Groundwater storage, depletion, degradation, and sustainablity: case studies Punjab, India

Presented by:

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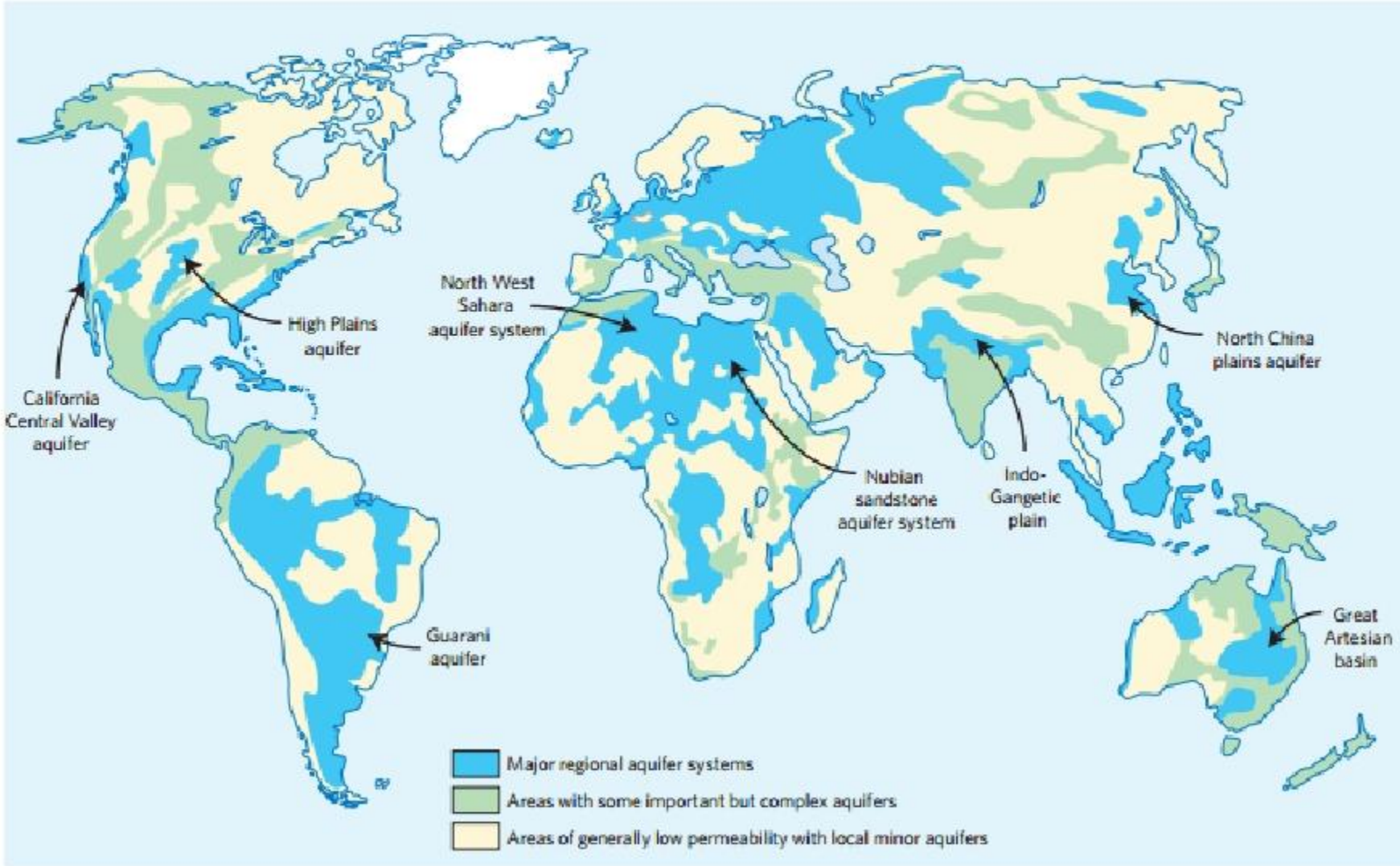
Study team

(BGS): Prof. A MacDonald, Dr. Donald, Dr. Dan Lapworth

21st March 2023

Amritsar

Global groundwater resources map , highlighting the locations of regional aquifers systems



Taylor et al., 2015

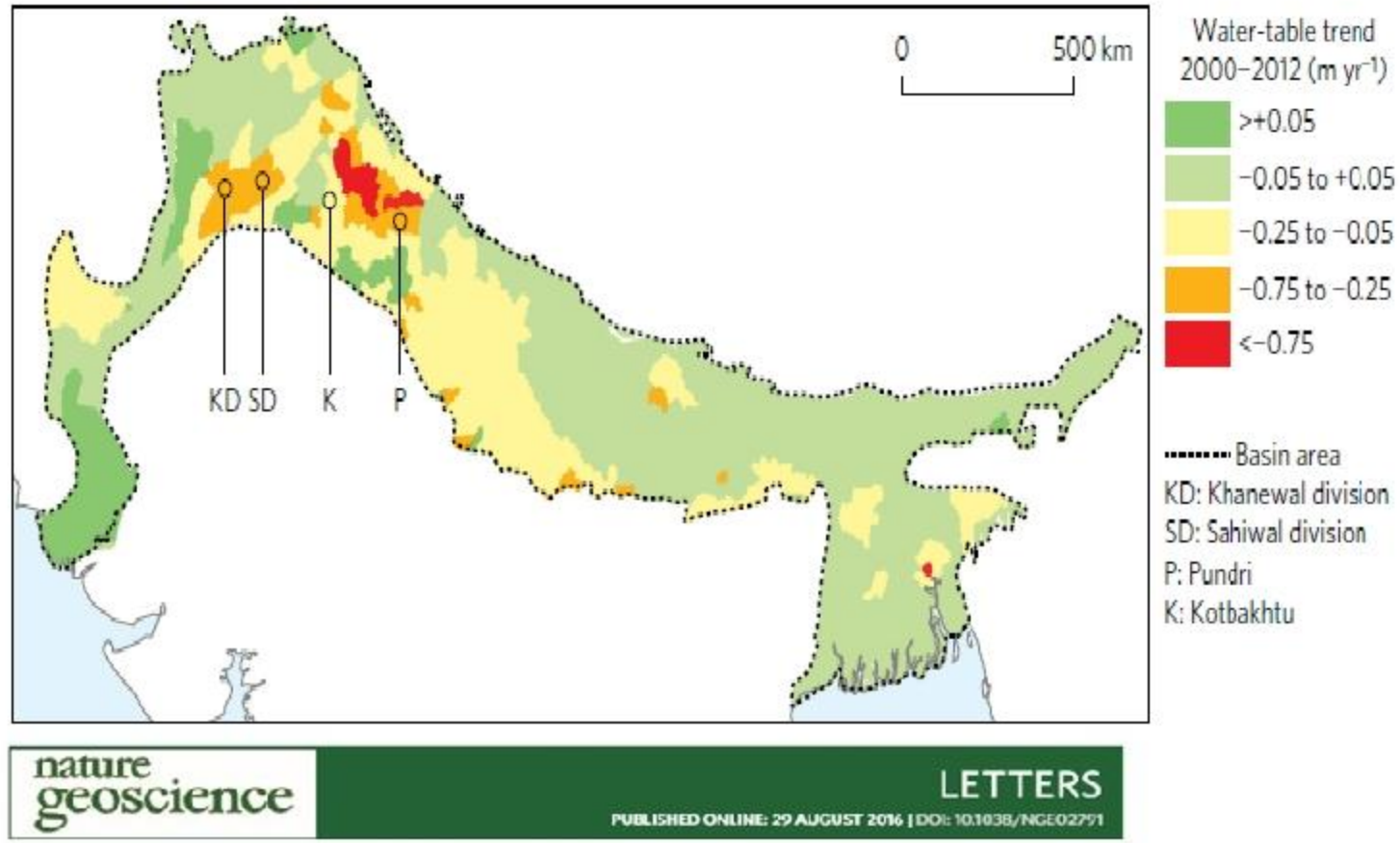
Groundwater depletion

Indo-gangetic basin

It has been estimated that the total volume of groundwater is about 30,000 km³.

About 20 times the combined annual flow in the Ganges, Indus, and Brahmaputra (1200 km³).

**However, as estimated,
23% of this is saline and
37% is affected by arsenic.**



nature geoscience
LETTERS
PUBLISHED ONLINE: 29 AUGUST 2016 | DOI: 10.1038/NGEO2791

Groundwater quality and depletion in the Indo-Gangetic Basin mapped from *in situ* observations

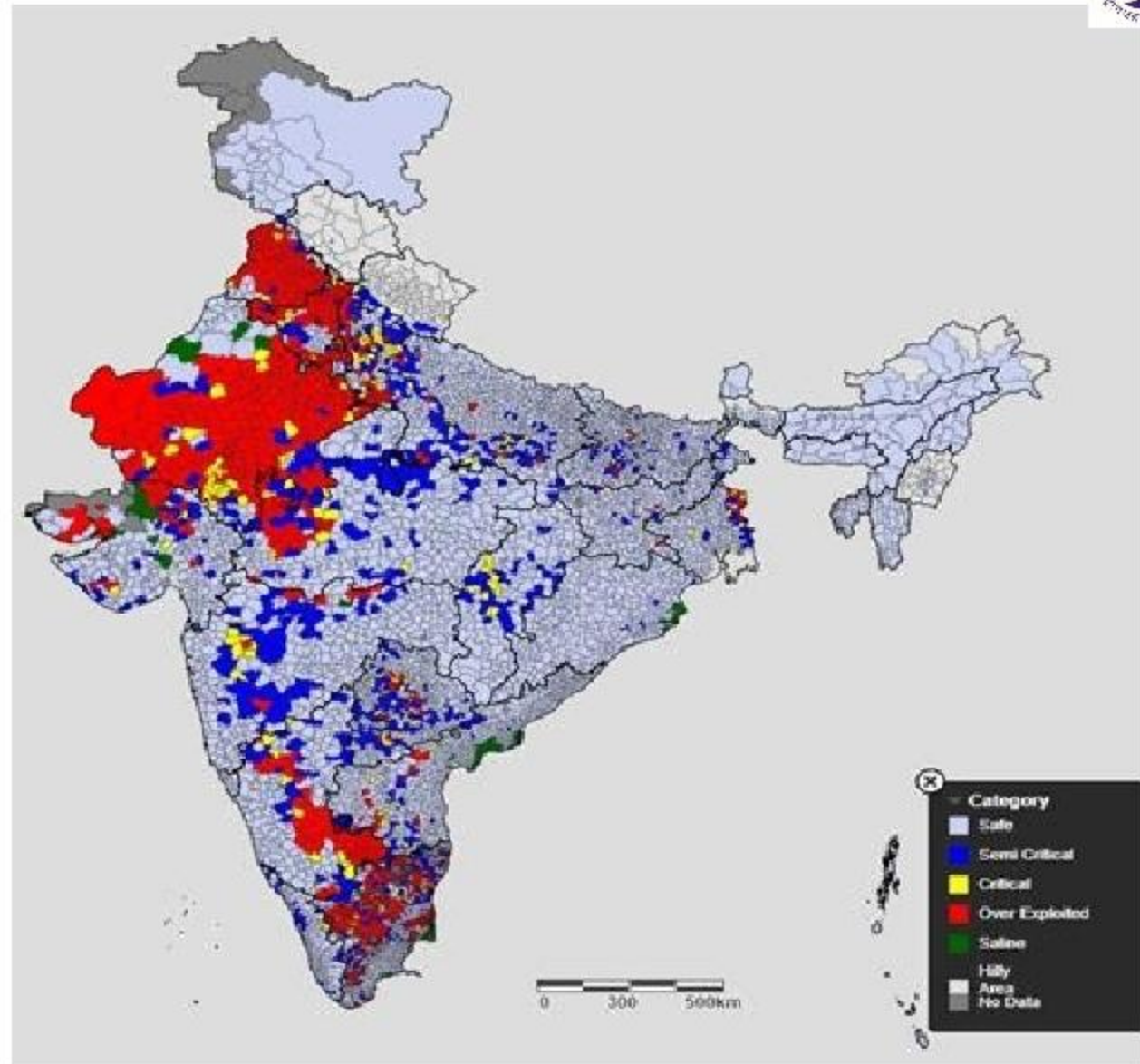
A. M. MacDonald[1]*, H. C. Bonsor[1], K. M. Ahmed[2], W. G. Burgess[3], M. Basharat[4], R. C. Calow[5], A. Dixit[6], S. S. D. Foster[7], K. Gopal[8], D. J. Lapworth[9], R. M. Lark[10], M. Moench[11], A. Mukherjee[12], M. S. Rao[8], M. Shamsudduha[13], L. Smith[14], R. G. Taylor[15], J. Tucker[5], F. van Steenbergen[16] and S. K. Yadav[6]

Groundwater development in India

GW Resources (Blocks)
Total - 6965

Over-exploited – 1114 (16%)
Critical – 270 (4%)
Semi-critical – 1057 (15%)
Saline – 97 (1%)
Safe – 2427 (64%)

- **GW Level decline**
  - **0-2 m: 42.7%**
  - **2-4m: 11.5%**
  - **>4 m 7.2%**
- **More than 60% of the Assessment units in Delhi, Punjab, Haryana & Rajasthan are either OE or Critical**



CGWB 2020

Groundwater depletion

NASA GRACE satellite-based study –
annual depletion in groundwater resources recorded

Three most groundwater-stressed areas (OECD, 2017)

California Central Valley 2003-2012:
4.8 ± 0.4 km^3/year
(Famiglietti et.al., 2011, Chen et.al. 2014)

Northern China Province 2003 -2010:
8.3 ± 1.1 km^3/year
(Feng et.al., 2013, Chen et.al. 2014,)

North-western India, 2003- 2012:
20.4 ± 7.1 km^3/year
(Chen et.al. 2013).

Groundwater development in Punjab

GW Resources (Blocks)

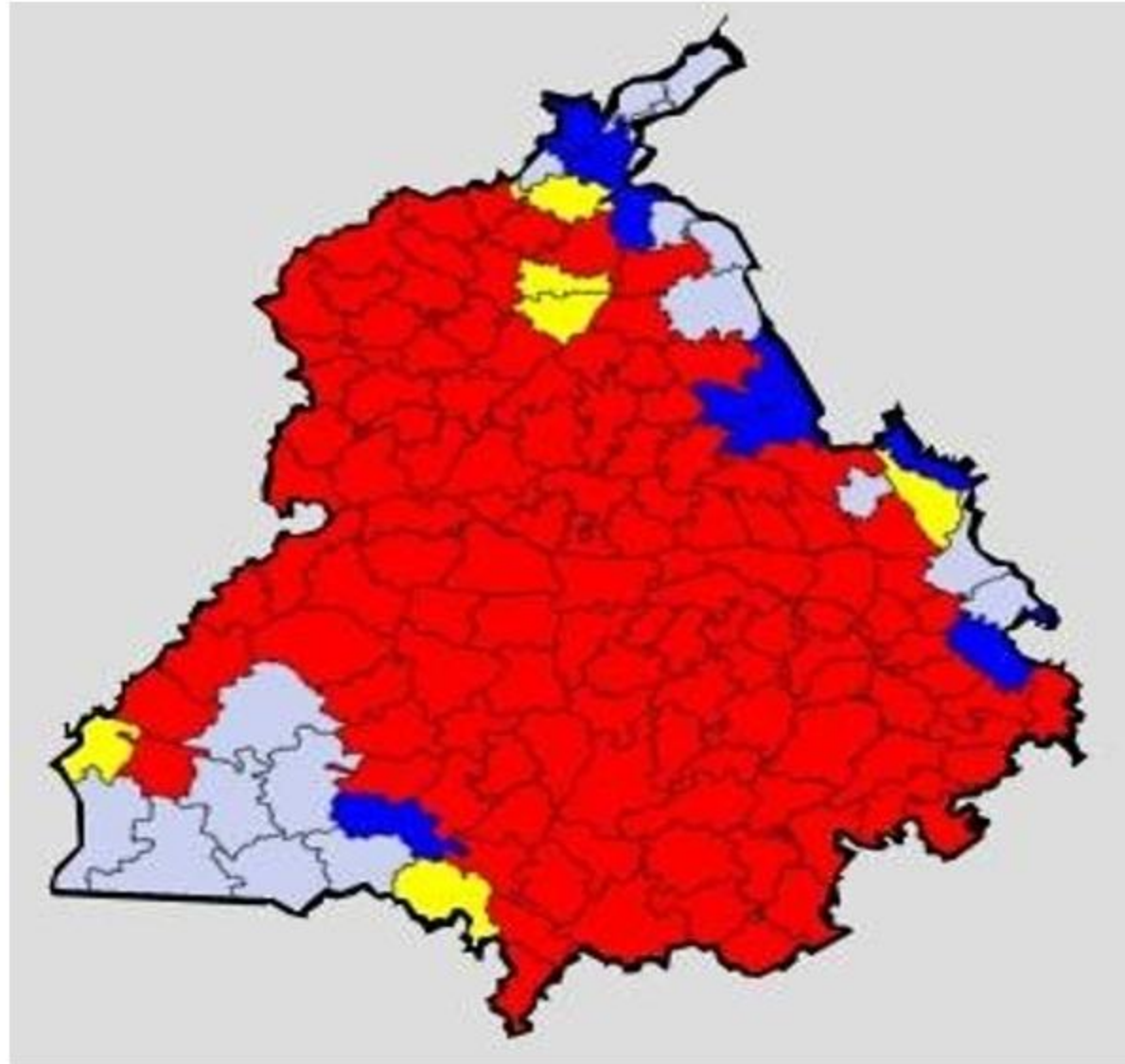
Total - 150

Over-exploited – 117 (78%)
Critical – 6 (4%)
Semi-critical – 10 (7%)
Safe – 17 (11%)
Saline – 10%

Fresh and good quality groundwater 60%
Amritsar, Fatehgarh Sahib, Nawan Shahr, Gurdaspur, Ropar, Hoshiarpur, Jalandhar, Ludhiana and Kapurthala;

Marginal and moderately saline quality 30%
Patiala, Moga, Ferozepur and Mansa

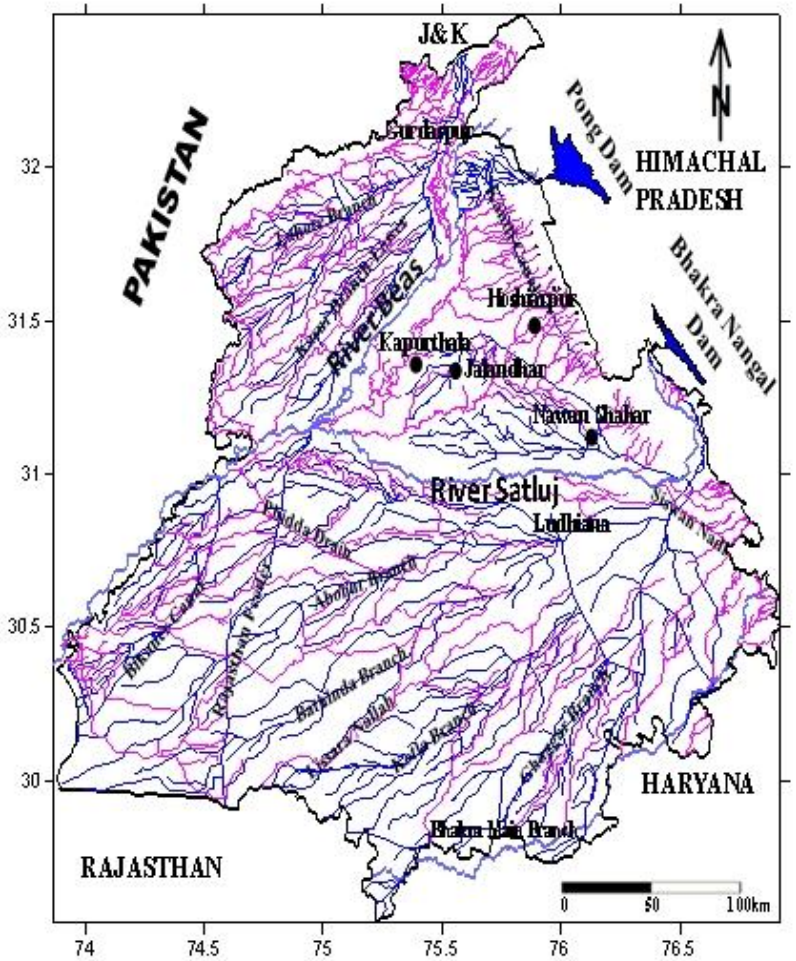
Saline not safe for drinking 10%
Faridkot, Muktsar, Bathinda and Sangrur



CGWB 2020

PUNJAB STATE

- Punjab comprises 1.53% (50,362 sq. km) area of the country (3,287,263 sq. km)
- contributing country's 19.5% wheat, 11% rice, and 10.3% cotton
- Cropping intensity increased(126% to 186% pres. 189%) from 1965-66 to 2004-05 (areas wheat- 216-756%; rice 895-3307%)
- Fertilizer Use/ha 223.46 kg against 90kg national
- Rainfall: 300 mm to 1200 mm; average ~680 mm
- Groundwater Draft = 35.78 BCM
- Groundwater availability = 21.58 BCM
- Deficit = 14.20 BCM
- % Extraction for irrigation = 97%



Canal network= 14,500 km

nature geoscience

Article | Published: 21 April 2022

A century of groundwater accumulation in Pakistan and northwest India

D. J. MacAllister, G. Krishan, M. Basharat, D. Cuba & A. M. MacDonald

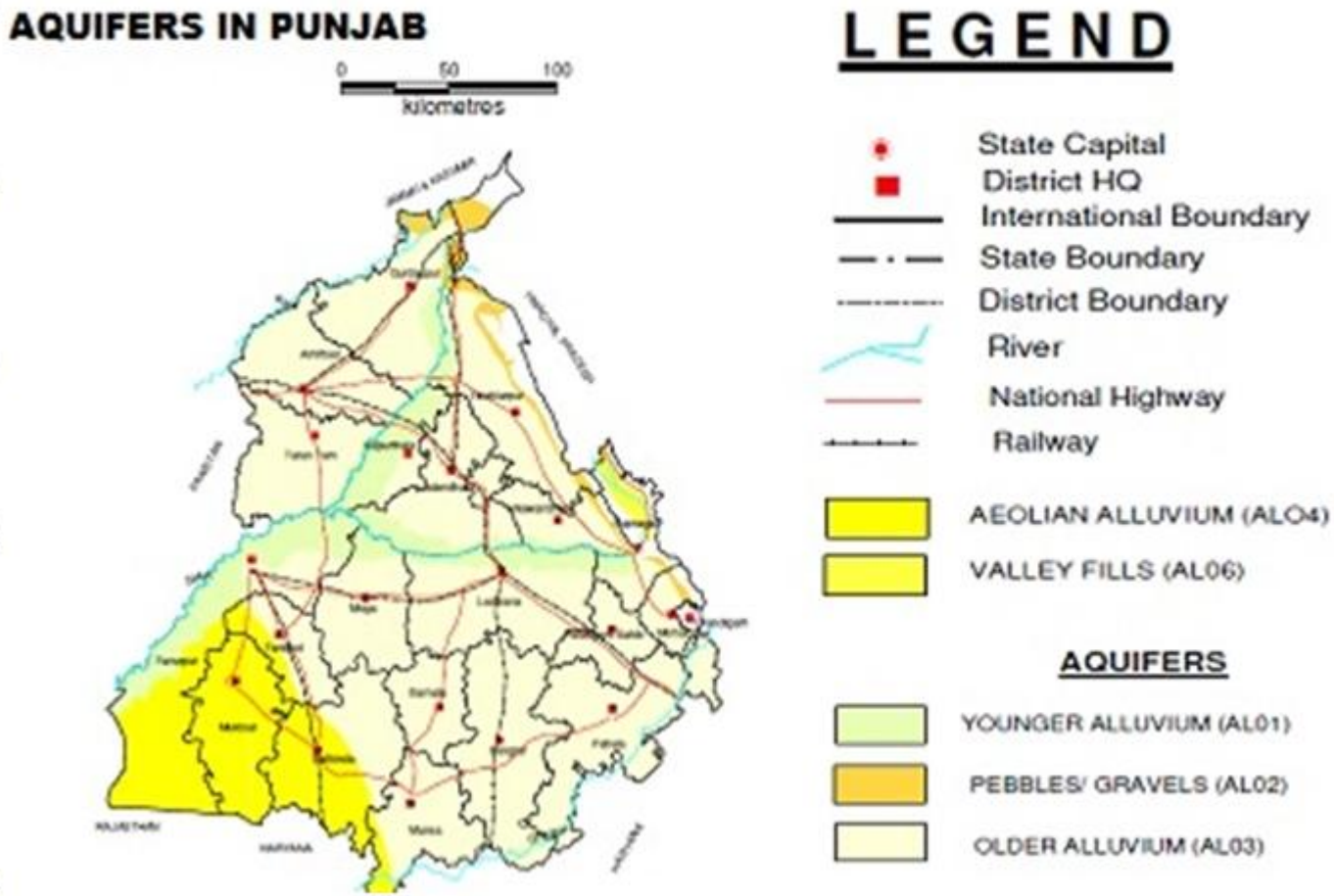
Nature Geoscience **15**, 390–396 (2022) | Cite this article

Abstract

The groundwater systems of northwest India and central Pakistan are among the most heavily exploited in the world. However, recent, and well-documented, groundwater depletion has

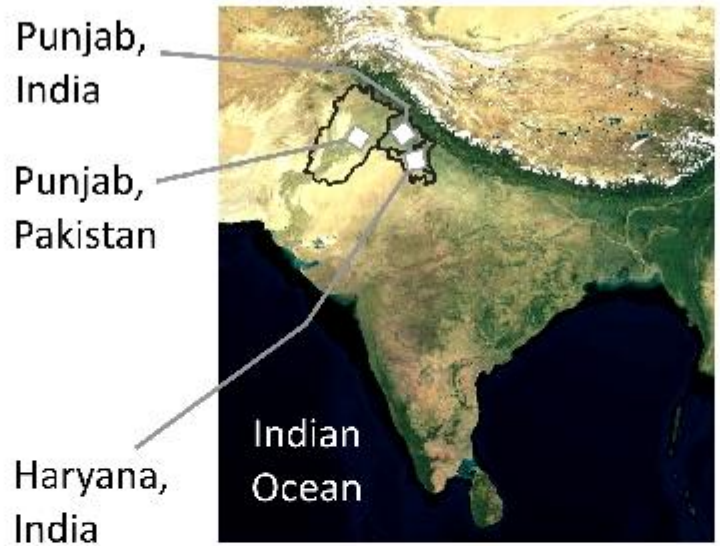
Aquifer systems

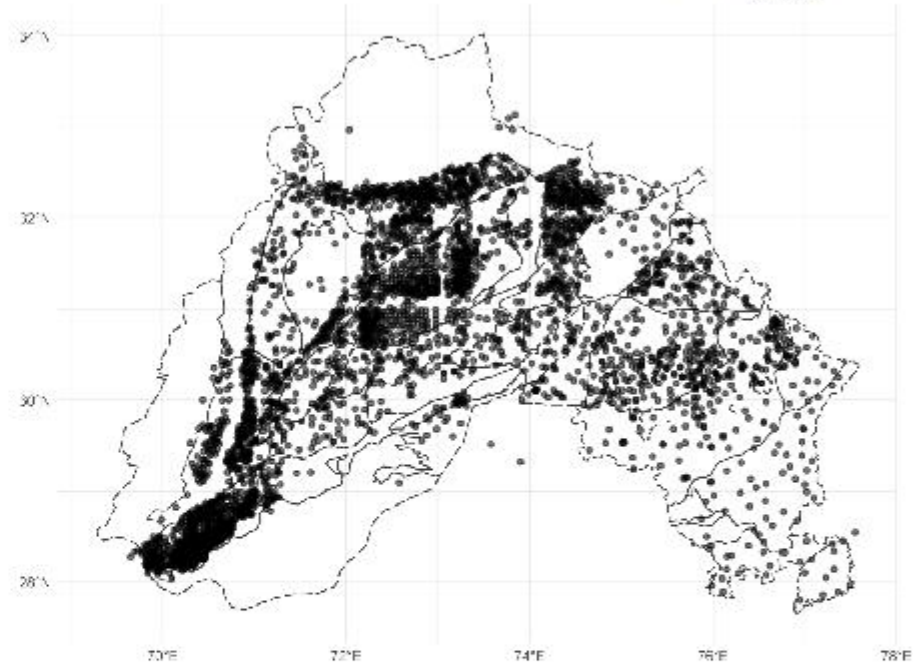
- **In general, single and multiple aquifers systems have been identified**
- **In the major part of the state, multiple aquifer systems exists**
- **Mainly Alluvium except in northern and eastern parts.**
- **Semi-consolidated Shivalik formations are exposed.**
- **Aeolian formations in south western part.**
- **Prolific Aquifers down to the explored depth of more than 450 m**



Source: CGWB

- **Groundwater depletion is a major concern.**
- **Groundwater used for > 100 years.**
- **Groundwater level change since 1900?**
- **4028 observation wells from 1900 - 2010**





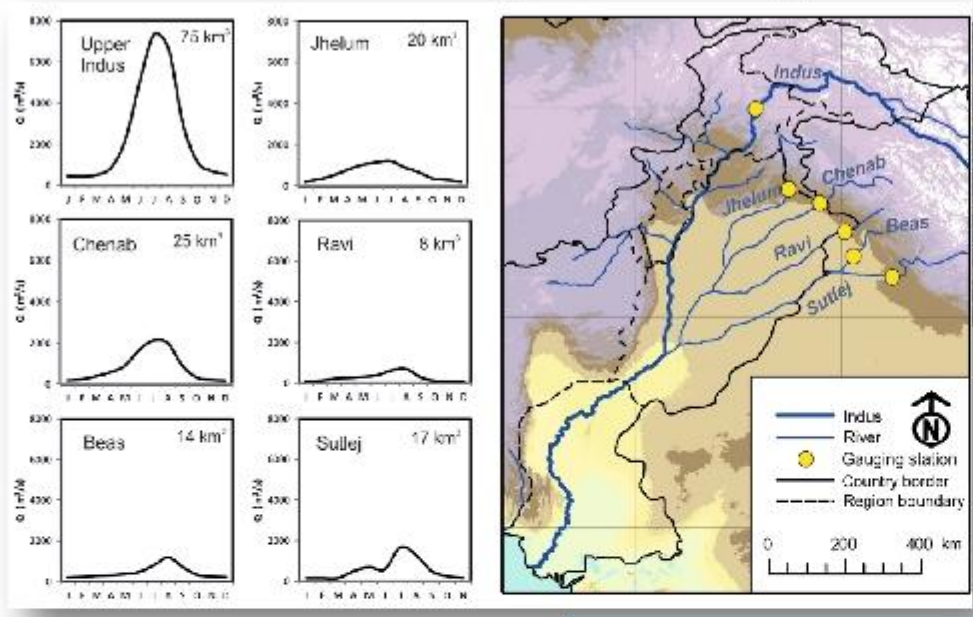
Pre1857

1800s - 1947

Post 1947

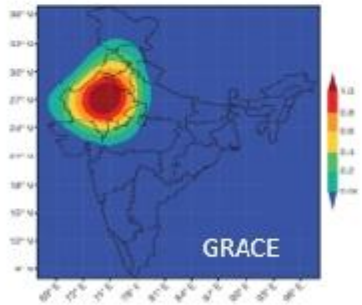
150 YEARS OF GROUNDWATER VARIATION

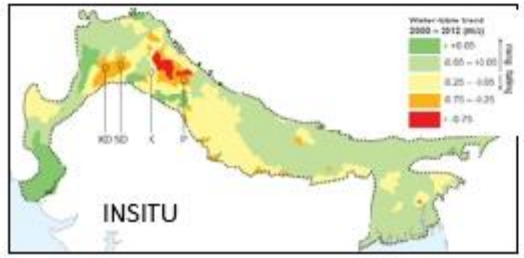
Pre 1850s – spate irrigation



Widespread use of wells **Ancient Irrigation systems**

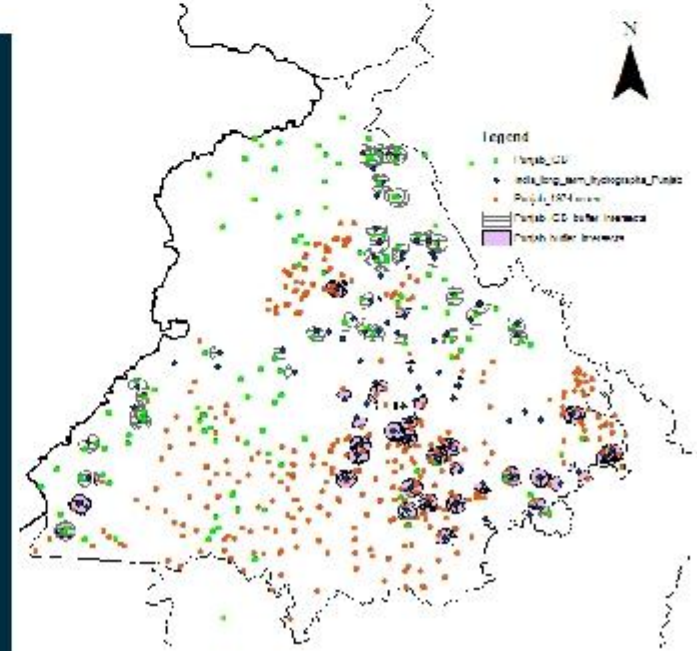
Ancient civilisations: wheat, barley peas, lentils; domesticated animals



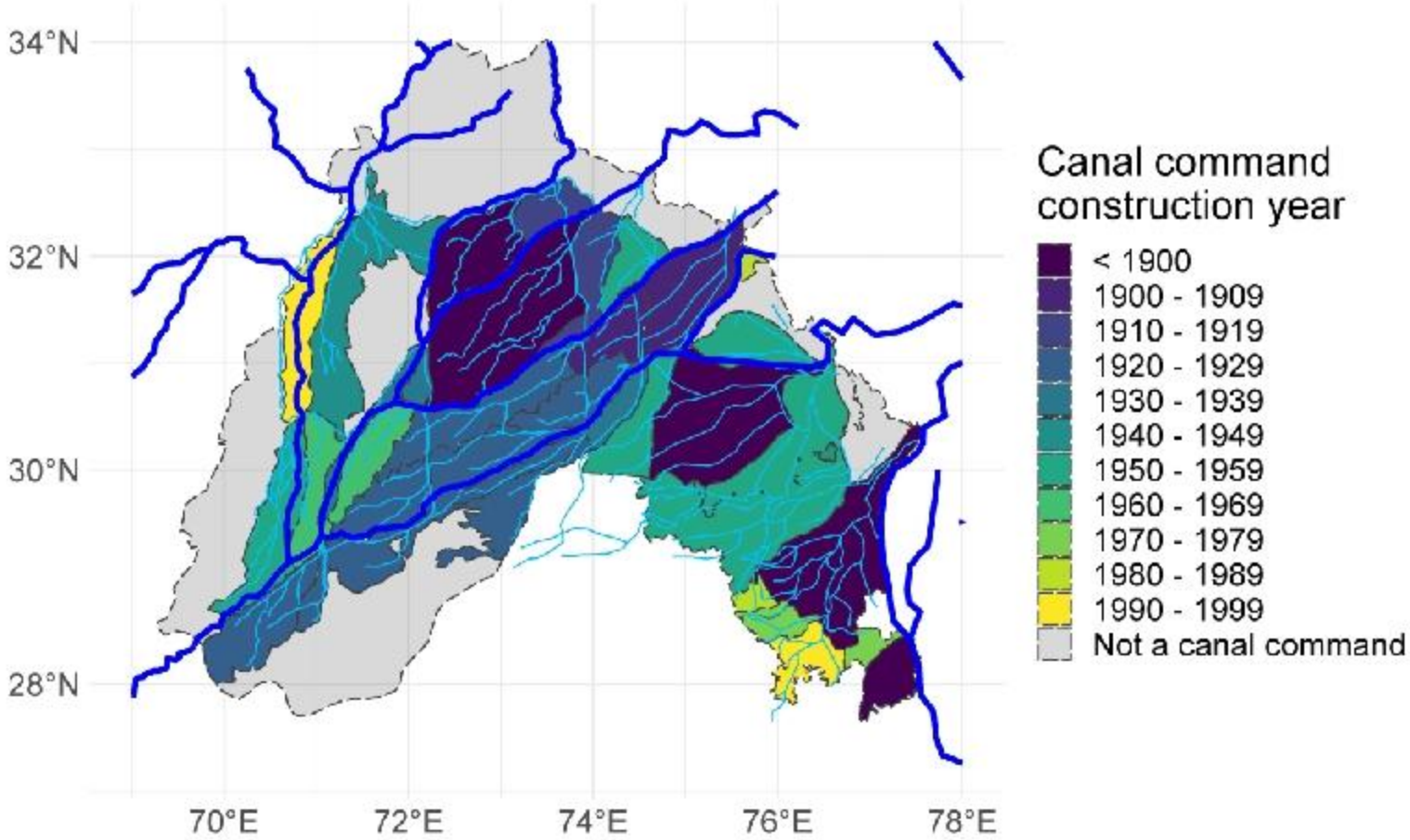


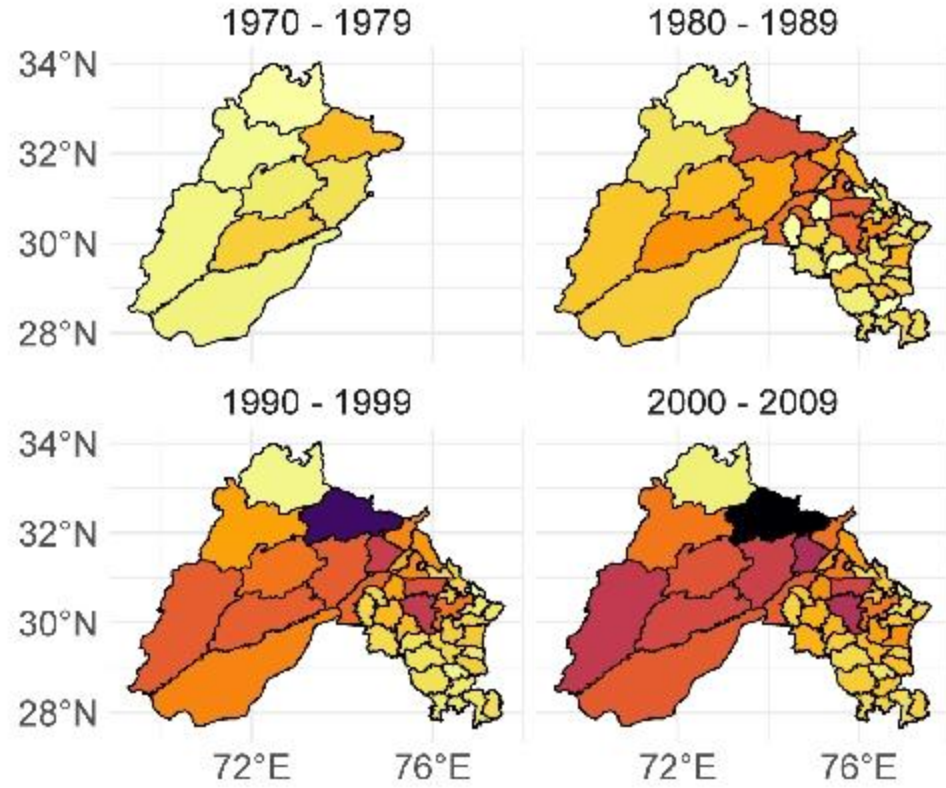
1. GRACE: declining water storage: Rodell, Tiwari, Ritchie, Chen, Panda, etc.

2. Insitu data – declining, but heterogeneous; MacDonald etc ..



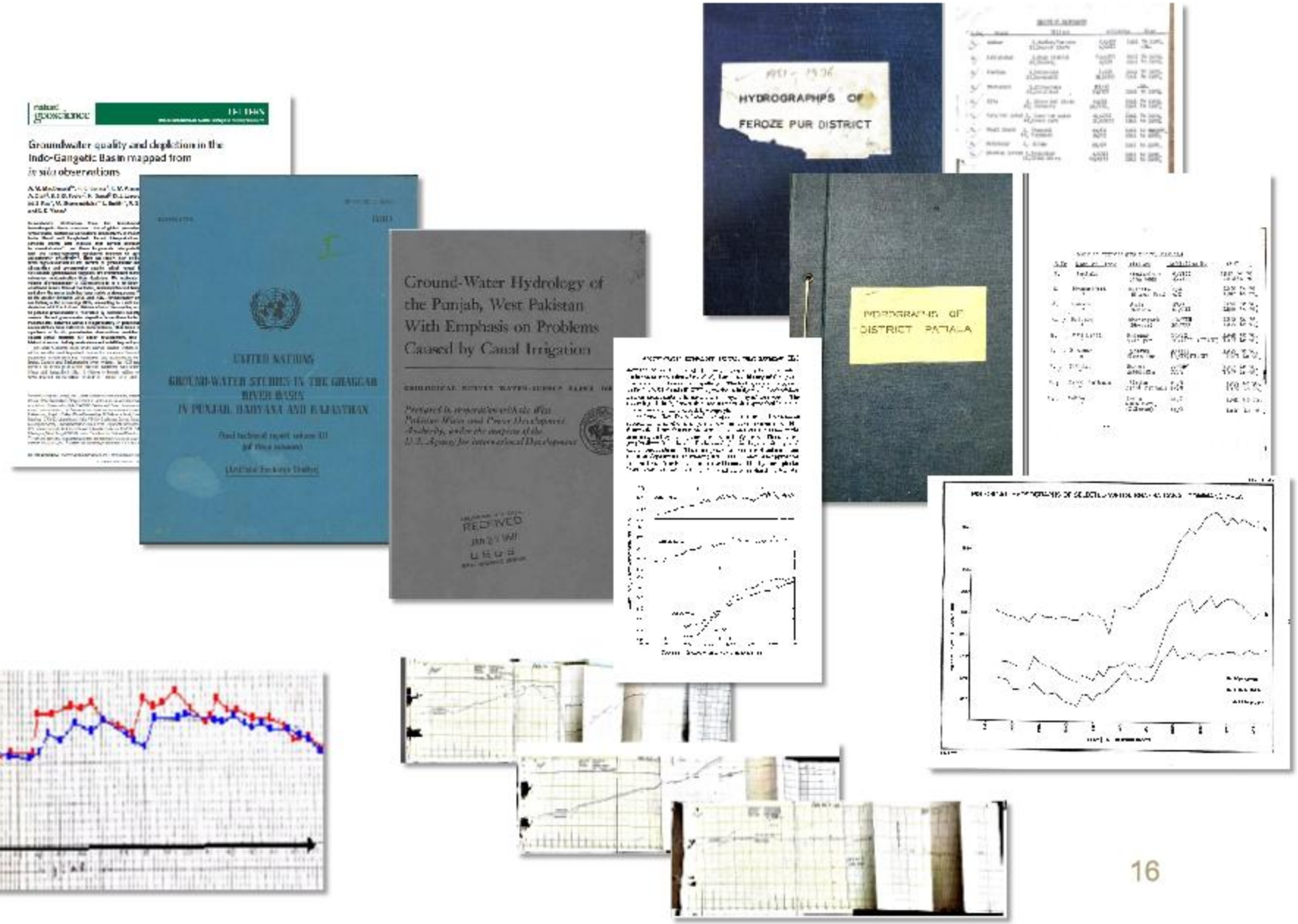
A CENTURY OF WATER RESOURCE DEVELOPMENT



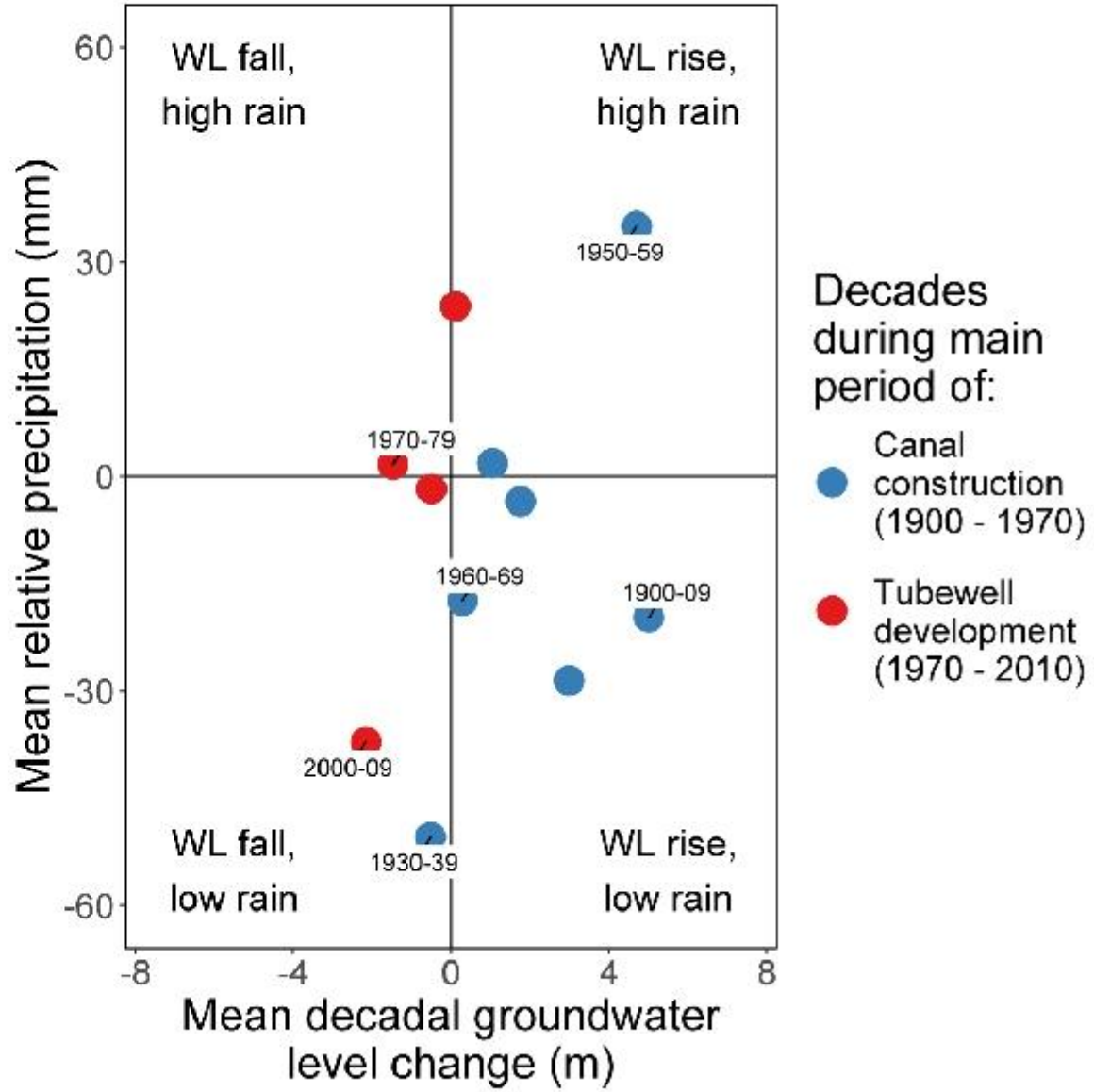


COMPILATION OF HISTORIC GROUNDWATER DATA

- > 100 hydrographs scans:
  - old reports
  - books
  - government archives
  - digital and hard copy

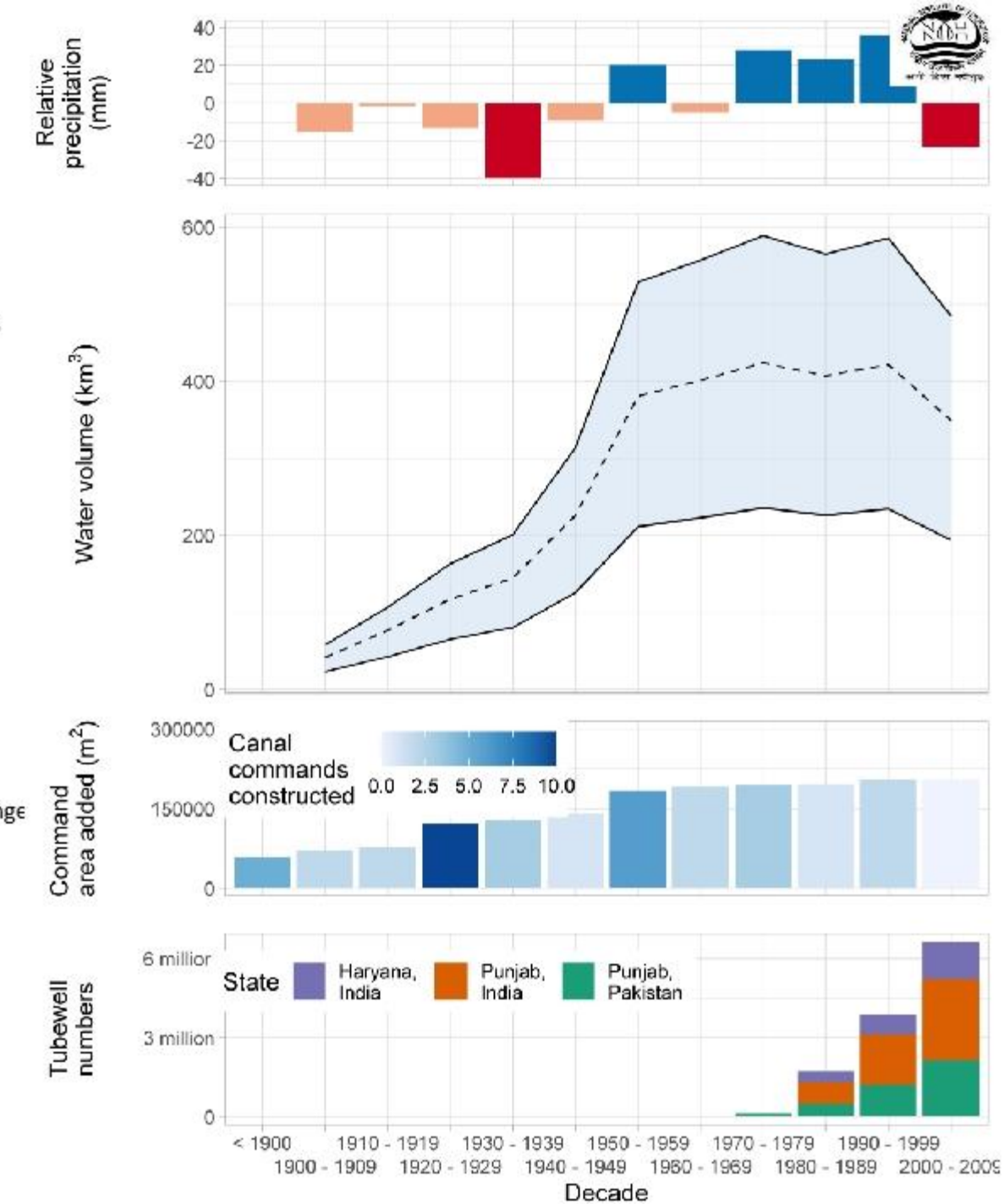


INFLUENCE OF CANALS AND TUBEWELLS ON DECADAL TREND

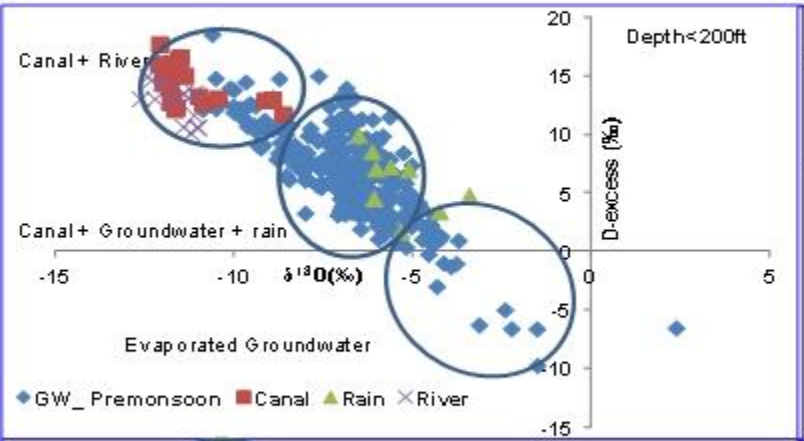


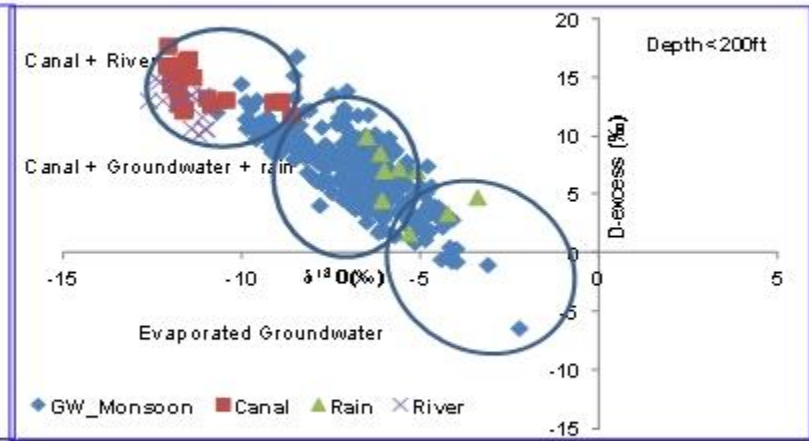
A CENTURY OF ACCUMULATION

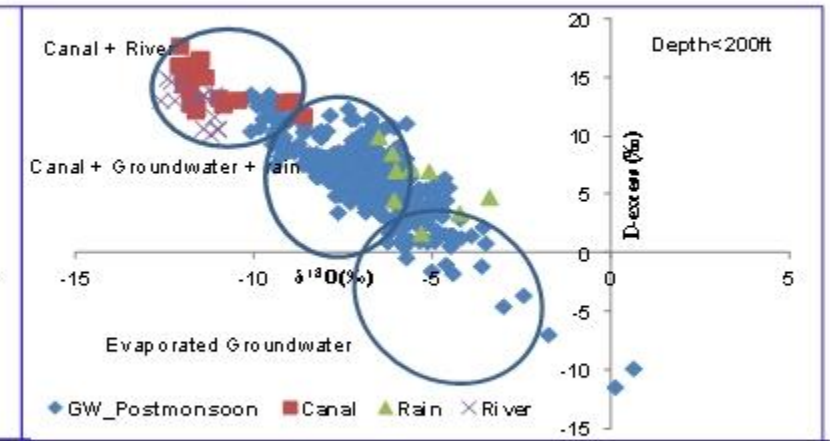
- 1900 – 1960:
  - Rainfall below period mean.
  - **125,000 km²** of canal area added.
  - Net groundwater accumulation: **350 km³**
    (range: 150-450 km³)
- 1960 – 1990:
  - Rainfall above period mean.
  - Little additional canal area added.
  - Tubewell development began.
  - Groundwater stabilised.
- 1990 – 2010:
  - Rainfall below period mean.
  - Groundwater depletion **75 km³** (range
    25-100 km³)

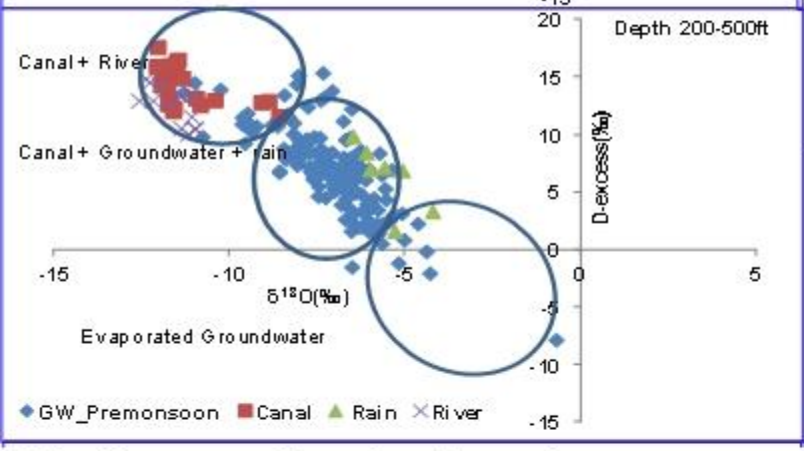


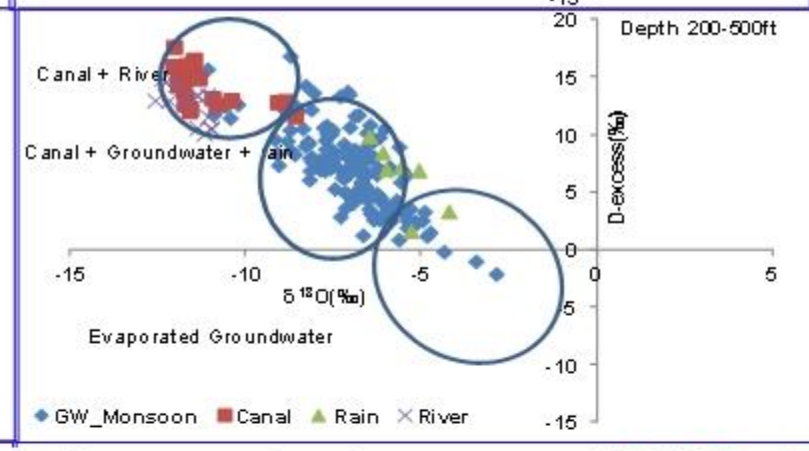
Isotope characterization

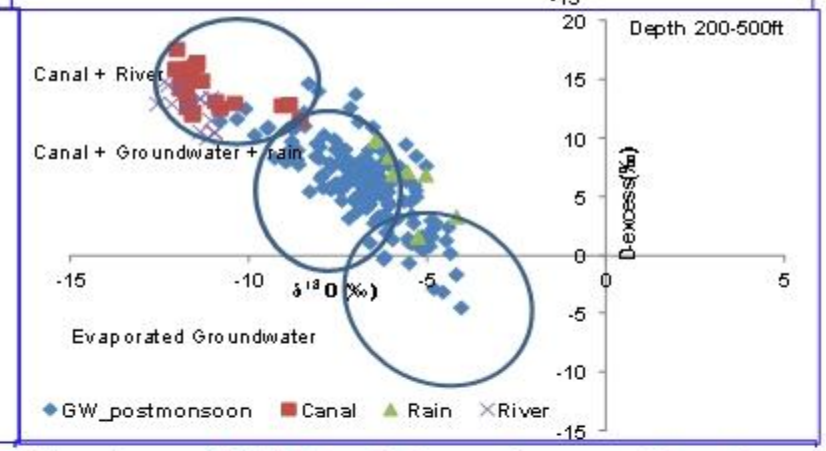








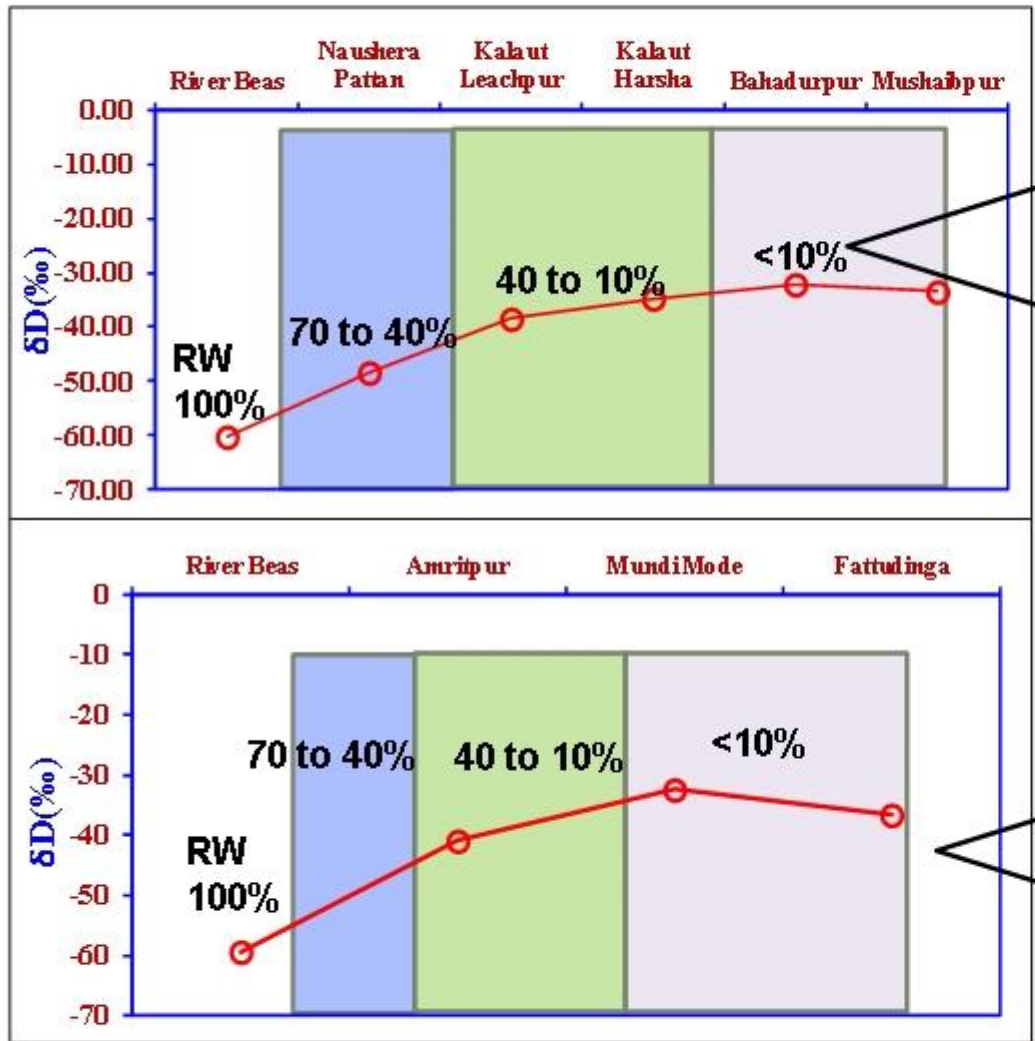




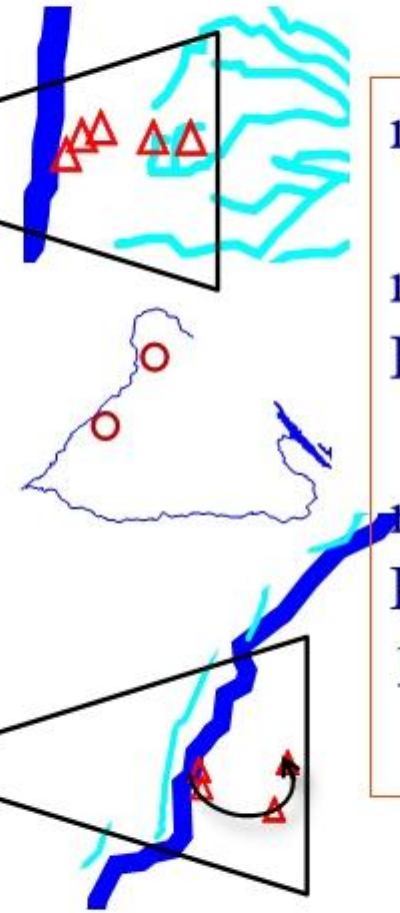
Shallow aquifer depth recharge sources for groundwater are canal (SW Punjab), river (SW Punjab and near the rivers), groundwater connectivity (parts of Malwa region) and precipitation (Doaba, Majha and parts of Malwa)

aquifer depth 200-500 ft, canal (parts of SW Punjab), river (near the rivers), groundwater connectivity (parts of Malwa region) and precipitation (parts of Doaba, Majha and eastern parts of Malwa),

Surface water – groundwater interaction



River water- groundwater interaction at R. Beas Stretch
(a) Upstream, (b) Downstream



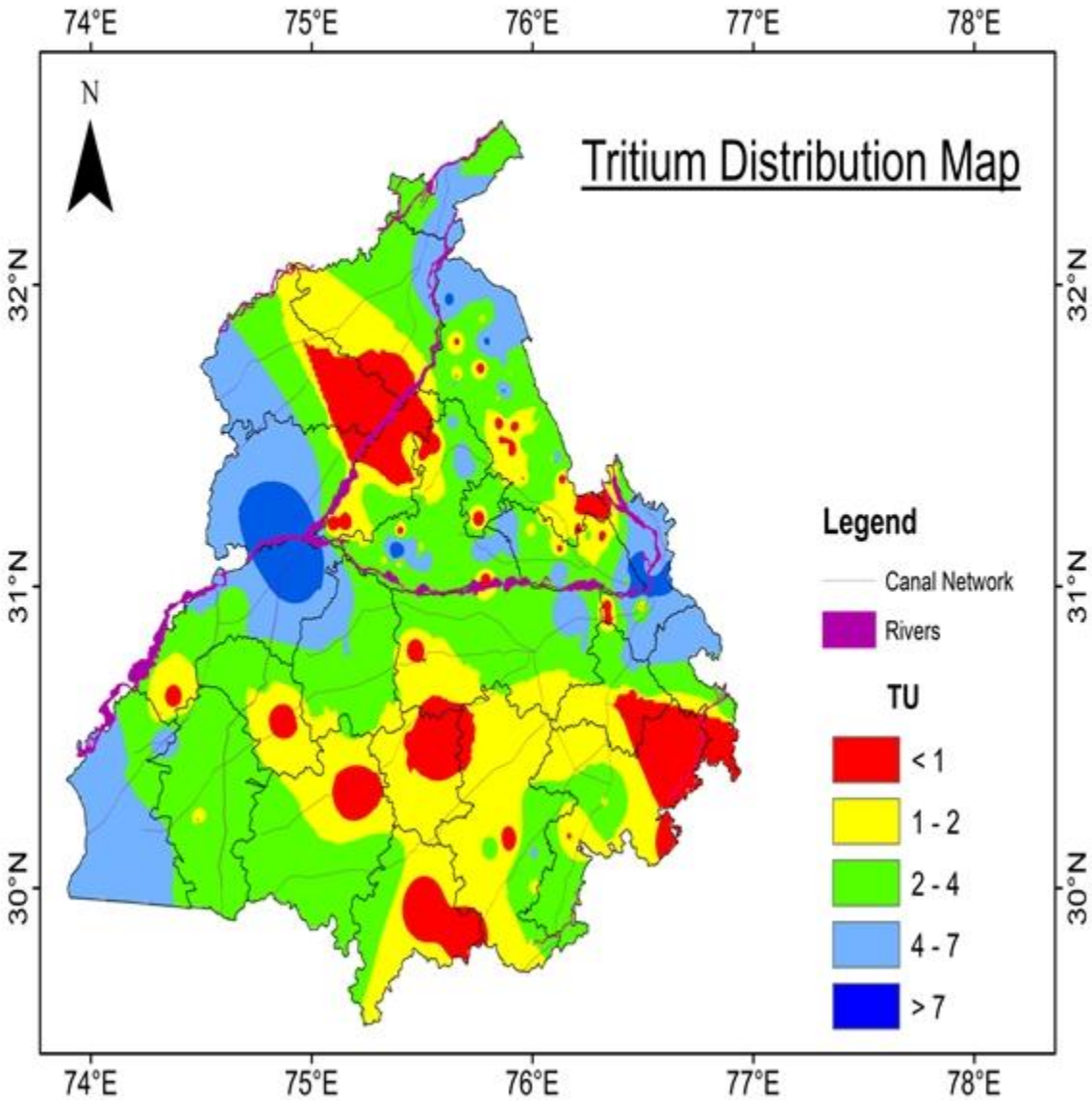
$$m_{gw} + m_r = 1$$

$$m_{gw}R_{gw} + m_rR_r = R_{ad}$$

$$m_{gw}(\%) = [(R_{ad} - R_r) / (R_{gw} - R_r)] * 100$$

$$m_{river} = \frac{\delta^{18}O_{(gw)mix} - \delta^{18}O_{(gw)}}{\delta^{18}O_{river} - \delta^{18}O_{(gw)}}$$

Tritium dating



In order to classify the groundwater as old, sub-modern and modern according to the tritium in groundwater, the observed data has been grouped into 4 classes as

>10TU; <20 yr; EC <400µS/cm, recent groundwater

>5TU; <50 yr; EC = 400-500 µS/cm modern groundwater,

>1TU; <100yr; EC=500-1000 µS/cm as sub-modern groundwater and

< 1TU; >100 yr or more older than 1000 yr; EC = > 1000 µS/cm as old groundwater.

Groundwater quality

Salinity

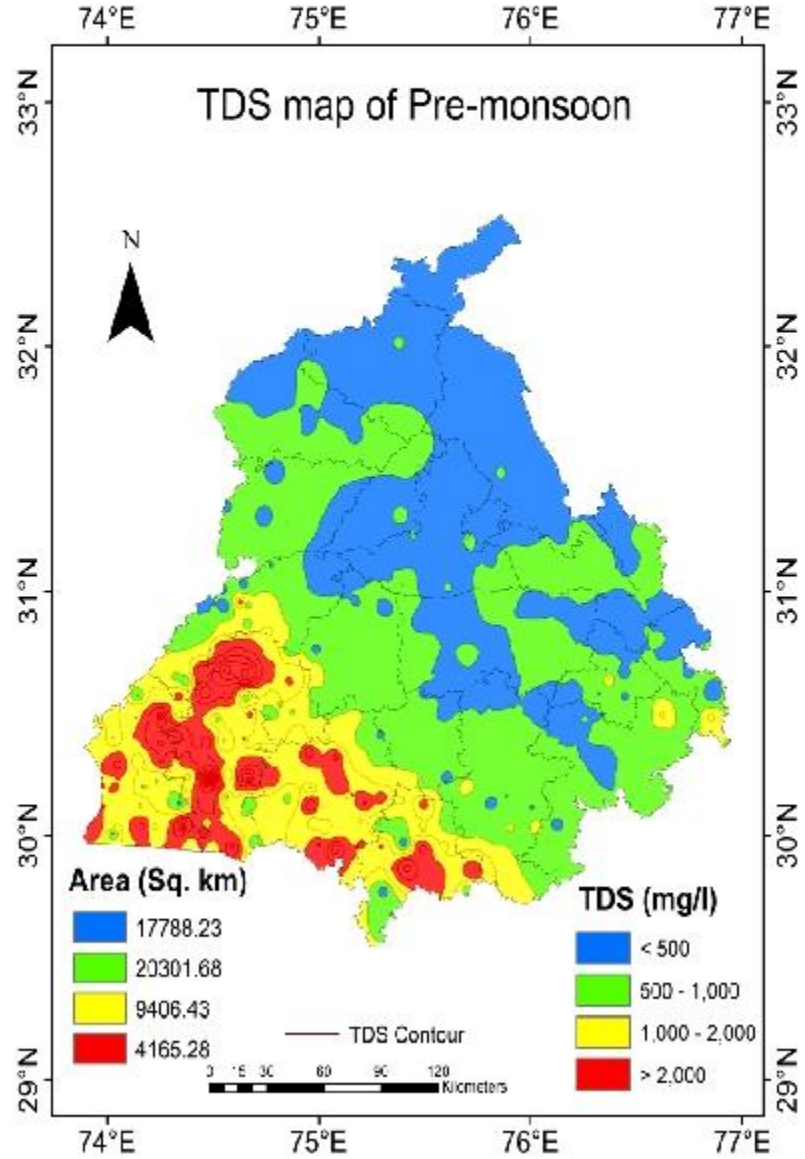
On the basis of salinity, groundwater of entire Punjab state has been categorized into 4 classes:

(i) Fresh groundwater (<500 mg/l),

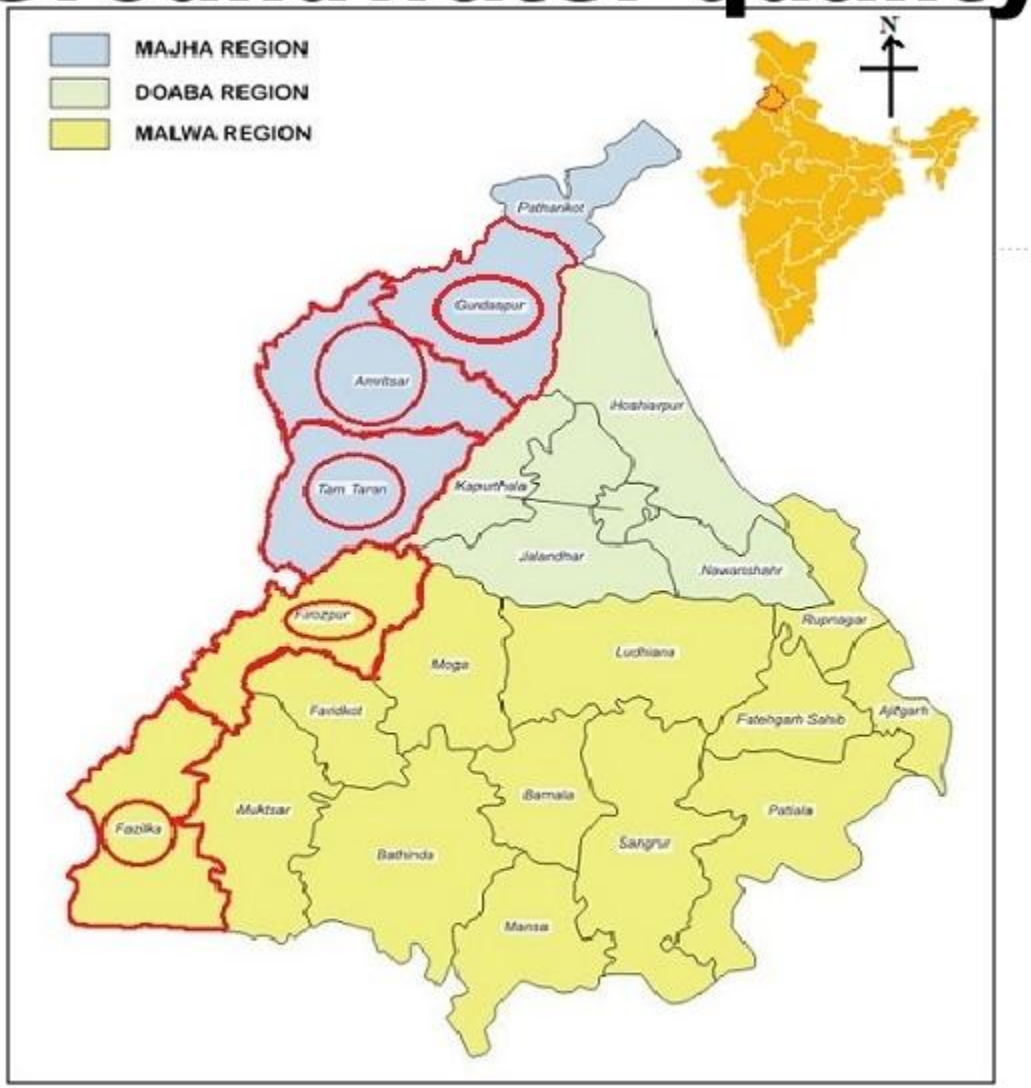
(ii) Moderately fresh groundwater (500-1000 mg/l),

(iii) Moderately saline groundwater (1000-2000 mg/l), and

(iv) Saline groundwater (>2000 mg/l)

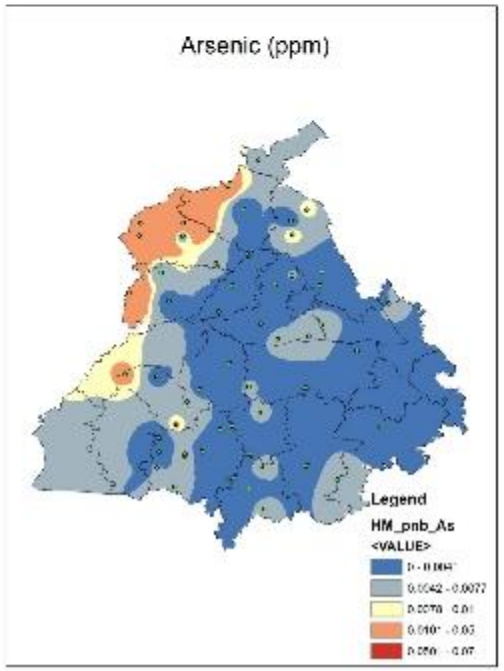


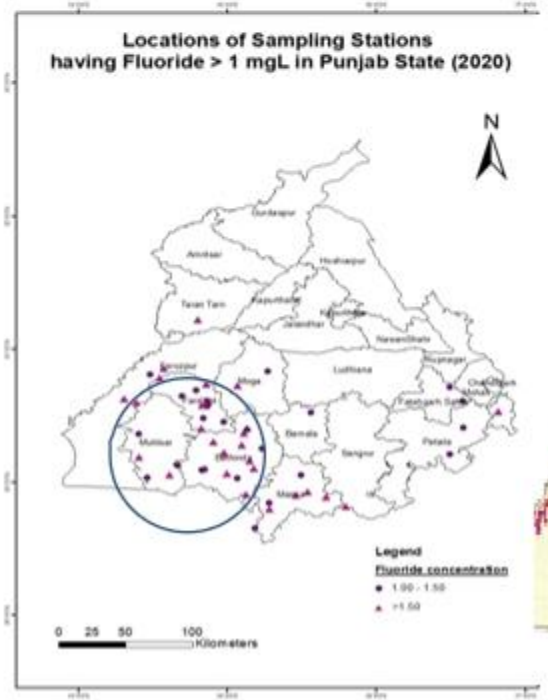
Groundwater quality

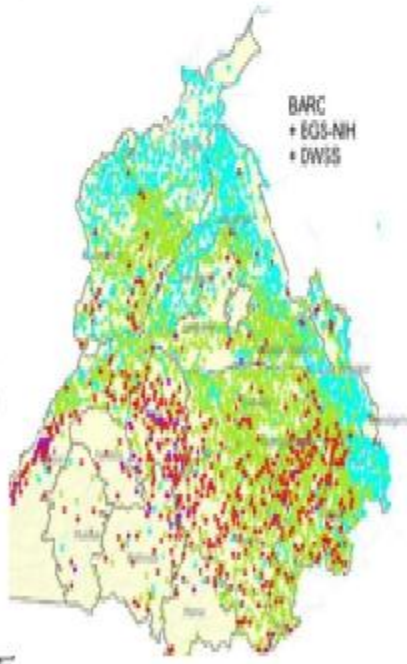


The total residing population in Malwa region is 10.82 crore, out of which mortalities due to cancer cases observed during the five years were reported as 42, 942.

Similar trend of deaths due to cancer cases was observed in Majha region in five years were 5790 out of 57.1 lakh residing population (Kaur and Sharma, 2017).







Summary

Aquifers are changing since last 150 years
Groundwater is more vulnerable to extraction
Now degradation is becoming greater concern
Aquifer properties and status vary considerable and need targeted governance
Groundwater - surface water clearly linked - one resource

Specific problems of groundwater in Punjab India

Area	Specific Problems Associated with Groundwater
Kandi (Boulders, pebbles, cobbles and coarse sand associated with clays) and Sirowal formations (Sirowal formations are fine grained in nature) -the foothills of Shiwalik range **Punjab**	**1. Presence of Deep water table** **2. Bouldary formations causes drilling problems**
South Western parts of Punjab	**1. Water Logging** **2. Presence of saline water in shallow and deeper levels**

Publications (All the manuscripts can be provided if required by the delegates) drgopal.krishan@gmail.com

water
MDPI

Article

Isotopic Assessment of Groundwater Salinity: A Case Study of the Southwest (SW) Region of Punjab, India

Gopal Krishan [1], Mavidanam Someshwar Rao [1], Rajesh Vashisht [2], Anju Chaudhary [1], Jaswant Singh [3] and Amit Kumar [4,*]

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2 Department of Soil and Water Conservation, Chandigarh 160017, India; rvashisht_chd@yahoo.com
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4 School of Hydrology and Water Resources, Nanjing University of Information Science and Technology, Nanjing 210044, China
* Correspondence: amitkdah@nuist.edu.cn

Abstract: In recent decades, due to rapid increases in water demand and greater usage of water for irrigation from surface canals, waterlogging problems have been created in the southwest zone of Punjab, coupled with a stagnation in saline zone formation due to salinity ingression. To understand

ELSEVIER
Science of The Total Environment
Volume 789, 1 October 2021, 148051

Isotopes ($\delta^{18}O$, δD and ^{3}H) variations in groundwater with emphasis on salinization in the state of Punjab, India

Gopal Krishan [a], Bhishm Kumar [a, b], Natarajan Sudarsan [a], Mavidanam Someshwar Rao [a], Narayan Chandra Ghosh [c], Ajay Kumar Taloor [d], Prosun Bhattacharya [e], Surjeet Singh [a], Chander Prakash Kumar [a], Anupma Sharma [a], Sharad Kumar Jain [a, f], Balwinder Singh Sidhu [g], Sumant Kumar [a], Rajesh Vasisht [h, i]

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Intensive Groundwater Exploitation in the Punjab – an Evaluation of Resource and Quality Trends

Groundwater Science Programme

AGU PUBLICATIONS

Geophysical Research Letters

RESEARCH LETTER
10.1002/2015GL065798

Key Points:
- Tracers reveal low regional anisotropy in the sedimentary aquifer system of NW India
- Local meteoric recharge sources dominate in both shallow and deep aquifers
- Evidence of enhanced modern recharge at depth due to intensive abstraction

Supporting Information:
- Texts S1–S6, Figures S1–S8, and Tables S1–S4

Groundwater recharge and age-depth profiles of intensively exploited groundwater resources in northwest India

D. J. Lapworth[1], A. M. MacDonald[2], G. Krishan[3], M. S. Rao[3], D. C. Gooddy[1], and W. G. Darling[1]

[1]British Geological Survey, Wallingford, UK, [2]British Geological Survey, Edinburgh, UK, [3]National Institute of Hydrology, Roorkee, India

Abstract Intensive irrigation in northwest India has led to growing concerns over the sustainability of current and future groundwater abstraction. Environmental tracers and measurements of groundwater residence times can help quantify the renewal processes. Results from 16 paired locations show that the interquartile ranges for residence times in shallow alluvial groundwater (8–50 m deep) to be 1–50 years and significantly less than those from deeper groundwater (76–160 m deep) at 40–170 years. The widespread occurrence of modern tracers in deep groundwater (>60% of sites had >10% modern recharge) suggests

ELSEVIER
Science of The Total Environment
Volumes 599–600, 1 December 2017, Pages 1433-1444

Groundwater quality in the alluvial aquifer system of northwest India: New evidence of the extent of anthropogenic and geogenic contamination

D.J. Lapworth [a], G. Krishan [b], A.M. MacDonald [c], M.S. Rao [b]

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Acknowledgement

- **Thank you to the National Institute of Hydrology for assisting with the projects sponsored by BGS, UK, DFID, NERC-UK, PSFC, DoAFW, World Bank.**

- **Directors NIH: Sh. RD Singh, Dr. Sharad Jain, Dr. JV Tyagi, Dr. S. Kumar**
- **Thanks to Dr. MS Rao, Sc. F. HID, NIH**

- **Thanks organizing committee – Prof. Bhupender Singh**

Thanks...