenting the replenishment of ground water storage by some method of construction, spreading of water, or by artificially changing natural conditions. Out of 146 blocks in the Chhattisgarh state, 27 have been categorized as semi - critical from groundwater development point of view as the stage of groundwater development is more than 70% but less than or equal to 90 %. If proper care is not taken and artificial groundwater recharge development plan is not developed and implemented on ground level, then this semi-critical zones will take no time to reach critical category.

Description of Technology: Groundwater recharge plan was developed for Durg, Balod, Bemetara, Bilaspur, Kawardha, Rajnandgaon and Dhamtari districts of Chhattisgarh state which have semi-critical blocks. It was done by superimposing various thematic maps including classified satellite image, lineament map, drainage map, slope map and groundwater fluctuation map. The subsurface storage space was estimated based on the thickness of available unsaturated zone (below 2 mbgl) in post-monsoon and the specific yield of phreatic aquifer. The limit to saturate the vadose zone below 2 m was kept with a view to avoid water logging and soil salinity. After assessing the actual volume of water required for saturating the vadose zone, the net amount of source water was calculated by considering 75% efficiency of the artificial recharge structure.

Output and Scalability:

Availability of source water to recharge the subsurface reservoir in all the districts was assessed and based on that the number of structures in potential ground water recharge zone was worked out. The developed plan has been disseminated to the line departments for implementation on ground level so as to get better results in terms of ground water recharging.



Development of Groundwater Resources for Irrigation in Burhi Gandak River Basin and South Bihar

Relevance: A planned approach is essential for sustainable development of a precious natural resource like groundwater whose importance is likely to increase in future. For this the first task would be to make a realistic assessment of ground water resources and plan their use in such a way that total crop water requirement is met and there is neither waterlogging nor excessive lowering of ground water table. Assessment of ground water resources for irrigation in the districts falling under Burhi Gandak River Basin and some of the districts of south Bihar falling under Agro-climatic zone-III B is important information for the development of the area.

Description of Technology: Groundwater recharge in the study area was computed by adding the recharge in monsoon and post-monsoon season estimated by the guidelines of Central Ground Water Board (CGWB). The groundwater draft in the study area was estimated by using well census and CGWB unit draft data for the state. The stage of groundwater development was estimated by dividing the groundwater draft by the estimated annual recharge. If the stage of groundwater development is less than 70%, then it falls within safe category, and there is further scope of groundwater development. If it is more than 70%, care should be taken for judicious use of groundwater resource.

Output and Scalability: The overall stage of ground water development varies from 20 % to 62 % in Burhi Gandak basin whereas it varies from 23 % to 58 % in Southern districts of Bihar falling under Zone III B. Hence all these districts fall under safe category indicating that there is good scope for further ground water development. Ground water development in the Burhi Gandak basin should be done with the help of shallow tubewell, bamboo boring and deep tubewell whereas the ground water development in southern districts should be done with the help of shallow tubewell and deep tubewell. Siwan, Gopalganj, Patna and Nalanda districts are fast approaching semi-critical category and there is a need for safe utilization of groundwater.

Groundwater development in different districts of Bihar

Burhi Gandak River Basin		South Bihar	
Districts	Stage of groundwater development (%)	Districts	Stage of groundwater development (%)
West Champaran	30.2	Patna	57.2
East Champaran	44.6	Gaya	48.6
Siwan	62.0	Nalanda	57.9
Saran	44.0	Nawada	50.4
Gopalganj	58.2	Bhojpur	35.2
Muzaffarpur	38.4	Buxar	31.4
Samastipur	20.2	Aurangabad	23.1

Groundwater Pollution in Bihar and Options for its Reuse

Relevance: Bihar is undergoing fast economic development which has impact on life style, natural resources and the environment. Agriculture plays a vital role in poverty alleviation, because more than 85 % population of Bihar are of rural background. The assured availability of ground water is the key factor in shaping the future economic scenario of the state. The huge volume of wastewater generated in the Ganga basin can be used for crop production as it provides a reliable source of water supply and valuable plant nutrients to the soil. However, there is a need for assessment of groundwater pollution due to sewage disposal.

Description of Technology: The groundwater samples of water bodies receiving continuous disposal of municipal wastes at Patna by-pass, areas receiving industrial effluents and fly ash at Barauni and the areas receiving intensive application of agro-chemicals at Masina farm, Samastipur were studied. Amongst the water bodies located in Patna by-pass area, open wells showed high values of EC ($>2.2 \text{ dSm}^{-1}$), calcium and magnesium ($>10 \text{ me/L}$), total dissolved solid ($>1000 \text{ ppm}$) and chloride content ($>10.0 \text{ me/L}$) which were beyond permissible range. Majority of the hand pumps and all open wells throughout the area yielded high $\text{NO}_3\text{-N}$ content (10.0 to 35.0 ppm) which indicated that water of these sources are unsafe for potable and irrigation use. In general, all hand pumps and open wells showed appreciably high Fe content which varied from 0.315 to 0.561 ppm which is not suitable for drinking purpose. Further study revealed that the water bodies situated nearby to discharge point showed high Fe content as compared to distant points. The content of other trace metal cations like Zn, Cu, Mn and heavy metals like Cd, Ni, Cr, and Co were found within the safe limit for drinking as well as irrigation purpose. Similarly, the study revealed that intensive use of agrochemicals at Samastipur may influence the groundwater to a greater extent. It was noticed that open wells nearby to the Masina Farm and Pusa Bharawn has high values of EC, TDS and Cl^- content which were not within acceptable range of the potable water. Similarly some hand pumps and open wells nearby to Masina Farm and cattle Farm, Pusa showed high $\text{NO}_3\text{-N}$ content which is unsafe for drinking as well as irrigation purpose.

Output and Scalability: Based on the investigations, it was observed that appropriate wastewater treatment must be applied to raw municipal sewage water before it can be used for agriculture. Hence to minimize the potential risk to the health of humans, animals and plant, it is necessary to coordinate sludge application. Plants growing on such soils accumulate excess amount of micronutrients and heavy metals in their tissues which may enter in the system of animal and human being. Accumulation of trace metal cations in different plant species differed widely which varied from crop to crop and place to place. The cultivation of leafy vegetables viz. red spinach, spinach, cabbage etc. should be discouraged in the areas receiving continuous disposal of sewage sludge and farmers should be advised to grow cereal crops. Vegetables which are eaten raw, viz., tomato, water melons, pumpkin, radish, turnip should be irrigated with treated sewage water with drip irrigation.

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