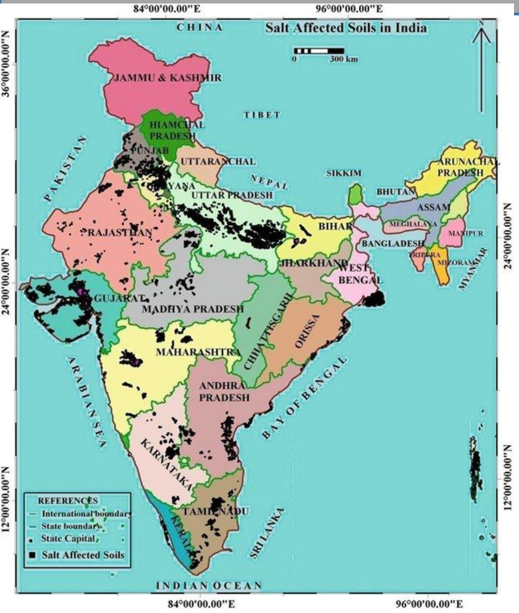
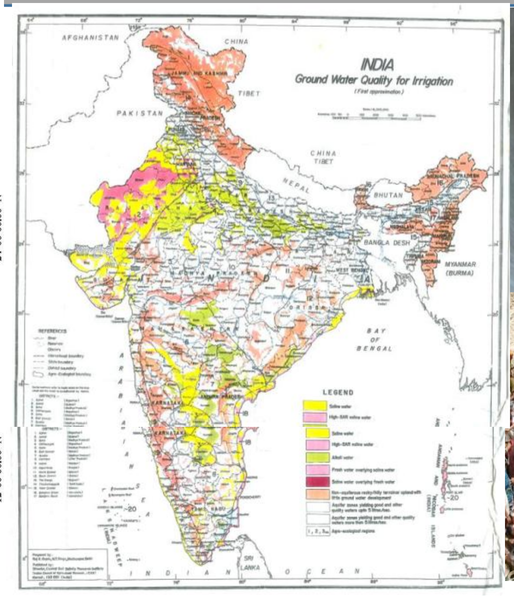
Long Term Estimates of Salinity in Water and Soil-Engineering Approaches for Salt Balances





Dr. Chhedi Lal Verma

Sr. Scientist & Ex. Professor

ICAR Central Soil Salinity Research Institute

Regional Research Station, Lucknow

जल का बृहत् चक्रण

जलं प्रथमो जायते वहति जीवनं रसं तु।
गंगा युगं संवहति वनं कल्पं तथैव च।।

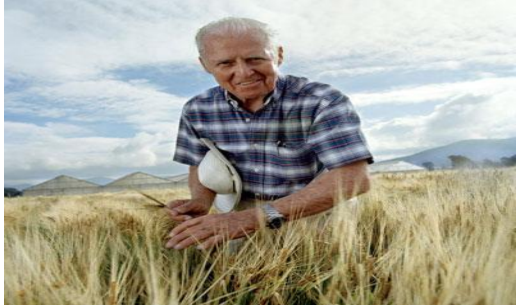
कलि कल्मषेन सन्तप्तो गंगा विष्णु लोके
समागमिष्यति।
संचयं जलं जलभृते रक्षणञ्च व्यापारं कलौ
धर्मः तु जायते।

-स्वस्फूर्त

GREEN REVOLUTION

1. High Yielding Dwarf Varieties
2. Chemical Fertilizers
3. Plant Protection Chemicals
4. Improved Tillage Machineries
5. **Assured Irrigation Water**

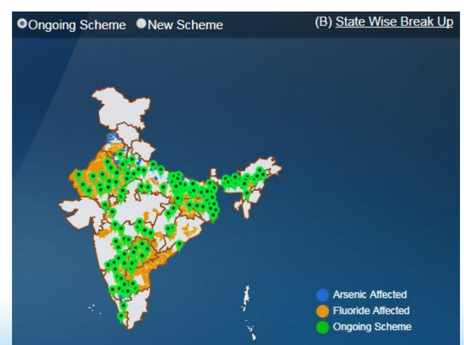
Canal=40% **GW=60%**

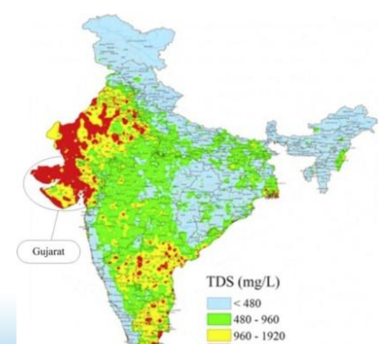




Water Crises

GROUND WATER DECLINE | **SCARCITY** | **DROUGHTS** | **SEWAGE**





POLLUTION | **ARSENIC,** | **FLUORIDE** | **SALINE GW**

ORIGIN OF SALTS IN SOIL

Primary Minerals: primary minerals

Chemical Weathering: Due to hydrolysis, hydration, solution, oxidation, carbonation and other processes, the salt constituents are gradually released and made soluble.

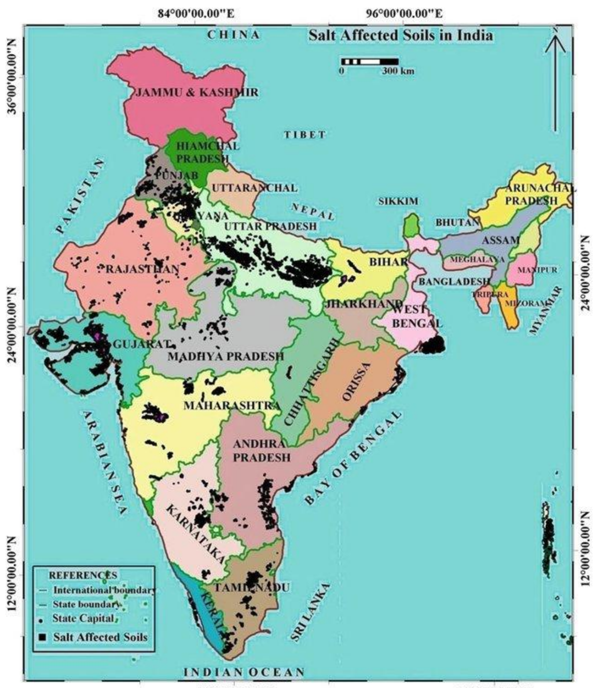
Released salts are transported away from their source of origin through surface or groundwater streams.

Types:

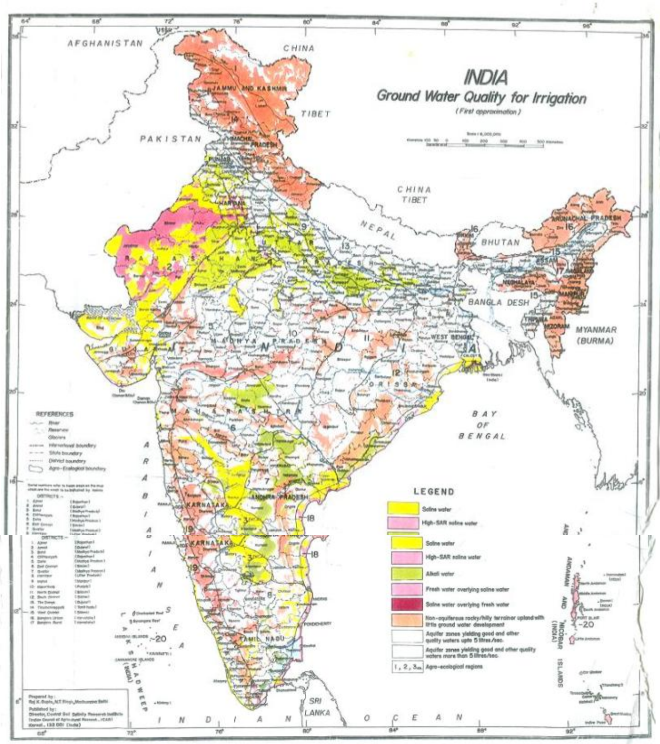
1. Saline soils - Soils containing sufficient neutral soluble salts to adversely affect the growth of most crop plants. The soluble salts are chiefly sodium chloride and sodium sulphate. But saline soils also contain appreciable quantities of chlorides and sulphates of calcium and magnesium. pH of saturated soil paste is less than 8.2. An electrical conductivity of the saturated soil extract of more than 4 dS/m at 25 °C.

2. **Sodic Soils -** Soils containing sodium salts capable of alkaline hydrolysis, mainly Na_2CO_3, these soils have also been termed as 'Alkali' in older literature. pH of the saturated soil paste is more than 8.2. ECe < 4 dS/m at 25 °C. pHe> 8.5, ESP> 15.0. at 25 °C.

3. **Saline Sodic Soils: Saline =2.956 Mha   Sodic=3.771 Mha**



Salt Affected Soil of India



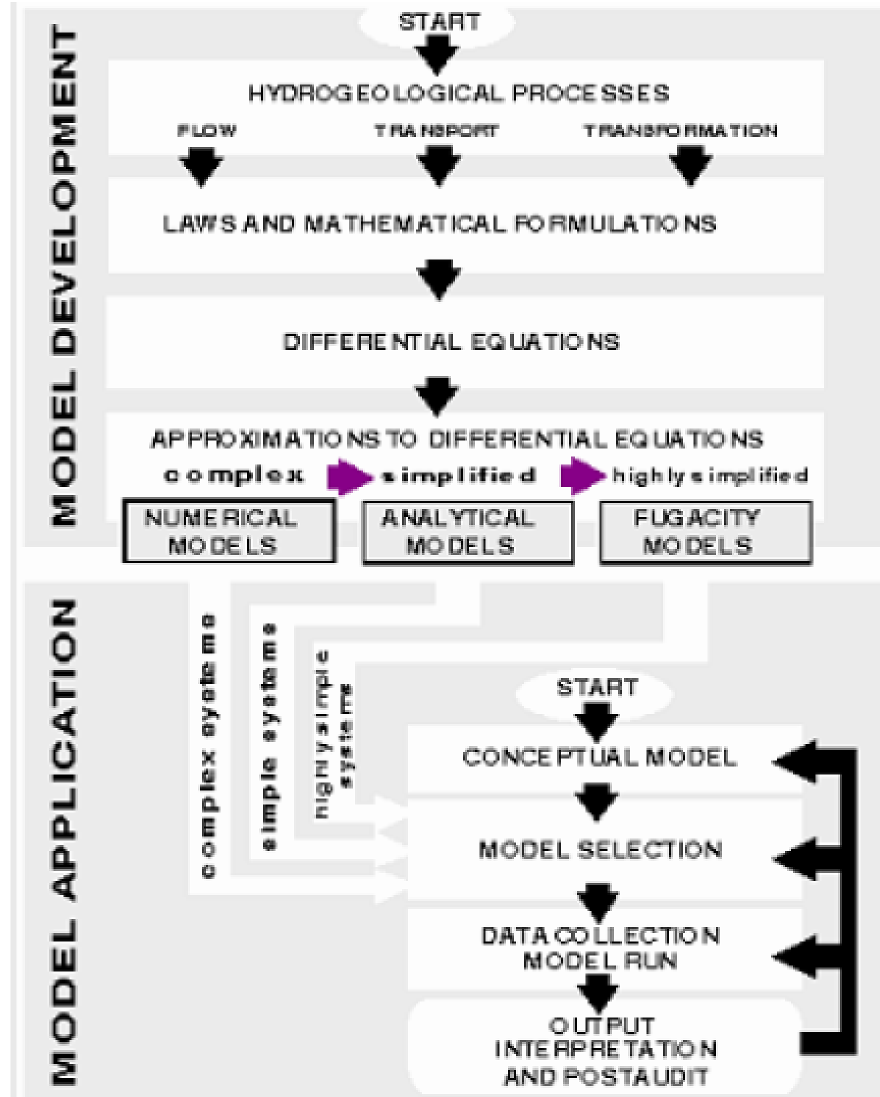
Ground Water Quality Map of India

DEVELOPMENT OF GROUND WATER SIMULATION MODEL

1. **Model Objectives**

2. **Hydrogeological Characterization**

3. **Model Conceptualization**



1. GROUNDWATER FLOW EQUATION

The governing flow equation for three-dimensional saturated flow in saturated porous media is:

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right)-Q=S_s\frac{\partial h}{\partial t}$$

where,

K_{xx}, K_{yy}, K_{zz}	=	hydraulic conductivity along the x,y,z axes which are assumed to be parallel to the major axes of hydraulic conductivity;
h	=	piezometric head;
Q	=	volumetric flux per unit volume representing source/sink terms;
S_s	=	specific storage coefficient defined as the volume of water released from storage per unit change in head per unit volume of porous material.

2. Solute Transport Model

$$\frac{\partial c}{\partial t}=-\frac{\partial}{\partial x_i}(cv_i)+\frac{\partial}{\partial x_i}\left(D_{ij}\frac{\partial c}{\partial x_j}\right)+R_c \qquad i,j=1,2,3$$

where,

c	=	concentration of the solute;
R_c	=	sources or sinks;
D_{ij}	=	dispersion coefficient tensor;
v_i	=	velocity tensor.

MOST COMMON AVAILABLE MODELS

1. **FEFLOW**

   (Finite Element Subsurface Flow System)

2. **HST3D**

   (3-D Heat and Solute Transport Model)

3. MODFLOW

(Three-Dimensional Finite-Difference Ground-Water Flow Model)

MODFLOW is the name that has been given the USGS Modular Three-Dimensional Ground-Water Flow Model. Because of its ability to simulate a wide variety of systems, its extensive publicly available documentation, and its rigorous USGS peer review, MODFLOW has become the worldwide standard ground-water flow model. MODFLOW is used to simulate systems for water supply, containment remediation and mine dewatering. When properly applied, MODFLOW is the recognized standard model.

4. MT3D

(A Modular 3D Solute Transport Model)

5. **SEAWAT**

(Three-Dimensional Variable-Density Ground-Water Flow)

6. **SUTRA**

(2-D Saturated/Unsaturated Transport Model)

7. **SWIMv1/SWIMv2**

(Soil water infiltration and movement model - simulate soil water balances)

8. **Visual MODFLOW**

(Integrated Modeling Environment for MODFLOW, MODPATH, MT3D)

9. UNSATCHEM

A software package for simulating water, heat, carbon dioxide and solute movement in one-dimensional variably saturated media. The software consists of the UNSCHEM (version 2.0) computer program, and the UNSATCH interactive graphics-based user interface.

The UNSCHEM program numerically solves the Richards' equation for variably-saturated water flow and convection-dispersion type equations for heat, carbon dioxide and solute transport.
The flow equation incorporates a sink term to account for water uptake by plant roots. The heat transport equation considers transport due to conduction and convection with flowing water.

Diffusion in both liquid and gas phases and convection in the liquid phase are considered as CO_2 transport mechanisms. The CO_2 production model is described.

The major variables of the chemical system are Ca, Mg, Na, K, SO_4, Cl, NO_3, $H_4S_iO_4$, alkalinity, and CO_2.

The model accounts for equilibrium chemical reactions between these components such as complexation, cation exchange and precipitation-dissolution. For the precipitation-dissolution of calcite and dissolution of dolomite, either equilibrium or multicomponent kinetic expressions are used which include both forward and back reactions. Other dissolution-precipitation reactions considered include gypsum, hydromagnesite, nesquehonite, and sepiolite. Since the ionic strength of soil solutions can vary considerably with time and space and often reach high values, both modified Debye-Huckel and Pitzer expressions were incorporated into the model as options to calculate single ion activities.

The program may be used to analyze water and solute movement in unsaturated, partially saturated, or fully saturated porous media. T The governing flow and transport equations are solved numerically using finite differences and Galerkin-type linear finite element schemes, respectively.

10. Model Using Machine-Learning Techniques:

Such model use comprehensive set of climatic, topographic, soil, and remote sensing data to develop models capable of making predictions of soil salinity (expressed as electrical conductivity of saturated soil extract) and sodicity (measured as soil exchangeable sodium percentage) at different longitudes, latitudes, soil depths, and time periods.

11. The Soil & Water Assessment Tool (SWAT):

It is a small watershed to river basin-scale model used to simulate the quality and quantity of surface and ground water and predict the environmental impact of land use, land management practices, and climate change. SWAT is widely used in assessing soil erosion prevention and control, non-point source pollution control and regional management in watersheds.

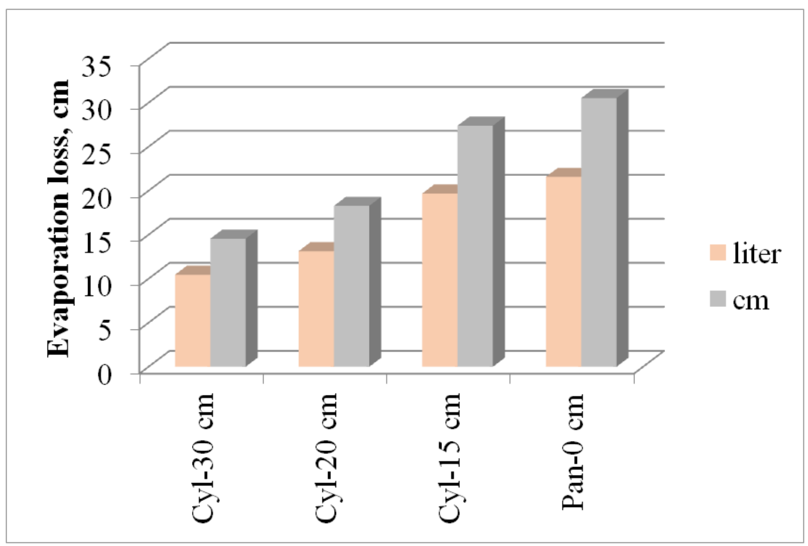
SALT ACCUMULATION MODELLING

The Model : Inverse Appropriated Water Table Depth Model **(Verma, et al. 2020)**

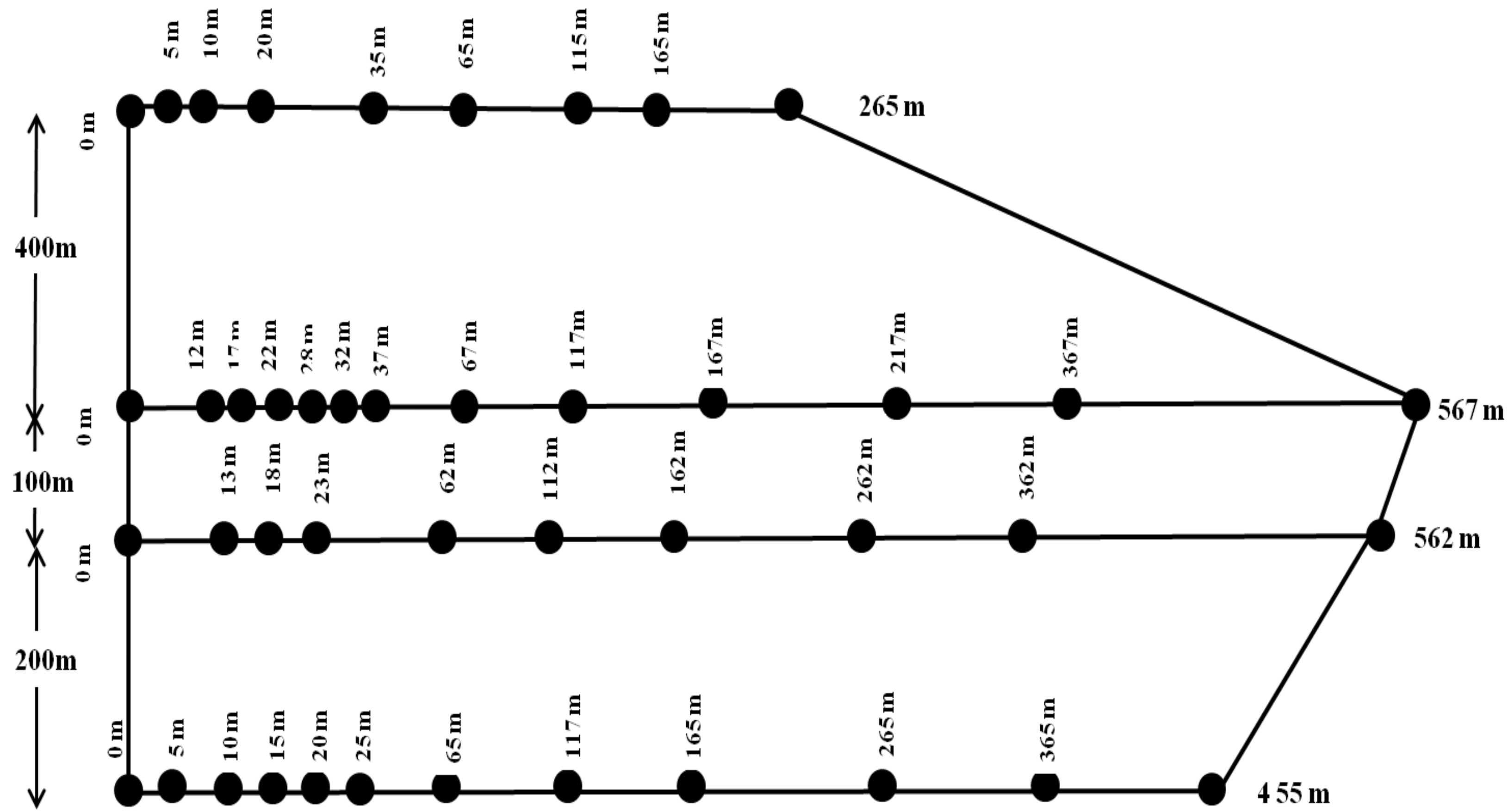
Hypothesis: The rate of change of incremental evaporation loss with respect to the incremental water table depth below ground surface (dy) over a specified time span is inversely proportional to appropriated water table depth below ground surface (y^a). Mathematically it can be expressed as below.

$$\frac{dE}{dy} = \frac{k}{y^a} \qquad (1)$$

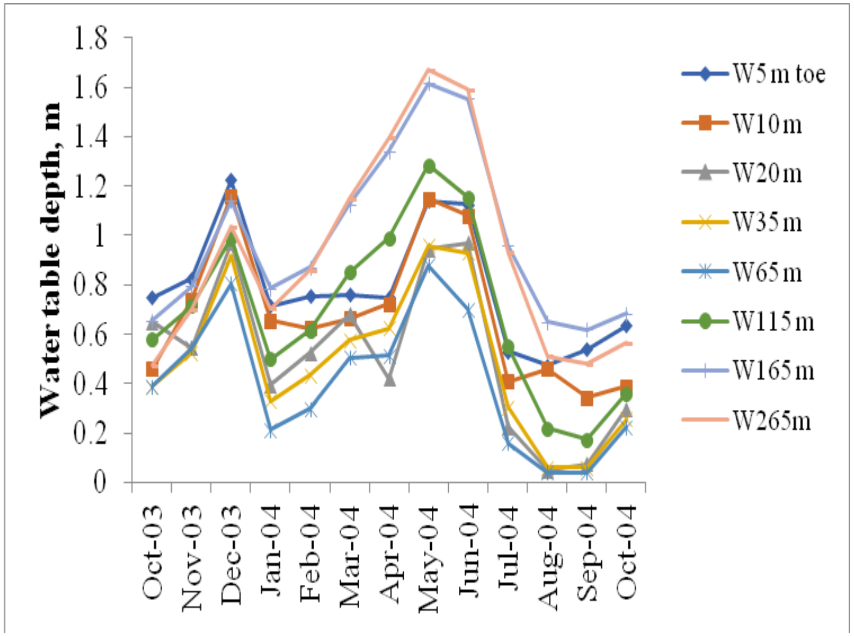
$$E_y = \frac{1}{\left(\frac{1}{E_p}\right) + \alpha\, y^{\beta}} \qquad (2)$$

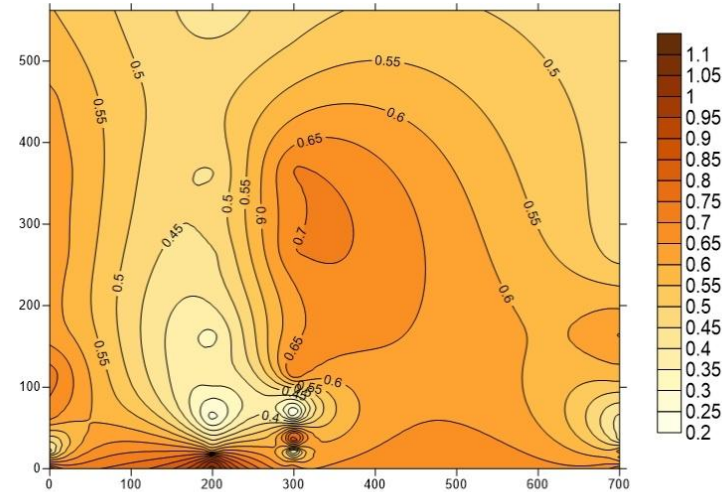


Variation of evaporation loss with water table depth

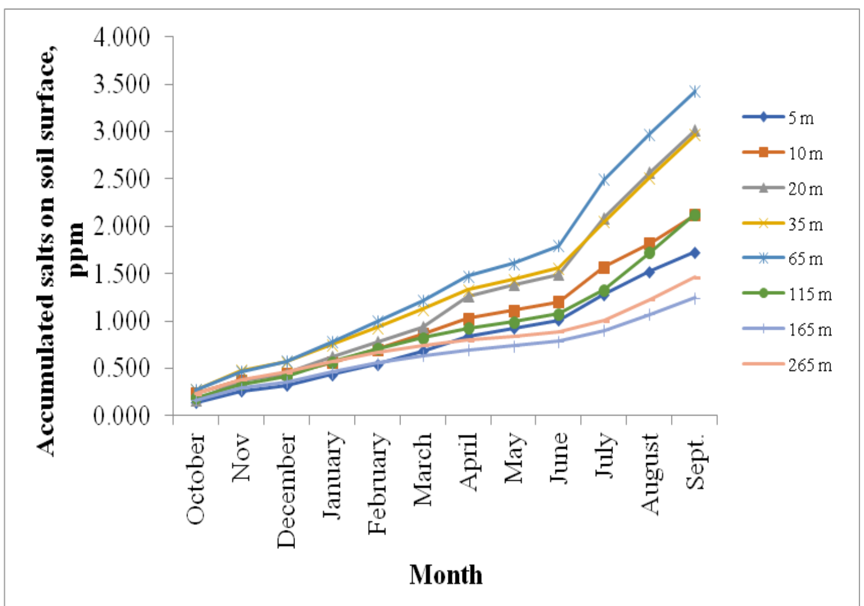


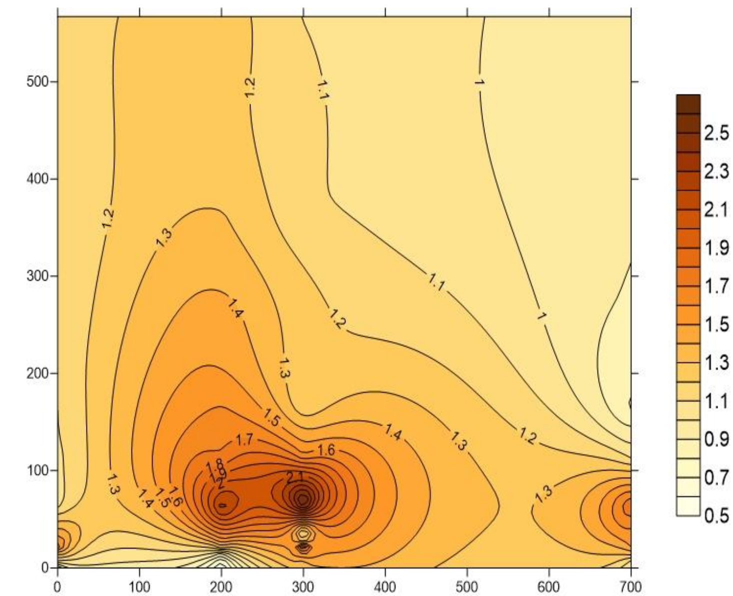
Water table measuring grid across Sharda Sahayak Canal





Water Table Contour for October



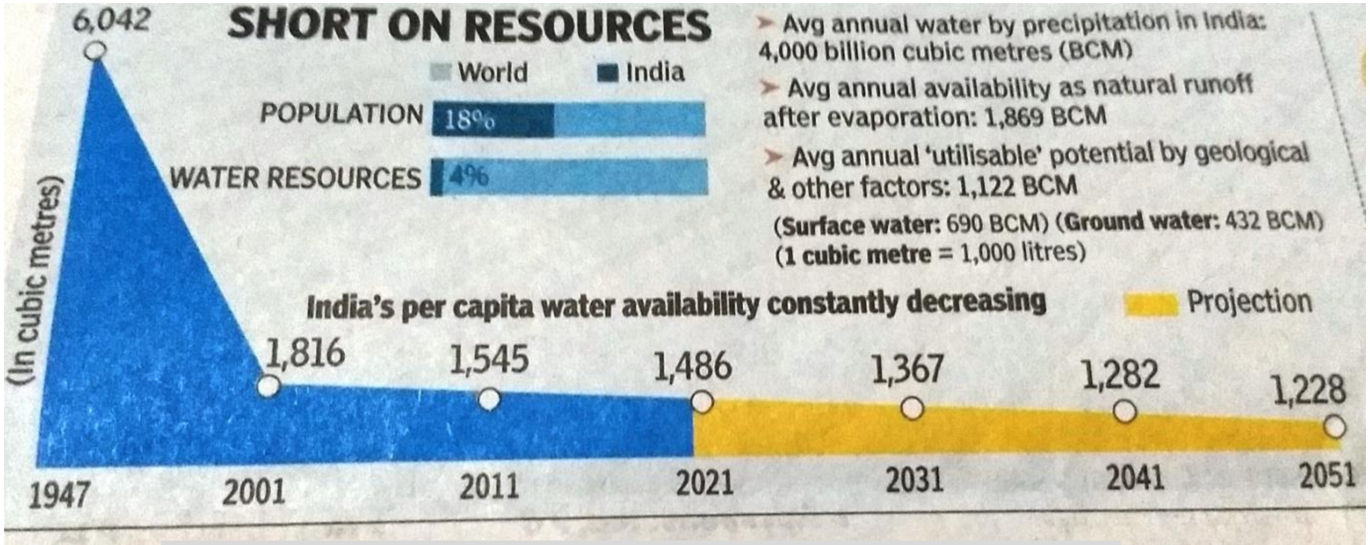


Salt Accumulation Contour for October

Water Table Fluctuations and Salt Accumulation

Growing Demand

Category	Year 2010			Year 2025			Year 2050		
	Low	Medium	High	Low	Medium	High	Low	Medium	High
Irrigation	489.0	536.0	556	619	688	734	830	1008	1191
Domestic	39.4	41.6	61	47	52	78	59	67	104
Industrial	37.0	37.0	37	61	67	79	69	81	116
Total	555.4	614.6	654	727	807	881	958	1156	1411

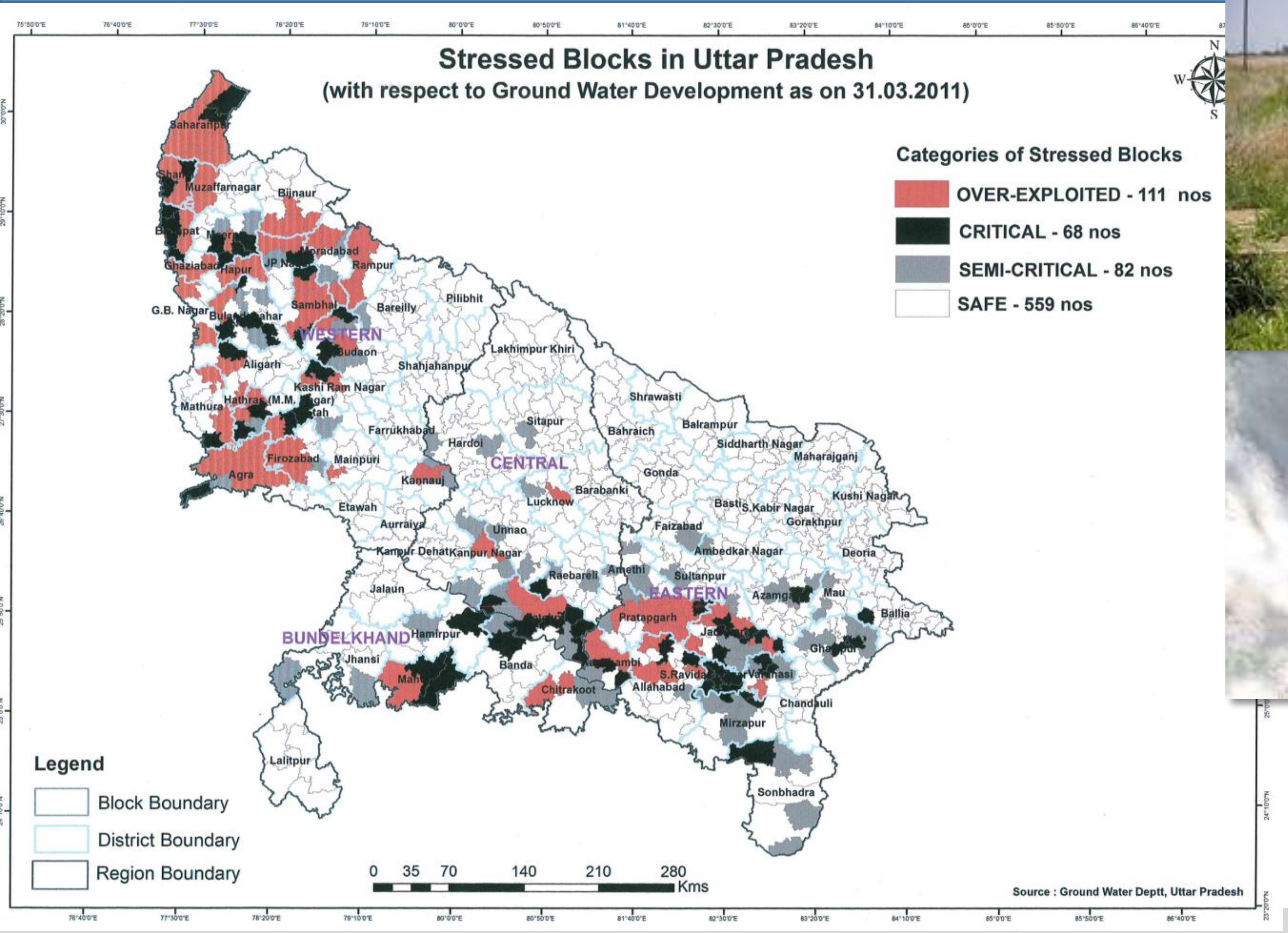


Percapita water availability.

Ground water utilization as a percent of ground water recharge in different states.

S.N.	States	Ground water utilization, % of recharge	S.N.	States	Ground water utilization, % of recharge
1.	Andhra Pradesh	40-50	15.	Madhya Pradesh	40-50
2.	Arunachal	10-20	16.	Maharashtra	40-50
3.	Assam	20-30	17.	Manipur	10-20
4.	Bihar	30-40	18.	Meghalaya	10-20
5.	Chhattisgarh	10-20	19.	Mizoram	10-20
6.	**Delhi**	**100**	20.	Orissa	10-20
7.	Goa	50-60	**21.**	**Punjab**	**100**
8.	Gujarat	70-80	**22.**	**Rajasthan**	**100**
9.	**Haryana**	**100**	23.	Sikkim	10-20
10.	H. P.	20-30	**24.**	**Tamil Nadu**	**70-80**
11.	J. & K.	10-20	25.	Tripura	10-20
12.	Jharkhand	10-20	**26.**	**Uttarakhand**	**60-70**
13.	**Karnataka**	**60-70**	**27.**	**Uttar Pradesh**	**60-70**
14.	Kerala	40-50	28.	West Bengal	30-40

GROUNDWATER OVEREXPLOITATION



- 70% of agriculture depend on GW in UP
- GW levels falling in 630 of 820 blocks
- Number of overexploited blocks is increasing

SOLUTION OF WATER RELATED PROBLEMS

-Storage and Direct Use of Rainwater

- Storage and Direct Use of Surface Runoff

-Ground Water Recharge Using Rain and Runoff Water

-Use of Poor Quality Water

- Dilution of pollutants by Mixing Good Quality Water

A. Ground Water Recharge Through Runoff Water

* Surface inundation due to rainfall at specific locations

* Low lying fields

* Non- functional surface drains

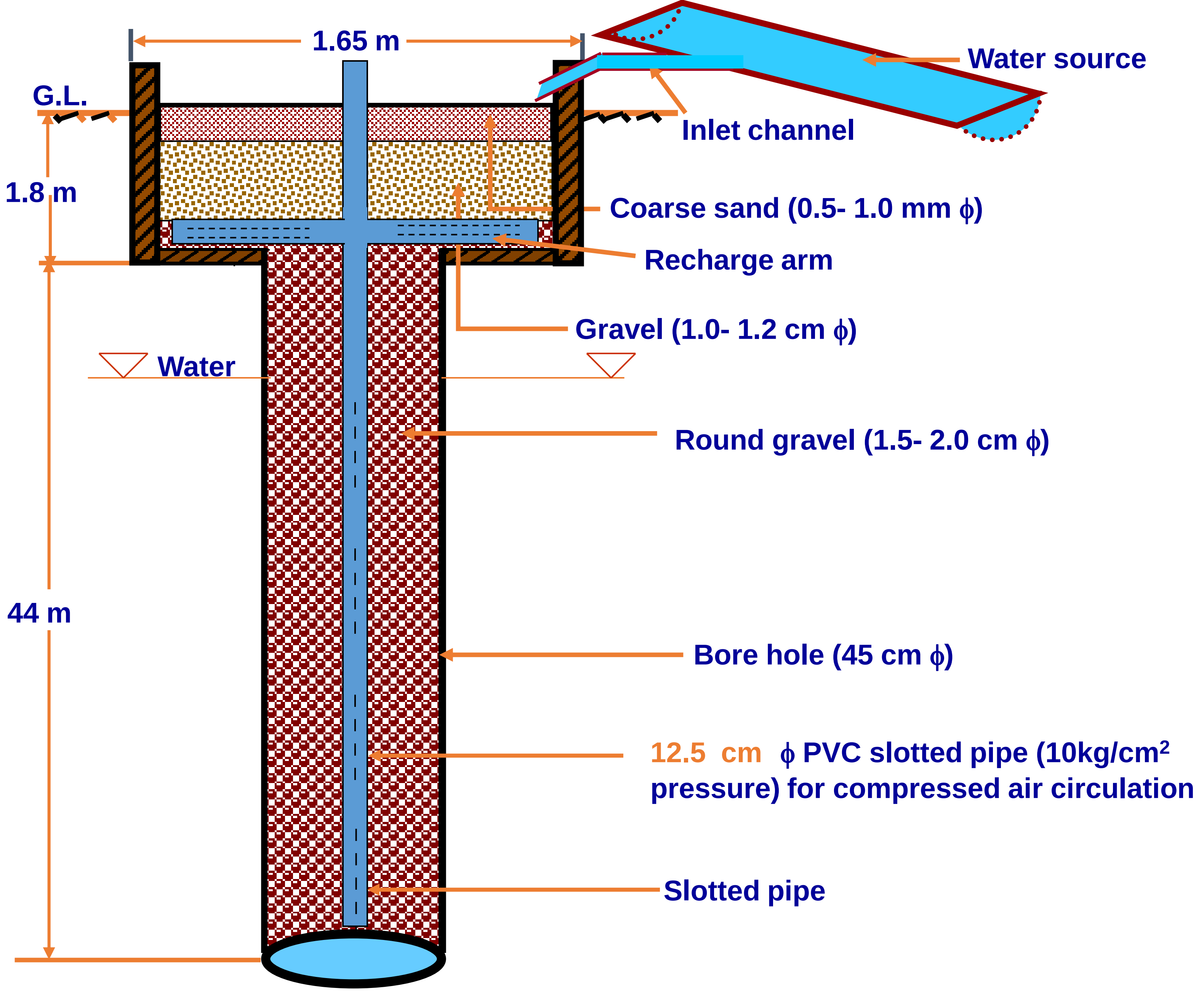
Small GR structures

* Acts as drainage outlet

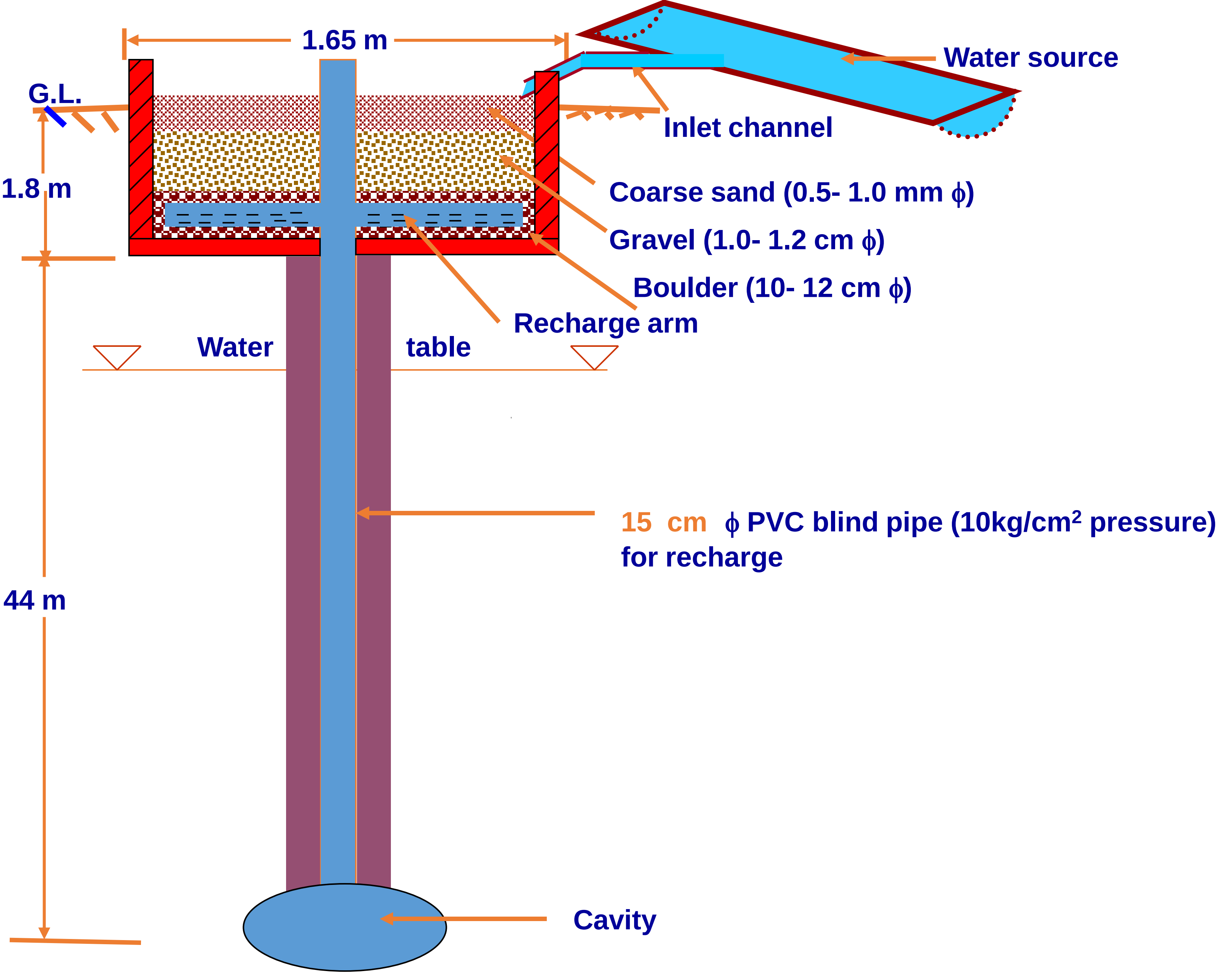
- Save crops from water stagnation
- Raise water table
- Improve groundwater quality (EC, RSC, fluoride, nitrate, fluoride, arsenic)

Technologies Demonstrated

State/ District	Technology/intervention	No. of sites
Haryana		**29**
Karnal, Kaithal, Jind, Kurukshetra, Yamunanagar, Sonipat	Recharge shaft	21
	Recharge cavity	08
Punjab		**05**
Patiala	Recharge shaft	05
Uttar Pradesh		**03**
Unnao	Recharge cavity	03
Gujarat		**12**
Bharuch	Recharge well	12
Total		**39**



Recharge Shaft for different selected sites of FPARP



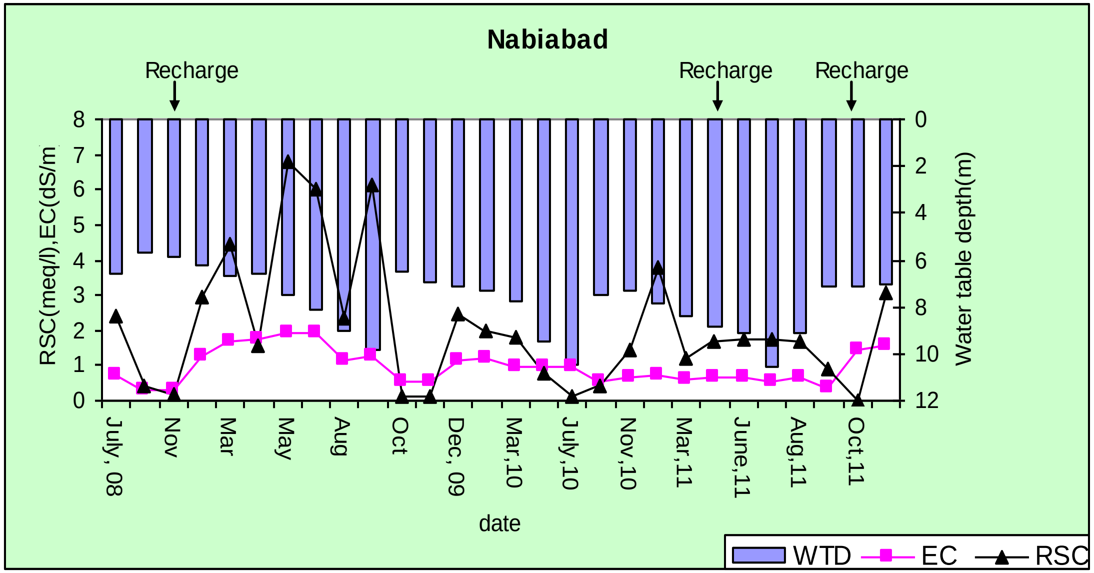
Recharge cavity for different selected sites of FPARP

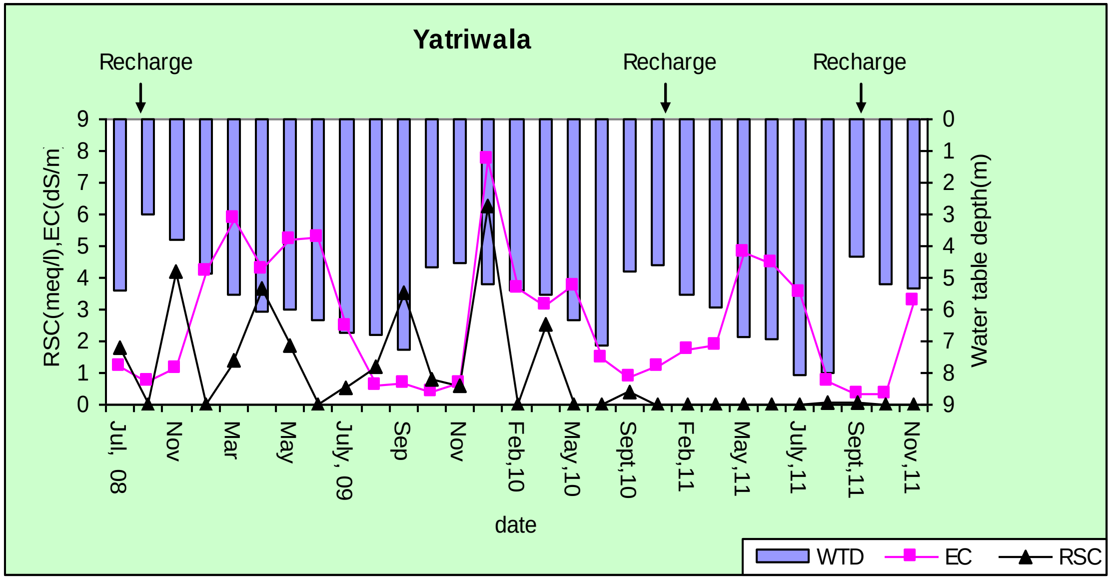
Installation of Recharge Wells

Construction of Recharge Filter

Clogging of filtering media

Monitoring of Groundwater


Nabiabad
Recharge
Recharge
Recharge
RSC(meq/l),EC(dS/m)
Water table depth(m)
8
7
6
5
4
3
2
1
0
0
2
4
6
8
10
12
July, 08
Nov
Mar
May
Aug
Oct
Dec, 09
Mar,10
July,10
Nov,10
Mar,11
June,11
Aug,11
Oct,11
date
WTD
EC
RSC


Yatriwala
Recharge
Recharge
Recharge
RSC(meq/l),EC(dS/m)
Water table depth(m)
9
8
7
6
5
4
3
2
1
0
0
1
2
3
4
5
6
7
8
9
Jul, 08
Nov
Mar
May
July, 09
Sep
Nov
Feb,10
May,10
Sept,10
Feb,11
May,11
July,11
Sept,11
Nov,11
date
WTD
EC
RSC

Hydraulic and Economic Impact of Groundwater Recharge Structure During 2009

Site	Runoff Area (ha)	Runoff Volume (m^3)	Investment Cost (Rs/m^3 recharge water)	Paddy saved	Net Saving (Rs.)
1	12	12480	3.5	25% in 1 ha area	24500
2	20	20800	2.1	30% in 2 ha area	58800

- **Recharge Rate** : 2500-3500 m^3 / weak (4-6 l/s)
- **Water table Rise** : 0.6-3.3 m
- **Reduction in ground water salinity** : 0.2-2.4 dS/m

Improvement in GW Quality due to Recharge During 2009

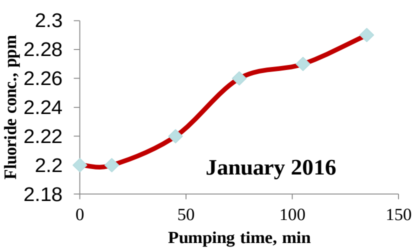
S.N.	State/Village	EC (dS/m)			RSC		
		May/ June	Aug.	Oct.	May/ June	Aug.	Oct.
1	Haryana						
	a) Nabiabad (Karnal)	1.9	1.1	0.5	6.0	2.4	0.2
	b) Paju Kalan (Jind)	1.2	0.9	0.5	5.6	3.4	0.62
	Dussain (Kaithal)	1.4	1.1	0.5	6.7	3.9	2.1
2	Punjab Jodhpur (Patiala)	2.0	1.7	1.1	7.1	3.4	3.2
3	Gujarat Borebhete (Bharuch)	1.9	0.3	-	-	-	-

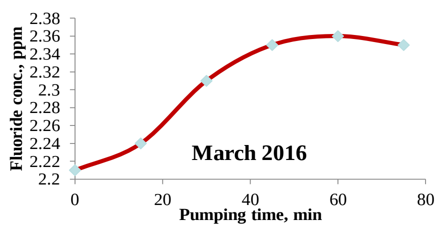
Fluoride levels in Hand Pumps and Open Wells (September 2020)

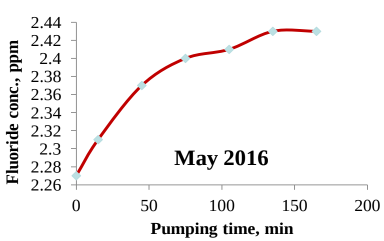
Name	F, mg/L	TDS, mg/L
Hand Pumps		
Ram Naresh	10.20	1637.0
Suresh	8.96	1439.0
Chandra Pal	0.67	483.0
Sajivan	7.86	2879.0
Shiv Ratan	2.32	356.9
Well-Road	5.94	1305.0
Ballu Yadav	2.98	787.8
Vasdev	0.68	385.4
Putti Gokul	8.95	2240.0
Prem Kumar	1.05	1920.0
Narendra Yadav	2.63	959.9
Putti Lal	0.83	460.8
Average	**4.42**	**1237.8**
Wells		
Arun Kumar- Well	9.96	313.9
Main Well	5.17	2142.0
Alok-Well	7.83	4054.0
Average	**7.65**	**2169.97**

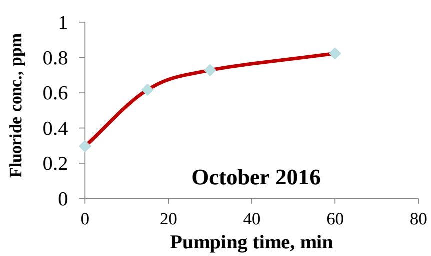
B. Ground Water Recharge Through Rainwater Harvesting

Sirsahakhera, Unnao





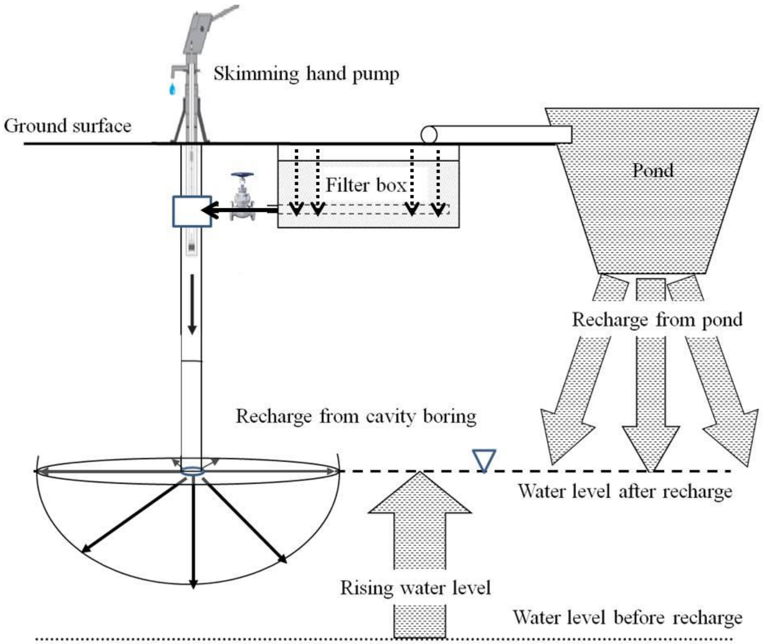




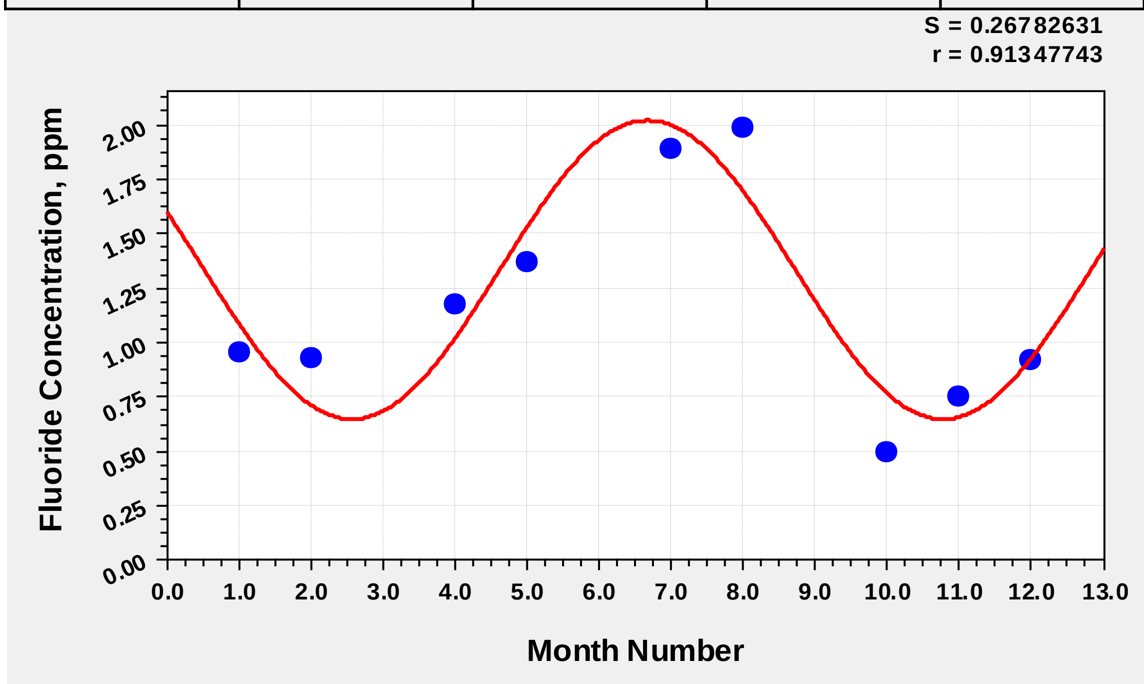
C. Ground Water Recharge Through Skimming Cavity Well



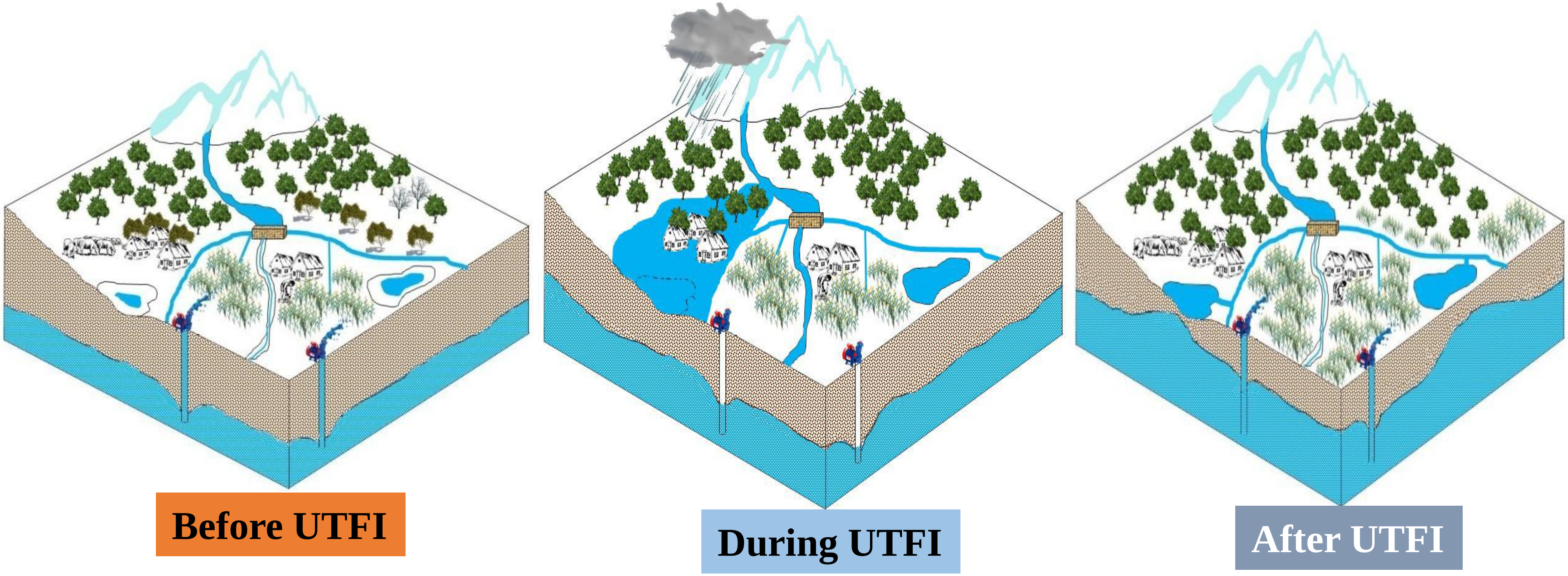


Month T	Rainfall (R_T) mm	Runoff converted to recharge (RCTR) m^3	Rainfall (R_T) mm	Runoff converted to recharge (RCTR) m^3
	2016		2017	
June	156.3	1293.200	48.3	369.357
July	243.7	1994.101	213.5	1735.768
August	180.2	1450.916	356.1	2955.582
September	81.2	606.981	60.6	430.766
October	11.1	51.144	0	0
Total	**672.5**	**5396.342**	**678.5**	**5491.473**



D. Underground Taming of Flood for Irrigation



UTFI – "Recharging aquifers that have latent or depleted groundwater storage capacity with wet-season high flows" (*Paul et al 2015*)

UTFI PILOTING ON THE UPPER GANGETIC PLAIN

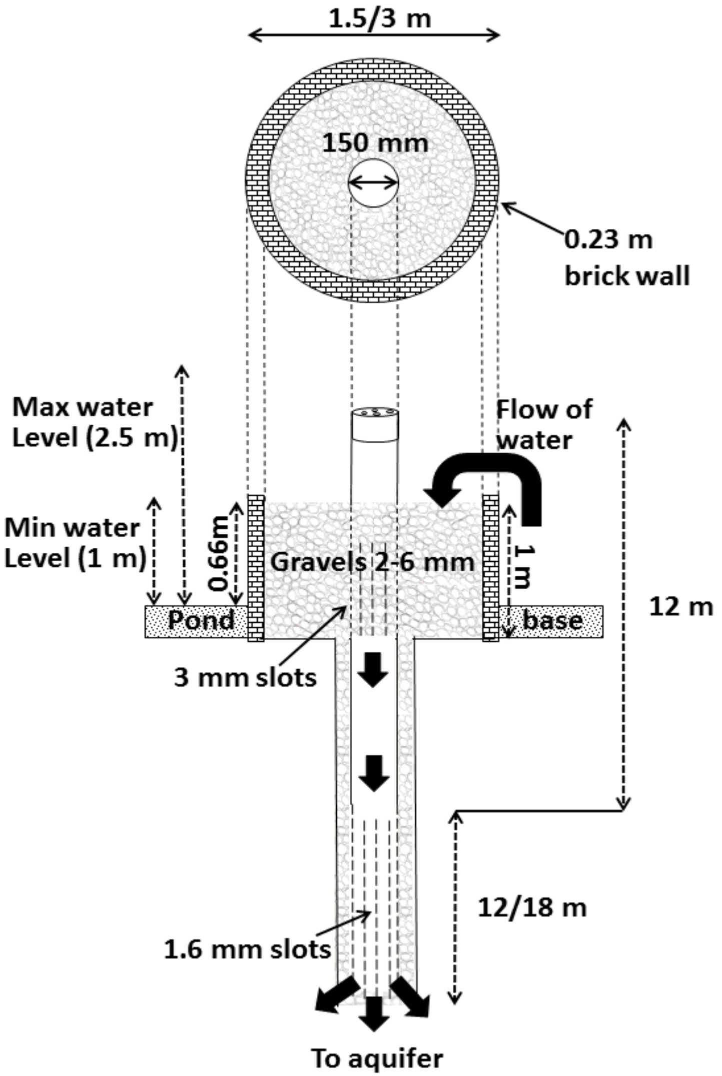
- UTFI pilot demonstration trial established in western Uttar Pradesh in 2015

- Detailed testing, monitoring and evaluation was done till 2018

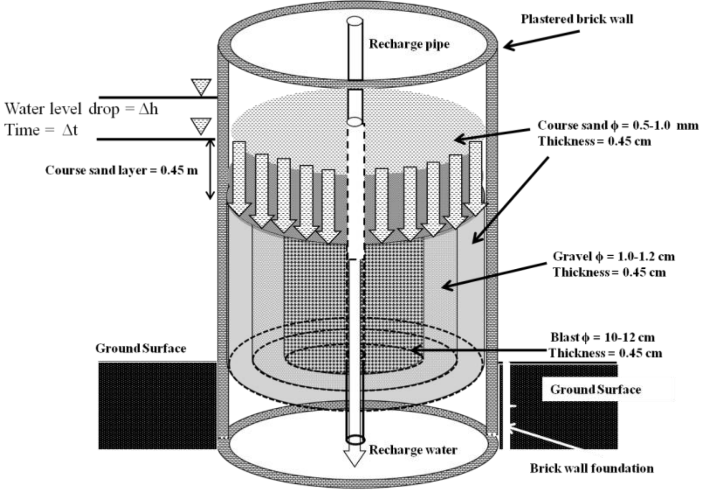
Community pond converted for UTFI in Jiwai Jadid village. The village is periodically flooded and groundwater levels have been falling, which impact on domestic water supplies and agricultural livelihoods.

Details of Recharge Wells

Features of the recharge wells		
Characteristic	Series-I	Series-II
Diameter	150 mm	150 mm
Depth	24 m	30 m
Perforated Section	18 m	18m
Gravel Pack Diameter	1.5 m	3.0 m
Gravel Pack Height	1.0 m	1.0 m
Filter Box Thickness	0.23 m	0.35 m



Not to scale, for representation purpose only.

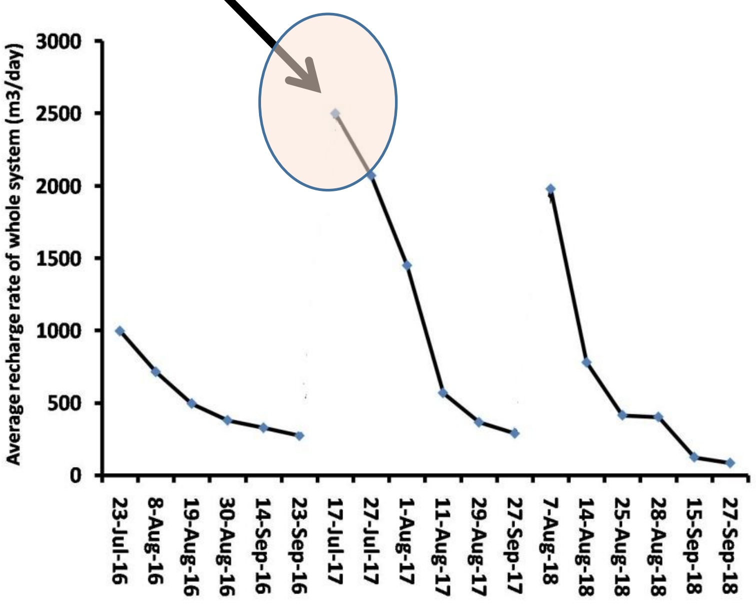


Highest Recharge Rate Observed in 3 Years

2499 m^3/day
2.89 lps

Designed Recharge Rate = 5.00 lps
Measured Recharge Rate = 2.89 lps
Safe Enough

Further increase in recharge rate due to drop in water level could be well taken into account.

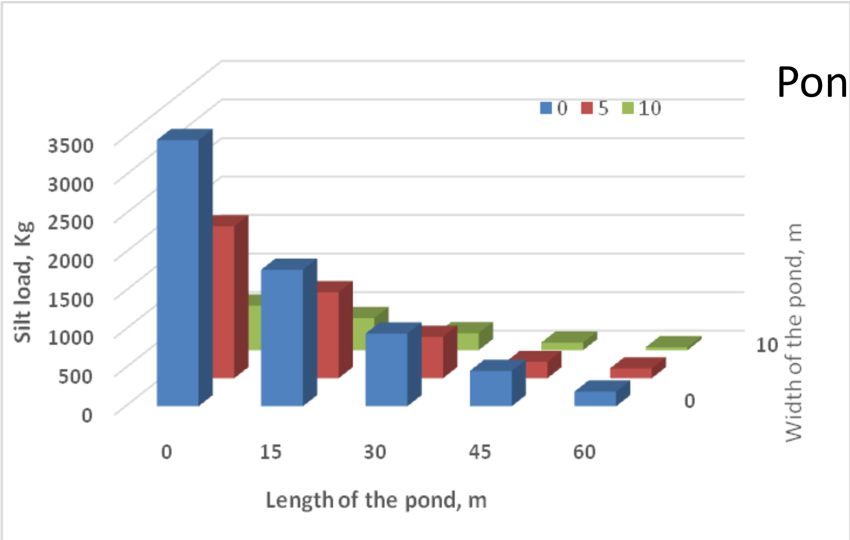


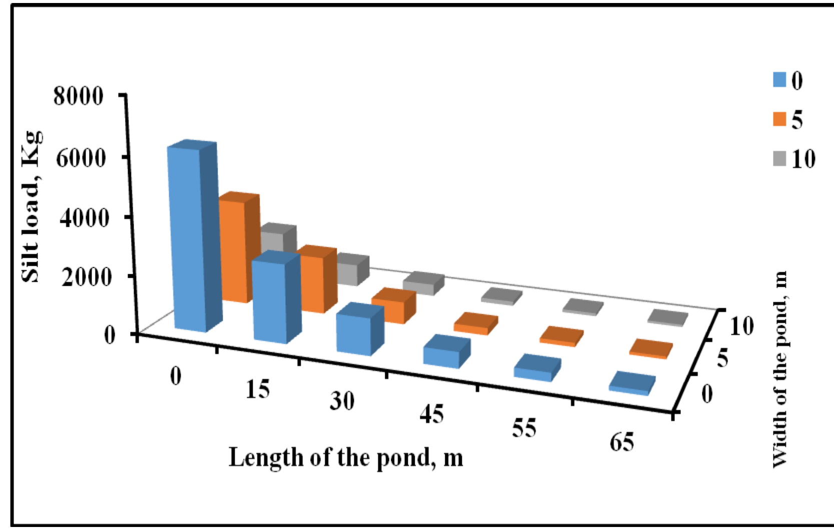
Implementation Schedule

Recharge volume and Irrigation Potential Created

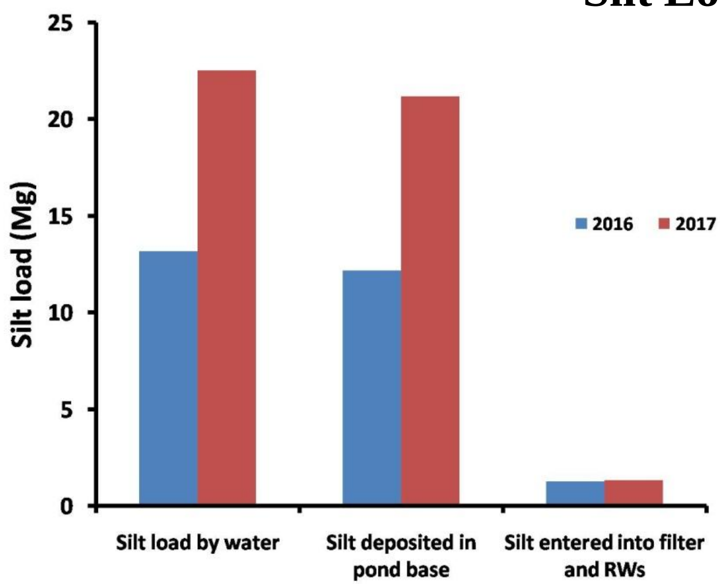
Year	Recharge days	Avg. Recharge rate, m^3/day	Range of recharge rate m^3/day	Recharge volume, m^3	Irrigation potential created ha
2016	**85**	**492**	**220-997**	**40435**	**16.17**
2017	**78**	**1207**	**290-2499**	**72426**	**28.97**
2018	**62**	**631**	**85-1978**	**35253**	**14.10**

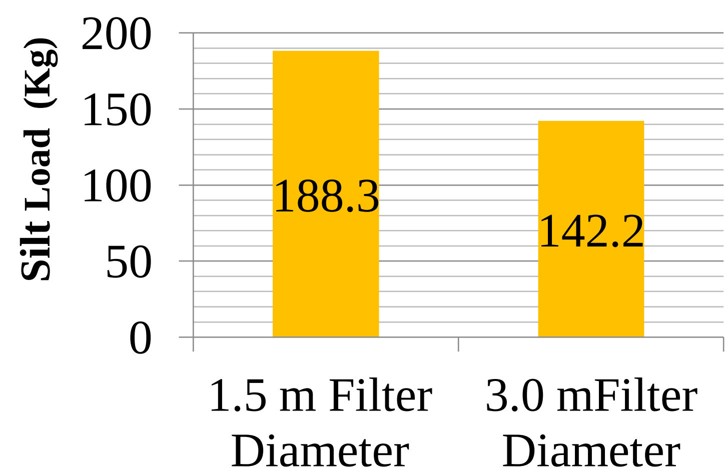
Silt Load Distribution





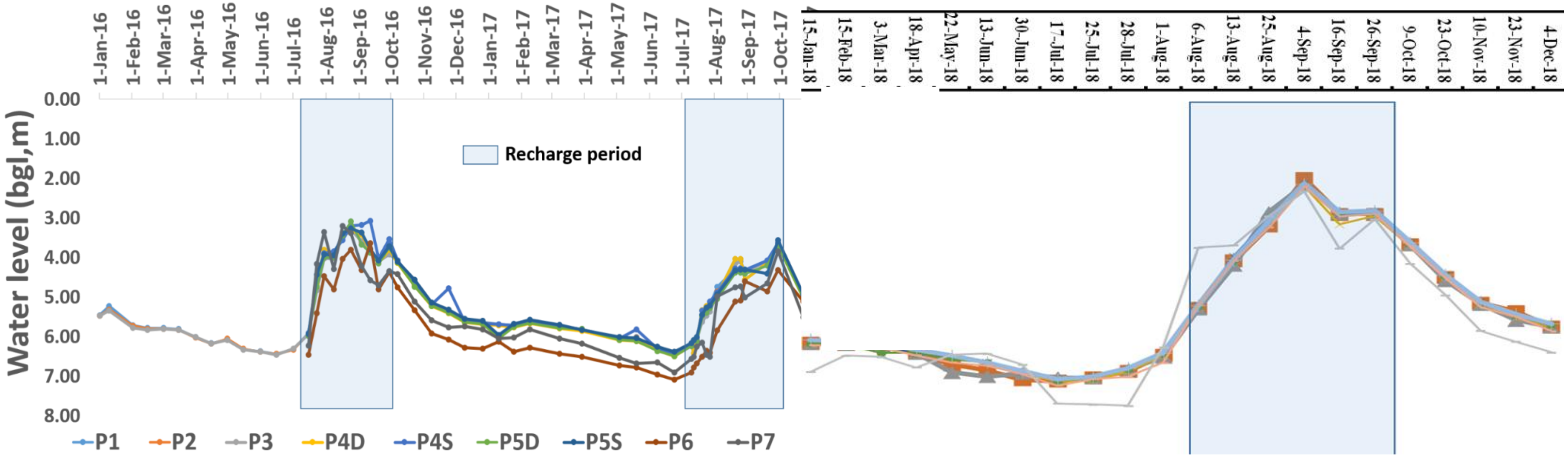
Silt Load Distribution at Pond Bottom





Silt Load Distribution in Systems

Pumped out Silt



Monitoring ground water levels

Heavy Metals Concentration in Ground Water

Element	Before Recharge Period (Mean and Standard deviation	After Recharge Period (Mean and Standard deviation)	BIS acceptable limit (IS 10500 : 2012) (ppb)
Iron , ppb	**228.04 ±5.64**	**229.10 ± 9.03**	3000
Zinc , ppb	**28.14 ±5.20**	**11.45 ± 4.30**	5000
Manganese (Mn) , ppb	**15.40 ±1.70**	**17.63 ± 6.37**	100
Arsenic (As) , ppb	**12.06 ±3.19**	**14.51 ± 1.95**	10 -50
Lead (Pb) , ppb	**2.80 ± 1.44**	**2.39 ± 0.73**	10
Chromium (Cr) , ppb	**11.22 ± 1.29**	**12.32 ± 4.31**	50
Cobalt (Co) , ppb	**0.23 ±0.17**	**0.88 ± 0.15**	
Mercury (Hg) , ppb	**1.88 ±0.53**	**1.12 ± 0.33**	1
Nickel (Ni) , ppb	**10.01 ±2.16**	**18.86 ± 4.22**	200
Fluoride (F) , ppb	**30 0± 100**	**270 ± 90**	1000
Phosphate (ppm)	**0.05 ± 0.05**	**0.05 ± 0.04**	-
Nitrate (ppm)	**8.15 ±3.69**	**9.11 ± 3.99**	45
Ammoniacal Nitrogen (ppm)	**0.43 ± 0.12**	**0.38±0.13**	-

Heavy Metals and Fluoride Analysis

No contamination w.r.t. As, Cr, Pb, Ni, Cd, Fe, Mn, Cu, Zn was found.

Fluoride was also found within permissible limits of BIS and WHO.

Coliform Test: **Negative**

FURTHER INFORMATION

धन्यवाद

http://utfi.iwmi.org/