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Building Hydrometeorological Networks for Irrigation Scheduling, Snowpack Monitoring and Flood Early Warning: Experiences from Pakistan

Abubakr Muhammad, PhD

with Ali Akbar Abbas (BDM)

LUMS | Centre for Water Informatics and Technology

NCRA NATIONAL CENTRE OF ROBOTICS & AUTOMATION | Agricultural Robotics Lab

ICTP Workshop on Communications in Extreme Environments
Nov 21, 2023

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Background

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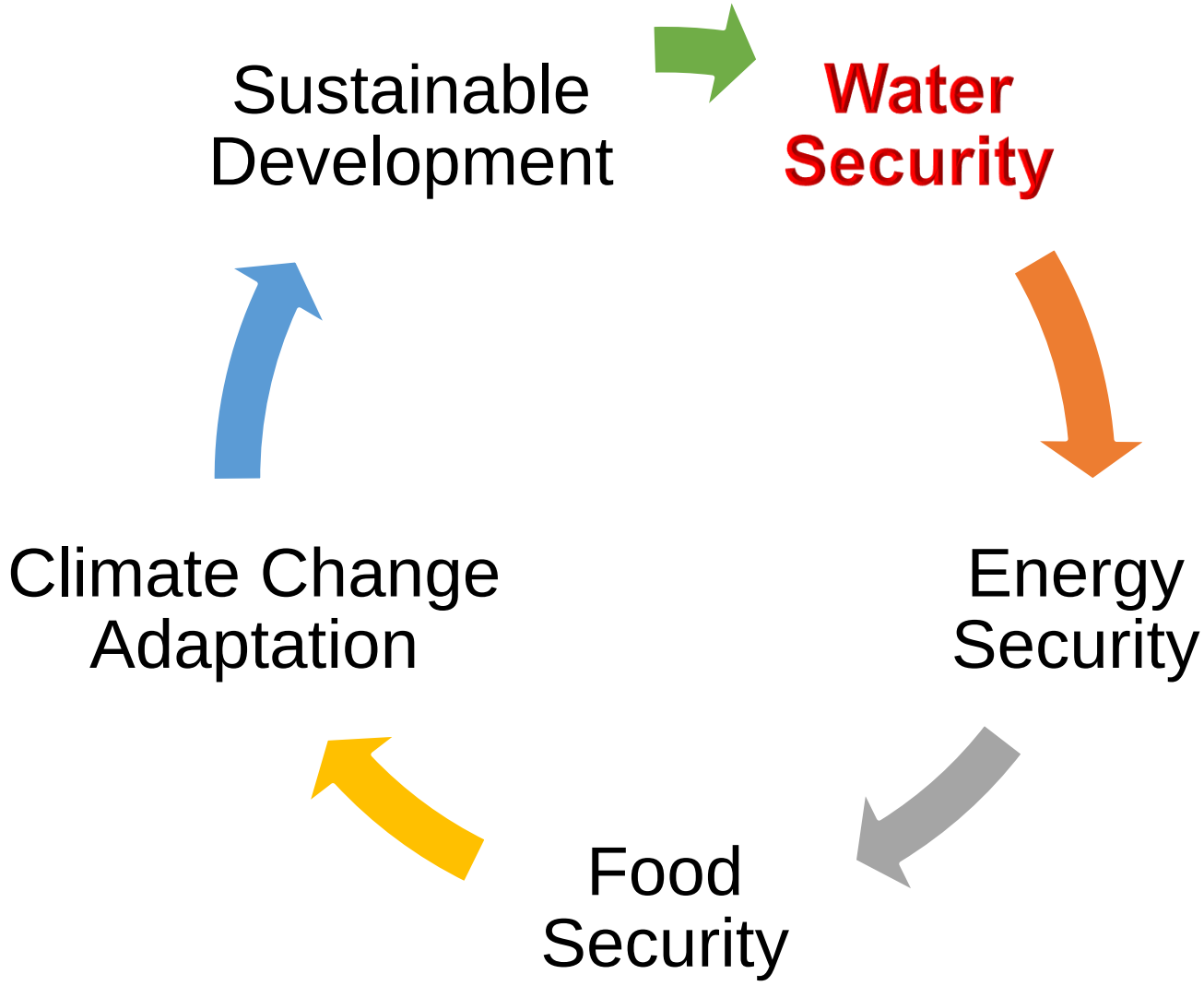
Water: Mother of All Developmental Challenges for Pakistan



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Two Key Questions

Policy Question: Will certain interventions work?

Policymakers are seldom sure about the response to new interventions by water users.

Technology Question: What role can new digital technologies play?

Space technologies, artificial intelligence, advanced communications, robotics …..

Cost of SDG Attainment for the Indus Basin

nature sustainability

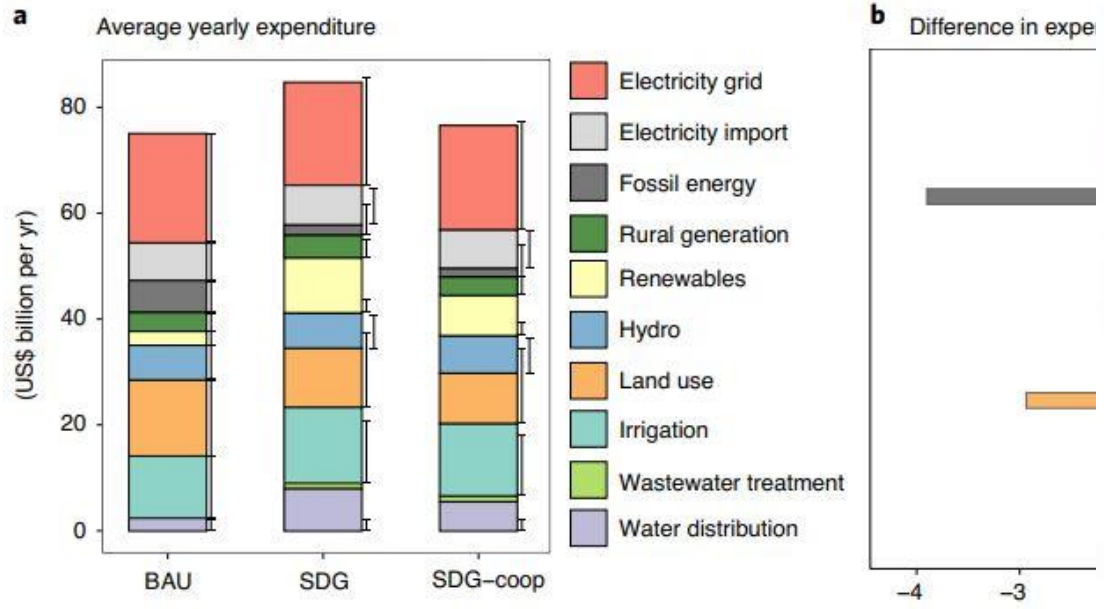
ARTICLES

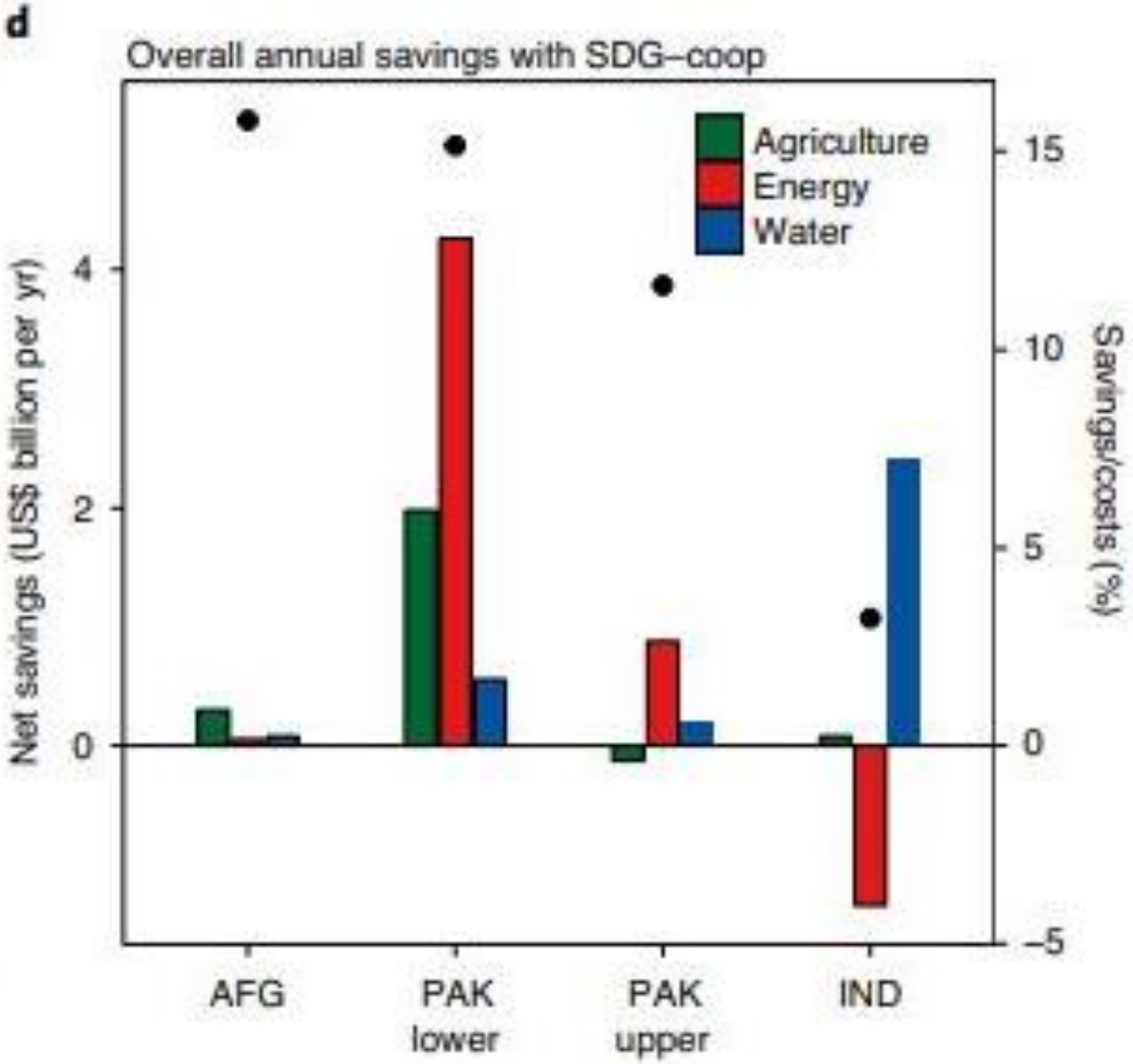
https://doi.org/10.1038/s41893-020-00654-7

Transboundary cooperation a potential route to sustainable development in the Indus basin

Adriano Vinca[1,2], Simon Parkinson[1,2], Keywan Riahi[1,2,3], Edward Byers[1], Afreen Siddiqi[4,5], Abubakr Muhammad[6], Ansir Ilyas[6], Nithiyanandam Yogeswaran[7], Barbara Willaarts[1], Piotr Magnuszewski[1], Muhammad Awais[1,2], Andrew Rowe[2] and Ned Djilali[2,8]

- BAU: $85billion per year until 2050 for the Indus Basin
- 13% more than BAU for SDG attainment
- Costing Pakistan nearly $5 billion / year until 2050
- Many options for off-setting this difference !





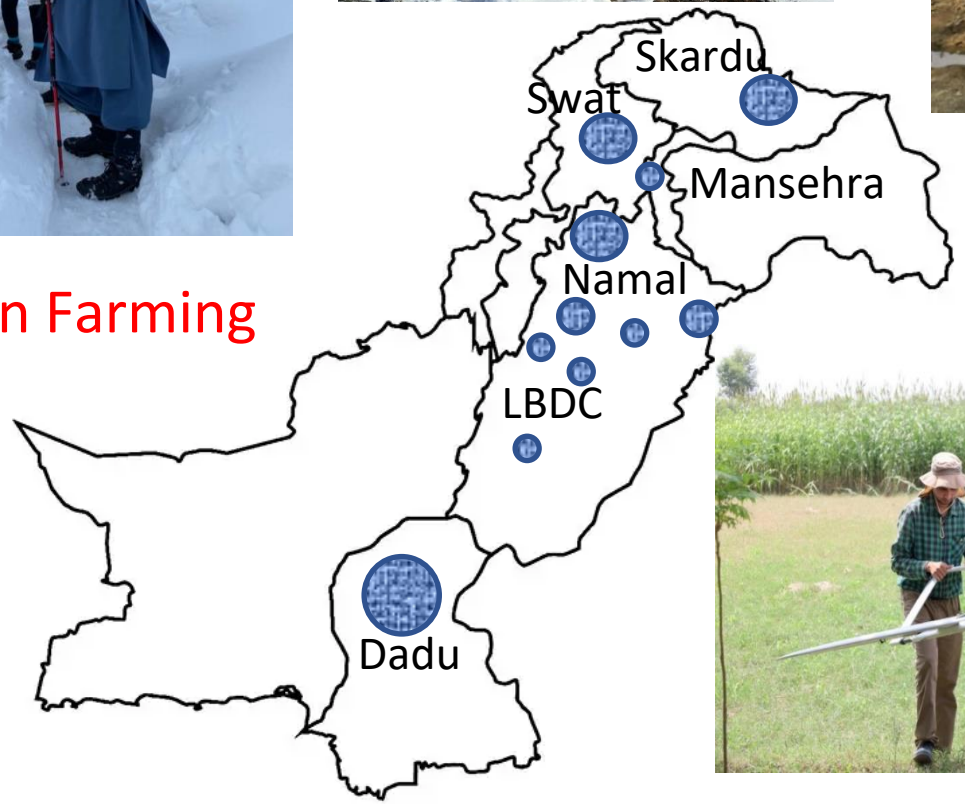
Centre for Water Informatics and Technology

Cryosphere and the Digital Divide

Dr Jawairia Ahmad wins Climate Fellowship

Poverty Alleviation of Small Farmers

Forest Fires & Biodiversity



Net-Zero GHG & Carbon Farming

Dr Talha Manzoor wins DAAD Grant to explore Namal Valley

Floods & Disaster Response

Digital Agriculture

Centre Themes

GMRC, WAPDA

PBL Netherlands Environmental Assessment Agency

Climate Analytics

Agriculture 4.0

Water Risks & Governance

Socio-Ecological Systems

On Farm Water Management
Directorate General Agriculture

Aga Khan Agency for Habitat

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State of Digital Divide in Pakistan

Setting the Context

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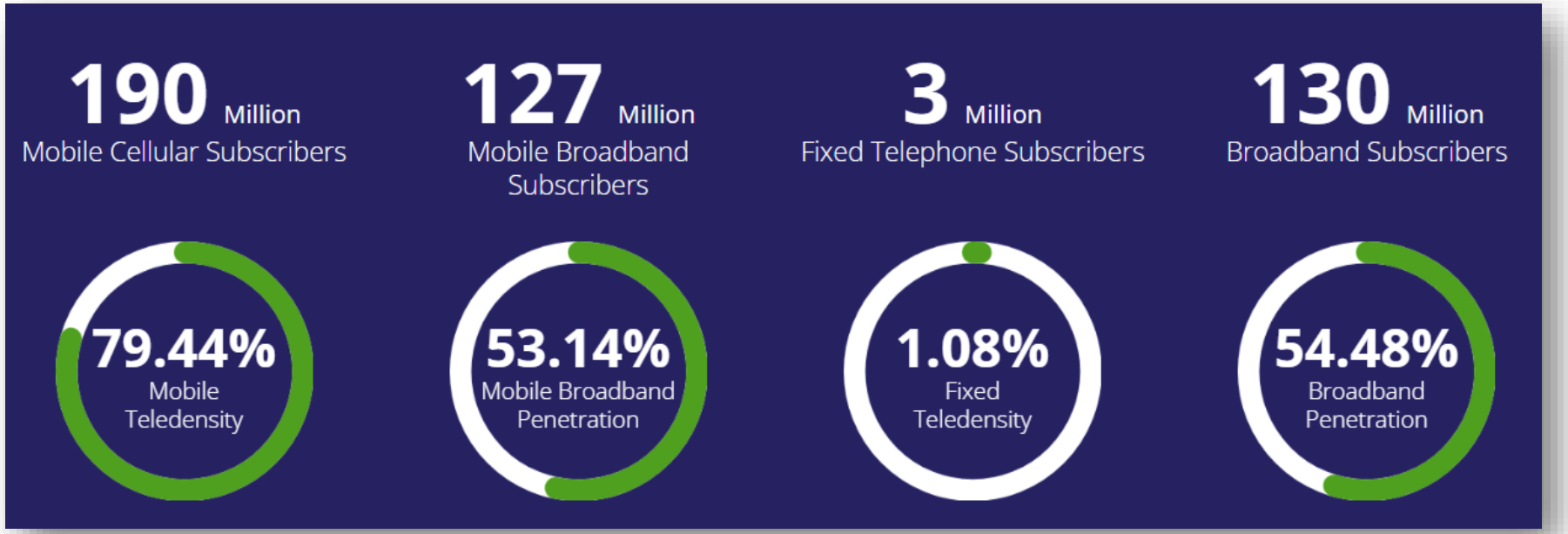
Access to Connectivity



Source: PTA

Low broadband penetration

China: 76.4%
India: 63%
Bangladesh: 75.9%

Source: Wikipedia

"Out of 54%, about 76% of subscribers are from four cities only."
(source, tribune.com.pk)

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Access to Connectivity: The Infrastructure Divide

Zong network coverage. (Source: GSMA)

Cellular network footprint of Pakistan, 2011. Source: PTA, ProPakistani.pk

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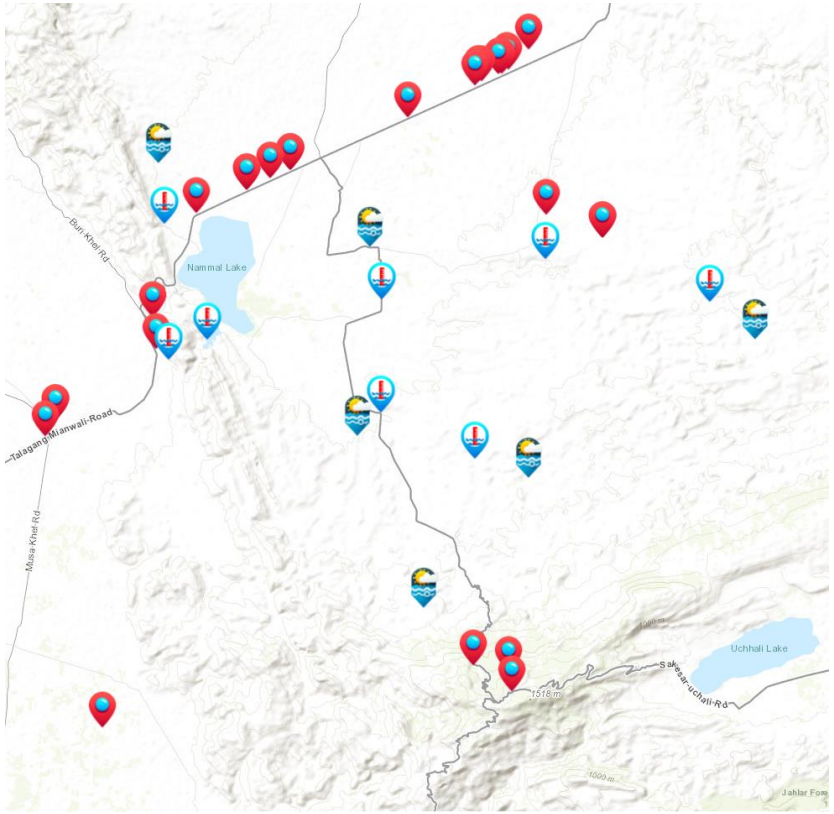
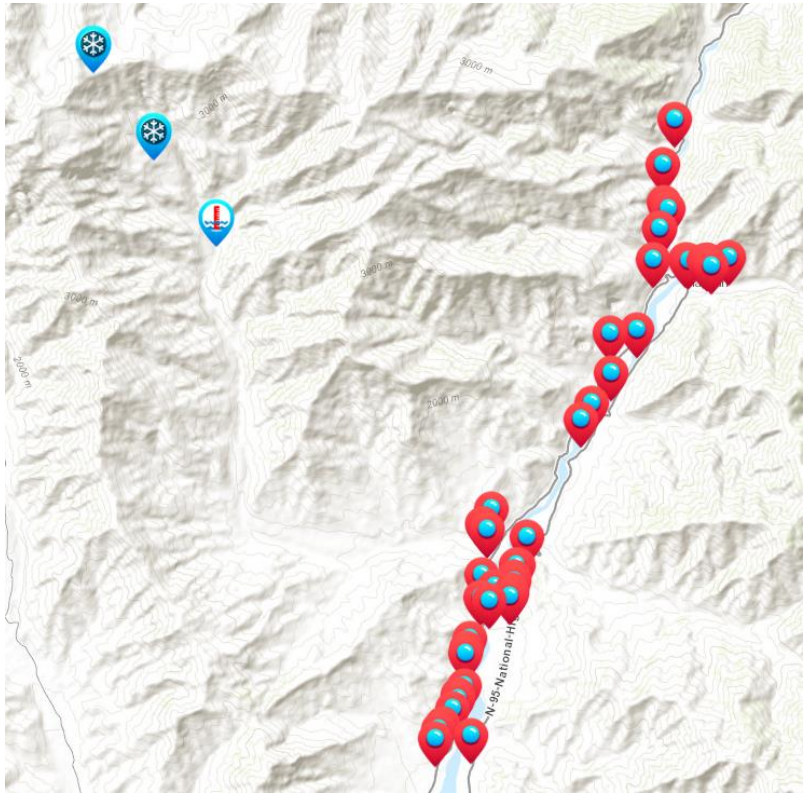
Access to Connectivity: The Unserved Communities



WIT's Hydrometry Network, Namal Valley



Cryosphere Monitoring Network, Gabbin Jaba, Swat

Cellular towers

Source: OpenCelliD

The **unserved communities** away from urban centers, **disconnected** from main roads, and **beyond the mountains**

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WIT's Experience in CyberPhysical Systems and IoT

Leveraging Scalable IoT for Climate Resilience

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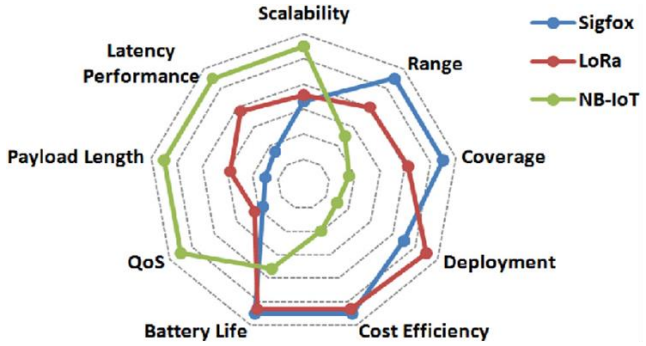
Evolution of IoT technology in the last decade

WiFi and Ethernet-based devices

4G IoT modules



Source: A comparative study of LPWAN technologies for large-scale IoT deployment by Kais Mekki

NB-IoT, LoRaWAN, SigFox

Opensource projects

AREDN™
AMATEUR RADIO EMERGENCY DATA NETWORK

AREDN and HAMNET are **high-speed**, self-discovering, self-configuring, and **resilient** amateur radio data networks for **emergency communications.**

Powered

An open source, **off-grid**, decentralized, mesh network built to run on affordable, **low-power** devices

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IoT based Interventions

Digital Agriculture with Soil Moisture Sensors

Integrated Irrigation Water Management

Cryosphere Research for Basin Scale Water Availability Assessment

Building Resilience in Data Scarce Watersheds

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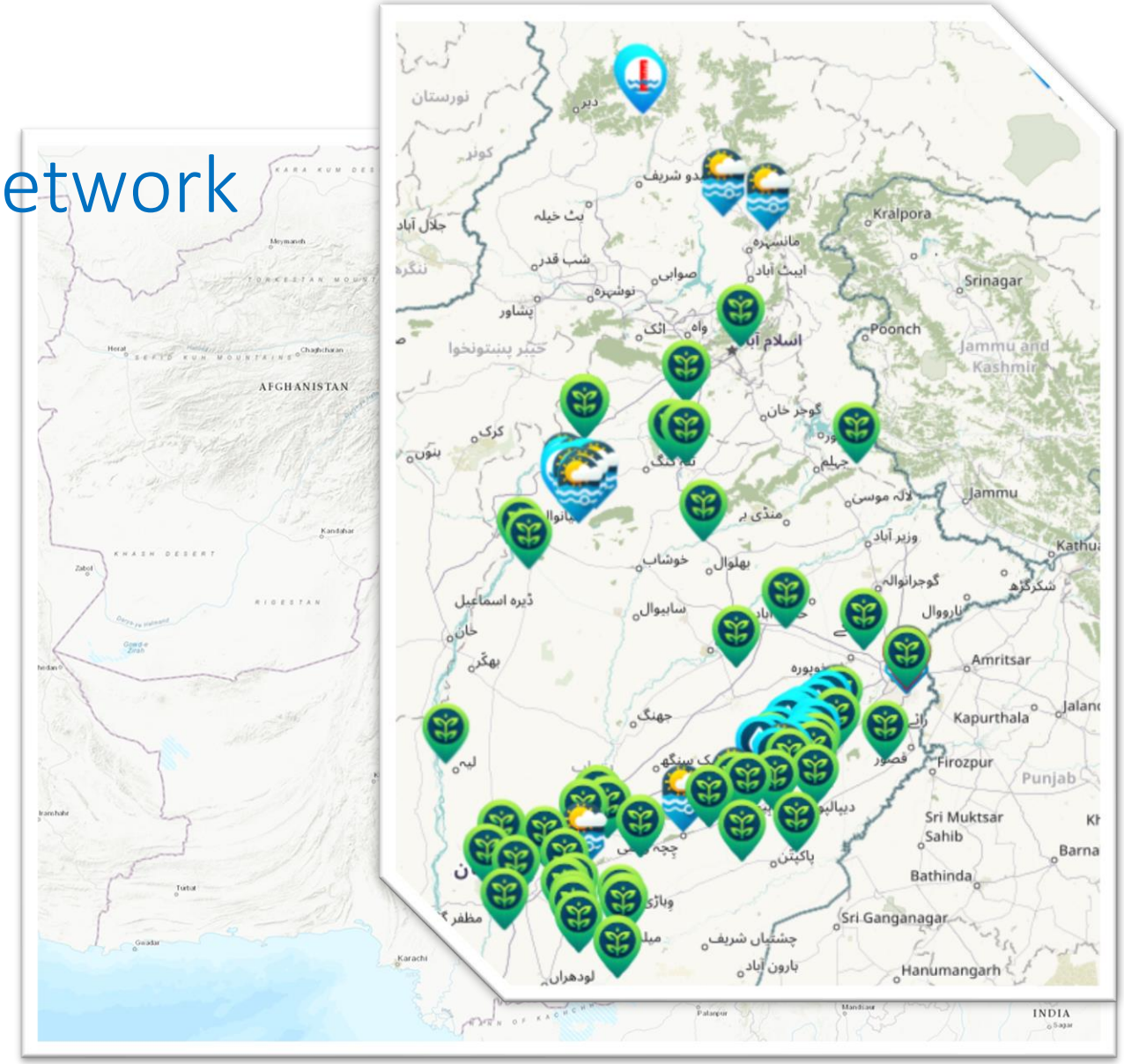
IoT Sensors Network



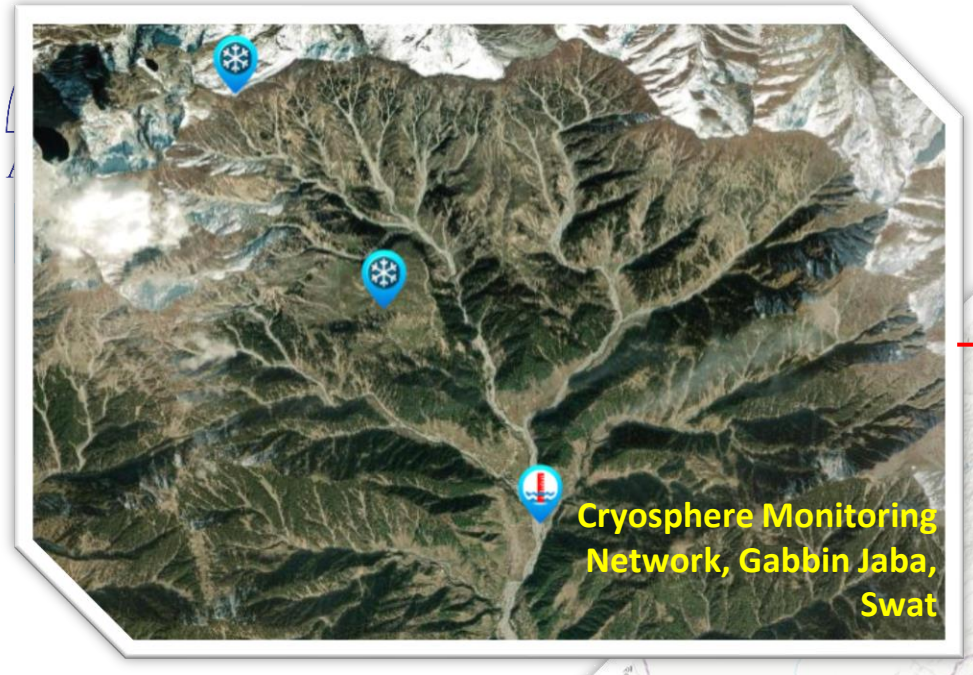
Digital Agriculture / Soil Moisture Sensors

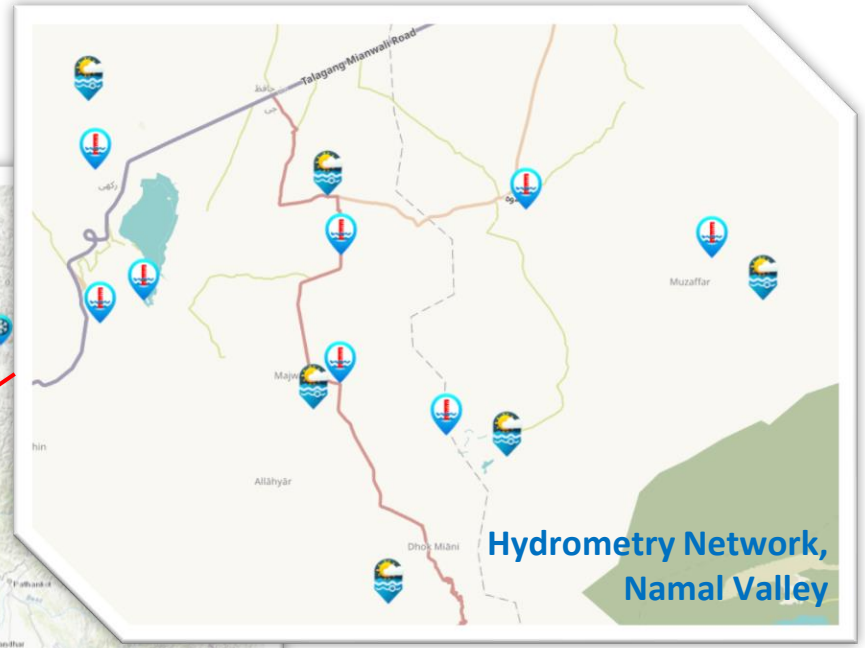
Flood Monitoring Sensors

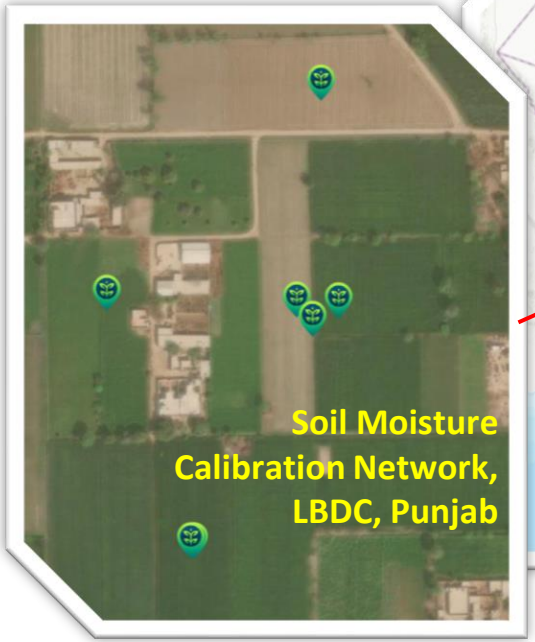
Weather Stations

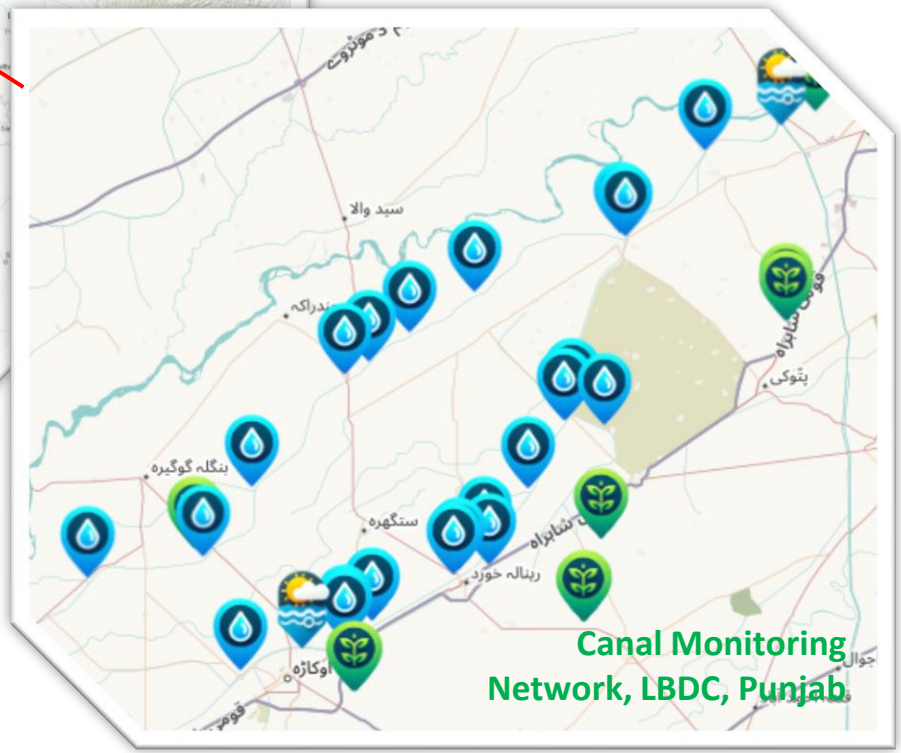
Snow Depth Sensors

Canal Monitoring Sensors


Cryosphere Monitoring
Network, Gabbin Jaba,
Swat


Hydrometry Network,
Namal Valley


Soil Moisture
Calibration Network,
LBDC, Punjab


Canal Monitoring
Network, LBDC, Punjab


5.11


Nikon
Nikon

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Real World Use Cases

Innovation for Climate Resilience

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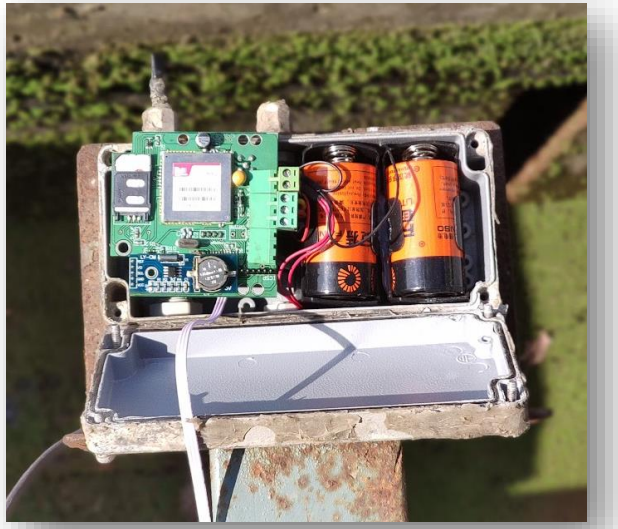
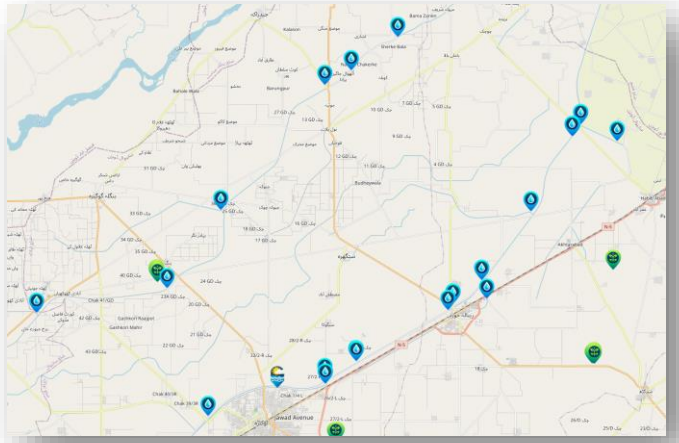
Use Case: GSM based Digital Canal Monitoring Gauges



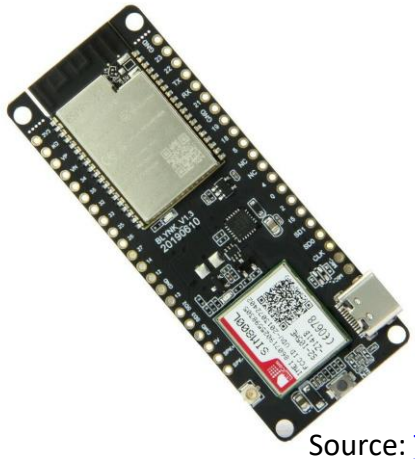
GSM Based Devices



Suitable for sensors deployed far apart

- **Benefits**: Low power easy to deploy solutions
- **Constraint**: Dependent on GSM Connectivity

Roadmap for Scaling up: Using off-the-shelf modules for rapid scalability, and reliable supply chain



Source: TTGO

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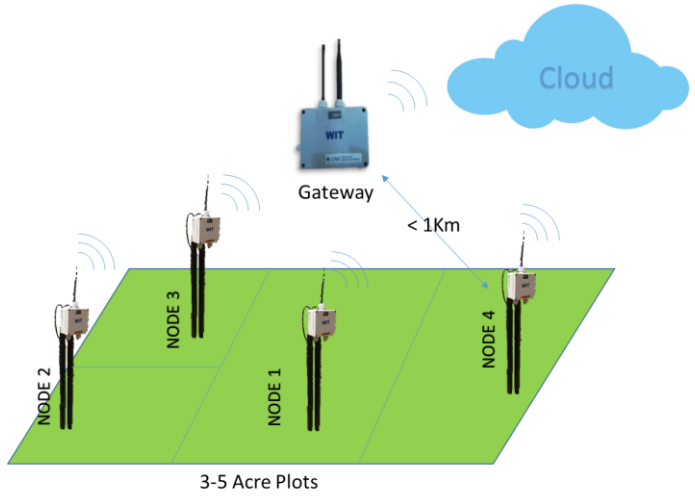
Use Case: LoRa based Digital Agriculture Sensors

LoRa based devices



Suitable to connect cluster of sensors at catchment level

- **Benefits**:
  - Helps extend coverage beyond the last GSM signal (5-10KM).
- **Constraint**: Dependent on GSM Connectivity

Roadmap for Scaling up:

- Migration to LoRaWAN, NB-IoT
- Development of low-cost LoRaWAN Gateways

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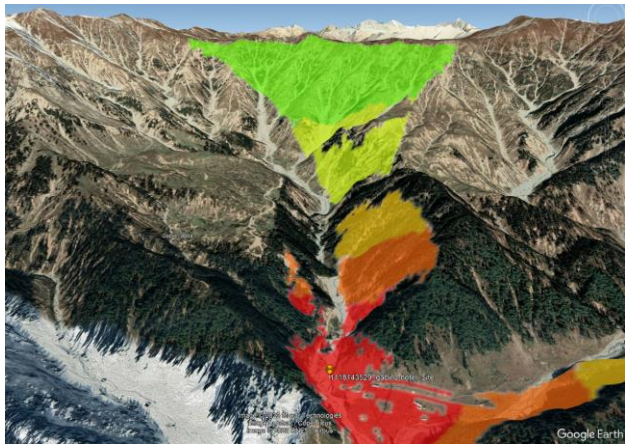
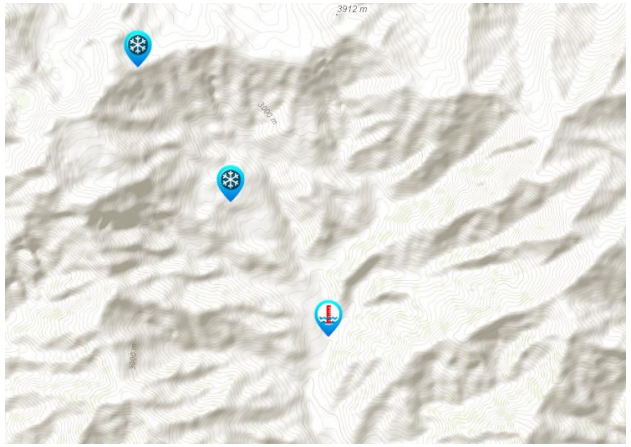
Use Case: LoRa for Cryosphere and Flood Monitoring Sensors

GSM and LoRa based Devices



Source: CloudRF simulation



Suitable to connect a cluster of sensors at the catchment level, even **beyond the last GSM Signal**

- **Benefits**: LoRaWAN devices can help extend coverage by 5-10km
- **Constraint**: Dependent on GSM/internet and can fail during disasters

Roadmap for Scaling up: Scalable mesh network, using open source Meshtastic Project

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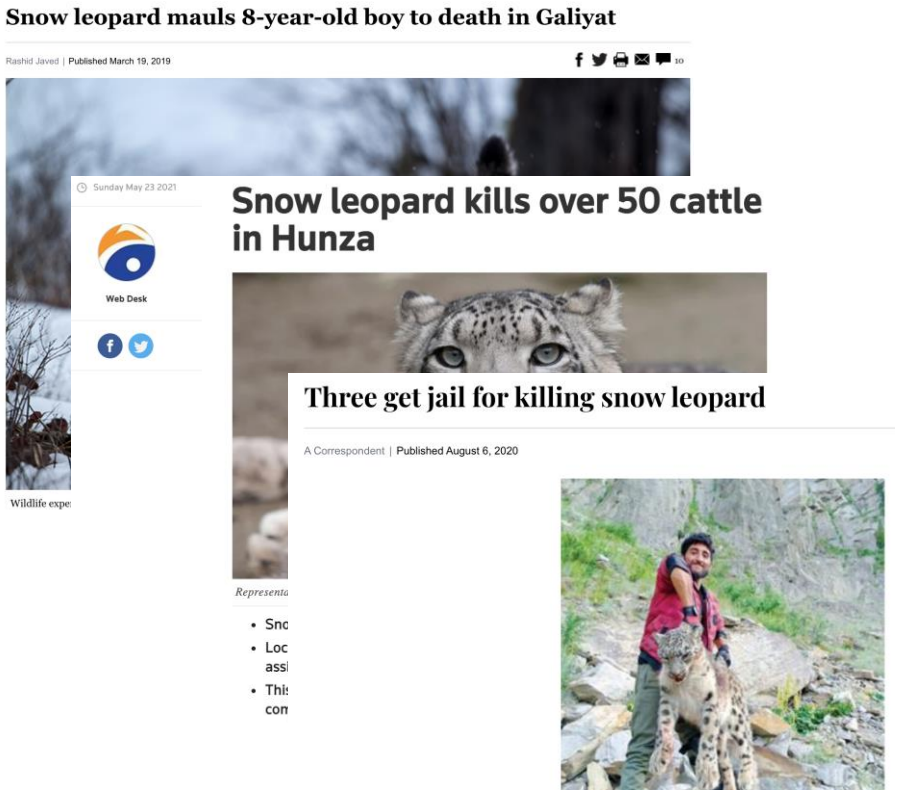
Use Case: AIOT & Computer Vision, Preventing Human Wildlife-Conflict



Snow leopard mauls 8-year-old boy to death in Galiyat

Rashid Javed | Published March 19, 2019

Sunday May 23 2021

Snow leopard kills over 50 cattle in Hunza

Web Desk

Three get jail for killing snow leopard

A Correspondent | Published August 6, 2020

Every year human, livestock and snow leopard lost their lives.

How can we avoid this human animal conflict?

Camera trap images - Feb 02, 2021

Sokhtarabad Nala

Shachkatr Nala

Camera traps record movement of snow leopard but there is lack of communication and automated early warning mechanism

Credit: Dr. Murtaza Taj, Computer Vision Lab, LUMS

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Use Case: AIOT & Computer Vision, Preventing Human Wildlife-Conflict

Realtime AIOT powered Camera Trap, Hunza, GB, Pakistan

Credit: Dr. Murtaza Taj, Computer Vision Lab, LUMS

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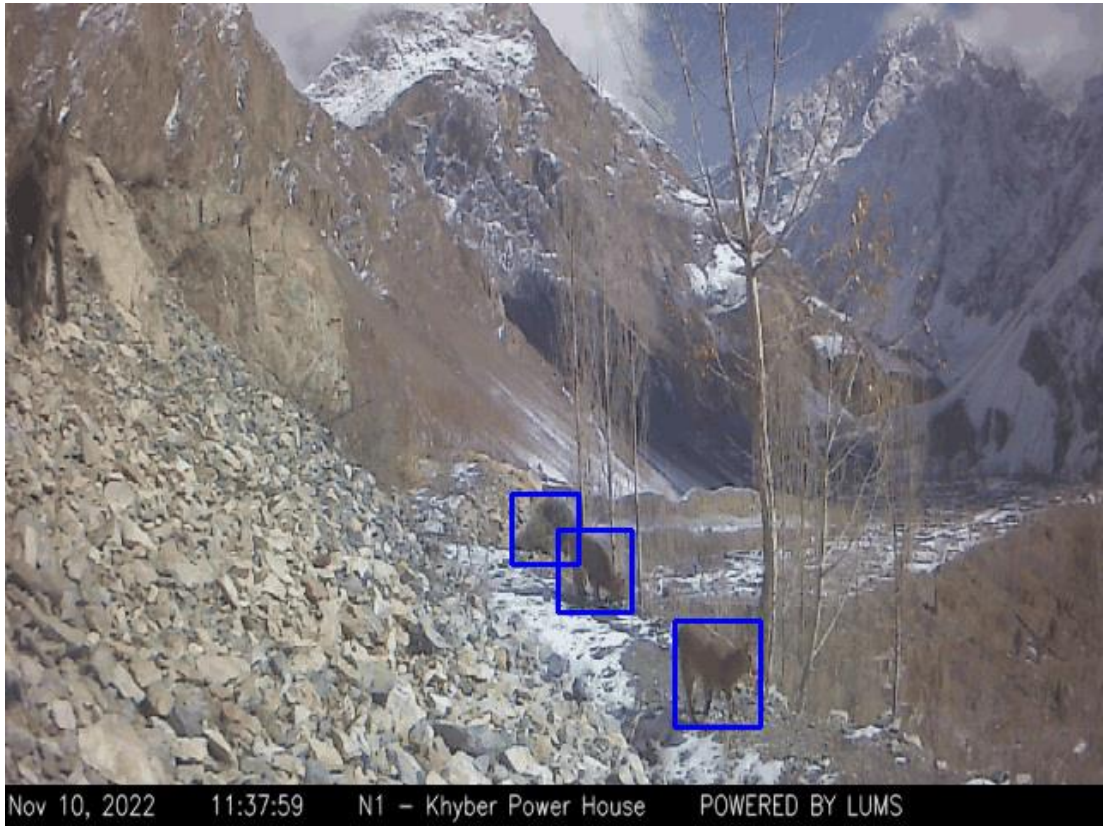
Use Case: AIOT & Computer Vision, Preventing Human Wildlife-Conflict



Credit: Dr. Murtaza Taj, Computer Vision Lab, LUMS

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Use Case: AIOT & Computer Vision, Forest Fire Detection and EWS

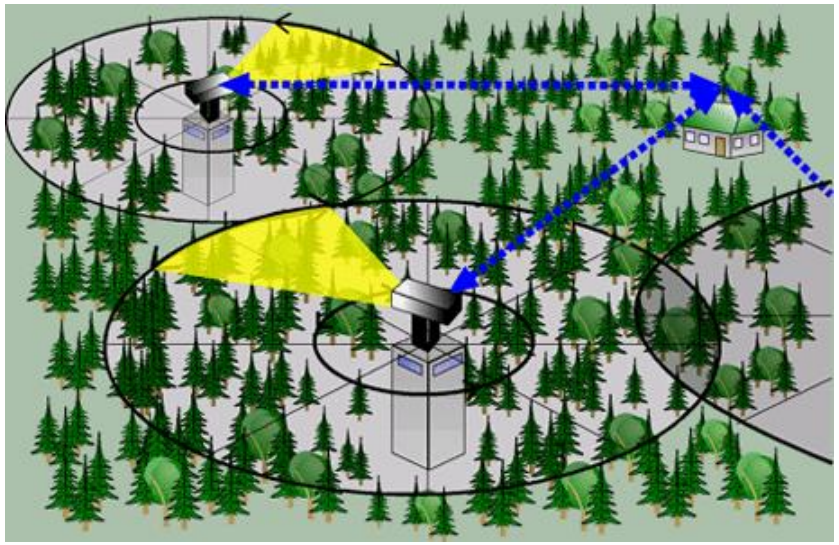

Image Source: FireWatch Australia

GSM and Ubiquiti long range WiFi based connectivity

Source: Forest Fire Detection and Early Warning System, Medium Article

Suitable for diversity of sensing using the power of CV, and AI

- **Benefits**: Computer Vision based sensing can extend coverage to visual range, depending on application
- **Constraint**: Dependent on GSM/broadband connectivity

Roadmap for Scaling up:

- Training **edge AI** models to enable connectivity using low bandwidth LPWAN network (e.g. LoRa).

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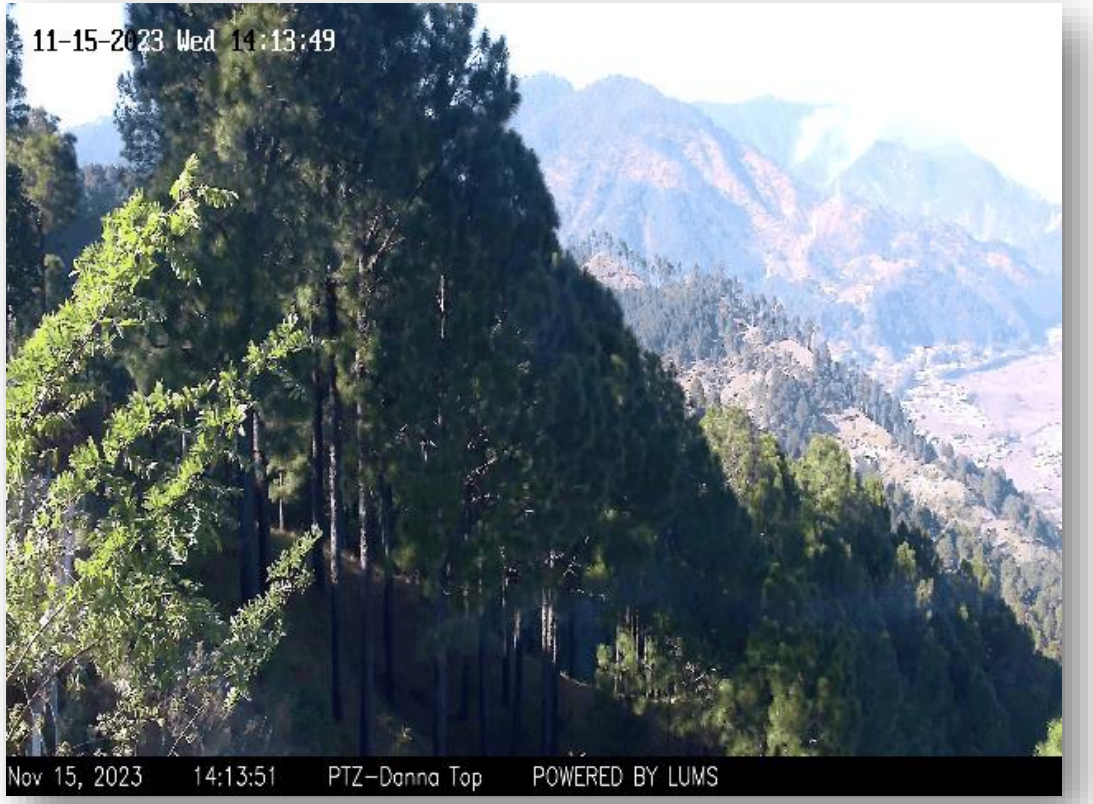
Use Case: AIOT & Computer Vision, Forest Fire Detection and EWS



Credit: Dr. Murtaza Taj, Computer Vision Lab, LUMS

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Mesh Network for Off-grid Communication

Resilience for the most vulnerable

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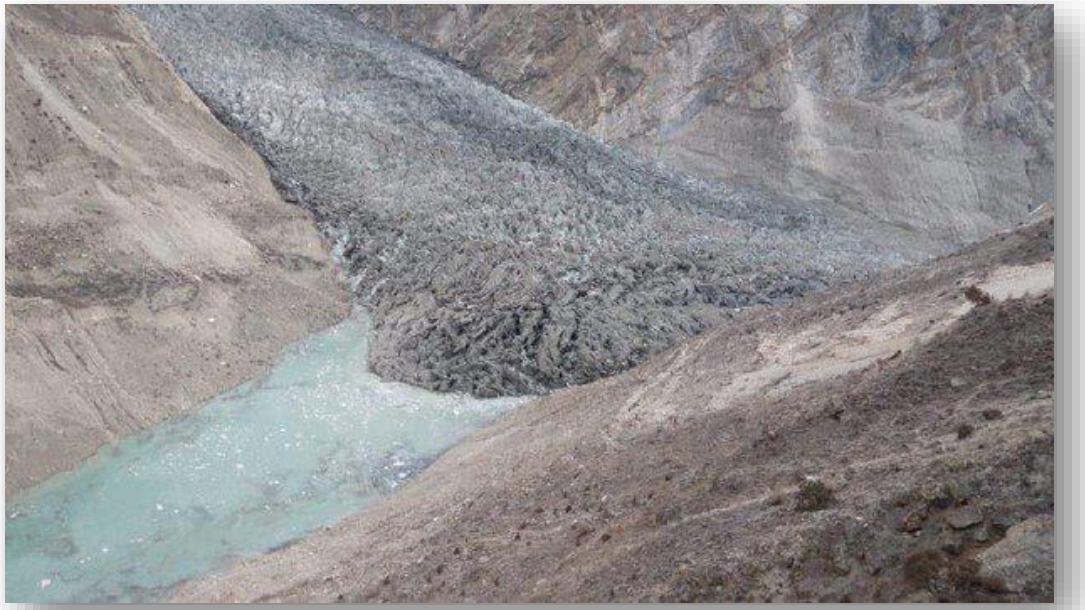
Use Case: Shisper Glacier, Hassanabad, Gilgit-Baltistan



Source: ICIMOD

Ice dammed lake at Shisper Glacier (Photo: PMD, GBDMA)

Source: Dawn News

Damaged bridge at Hassanabad, after May 2022 GLOF

Rapidly advancing **Shisper Glacier**, exemplifying the **Karakoram Anomaly**, has heightened the risk of Glacial Lake Outburst Floods (**GLOFs**).

There has been a GLOF events at Hassanabad, **every year since 2020**.

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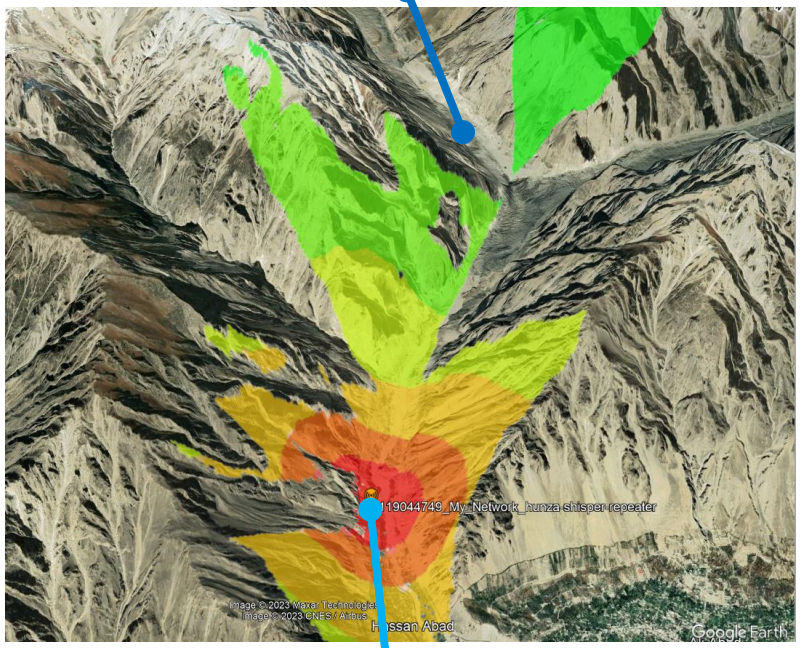
Use Case: Shisper Glacier, Hassanabad, Gilgit-Baltistan

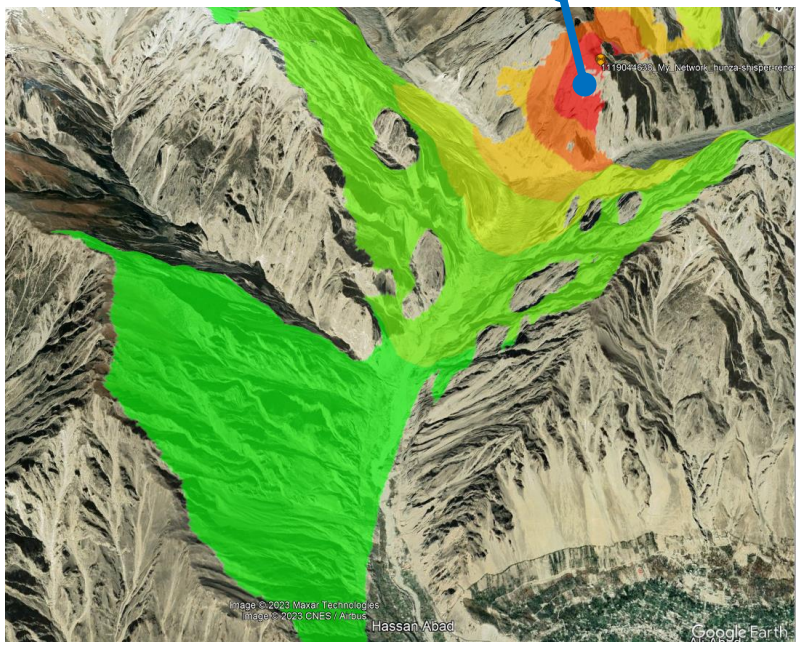
Area of Interest (for sensors deployment) still beyond the LoRaWAN Coverage



LoRaWAN gateway withing GSM coverage area

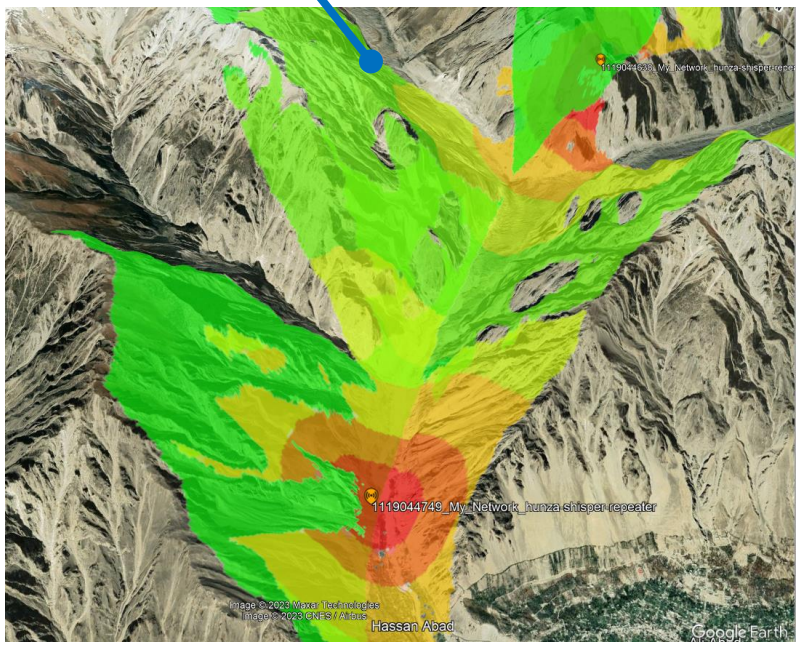
Gateway Coverage View

A LoRa Meshtastic Repeater within line of sight of the Gateway



Repeater Coverage View

Area of Interest (for sensors deployment) covered by repeater signals



Combined View

Source: CloudRF simulations

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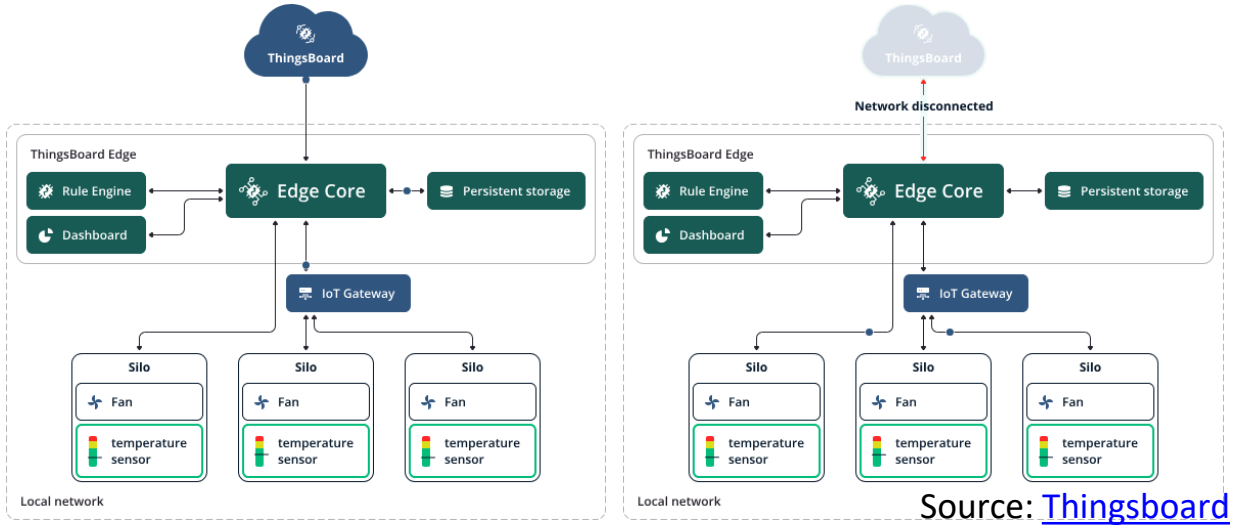
Local LoRa Servers and Edge Platforms

- **Work in Progress**
  - **Hybrid** use of LoRaWAN and Meshtastic devices
  - Local servers, disconnected from the internet
- **Benefits**:
  - Suitable to connect a cluster of sensors at the catchment level
  - Coverage can be extended using repeaters at selected locations (i.e, beyond a mountain)
  - Data analytics, rule-based decisions, alarm raising, etc. to be managed without needing internet
- **Constraint**: Realtime monitoring/syncing may not be available in areas with no internet coverage



Source: Thingsboard

Thingsboard Edge: A Comprehensive IoT Server Operating Independently **Without Internet Connectivity**

Similar Solutions:

Node-RED

TagoCORE

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Challenges of Communication in Extreme Environment

- Poor or no Internet Connectivity
- Poor or no GSM connectivity
- A general neglect for communities most vulnerable to climate change
- Poor physical access (road infrastructure)
- Lack of skilled labor, support services for the upkeep and maintenance of innovative solutions
- Adoption Challenges: community, government entities
- Regulations (imports, spectrum etc.)

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Way Forward for building scalable connectivity solutions

- Leveraging IoT and open-source ecosystem for connectivity solutions
- Involving the Communities
- Building Scalable solutions that can be transferred to local communities of maintenance (Arduino is the Inspiration)
- Ensuring a scalable supply chain, using off-the-shelf parts i.e ttgo, heltec etc.
- Off-grid solutions, innovative syncing solutions (drones?, example of forestFly project)
- Capacity building of Government Entities, helping in IoT Policy Development

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Our Collaborators

Partners, Donors, and Enablers

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Collaborators

Early warning and communication system for **flood risk reduction** in Gilgit-Baltistan

Forest Fire Detection and Early Warning System

Securing Socio-Economic Stability and **Data-Driven Resilience** for Ungauged Namal Valley Watershed at Monsoon Margins

Improving Canal Irrigation Management through Remote Sensing Based Decision Support Tool

NCRA-Agricultural Robotics Lab, 250+ node **basin-scale hydrological sensor-network** for soil moisture, canal flows, snowpack, precipitation

Saving Water through **Water Sense Project**- Caring for Water- Pakistan initiative

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Part 2: A Multi-scale Soil Moisture Monitoring Network for Pakistan

From Technology to End-Users

Decision

Demand

Intelligent Decision System

Supply

Uncertainty

Soil Moisture Sensing Network

Irrigation Infrastructure

Weather Station

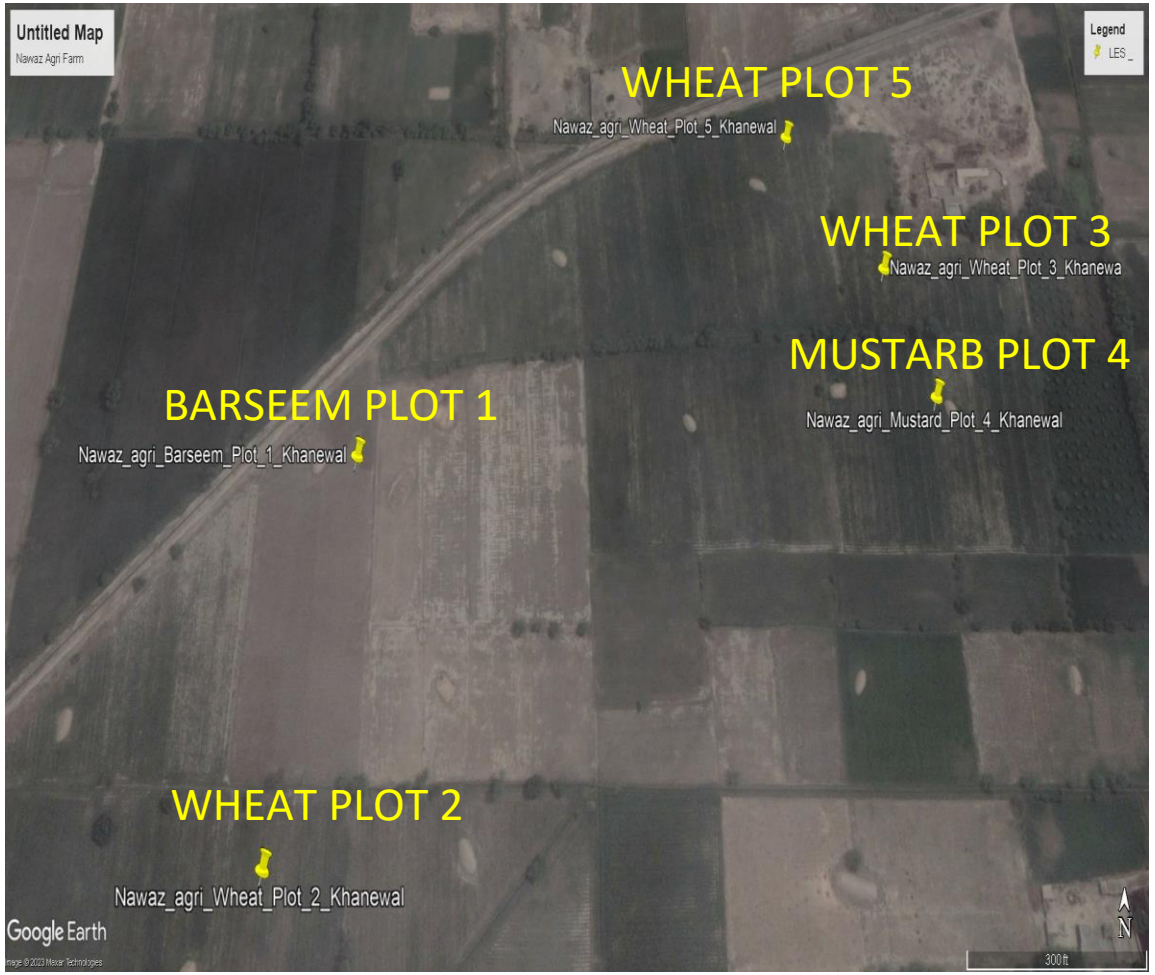
Dozens of active Installation Sites at Small & Medium Sized Farms

Spatial Variation of SM: Jarola Farm, Mian Channu

GPS Coordinates

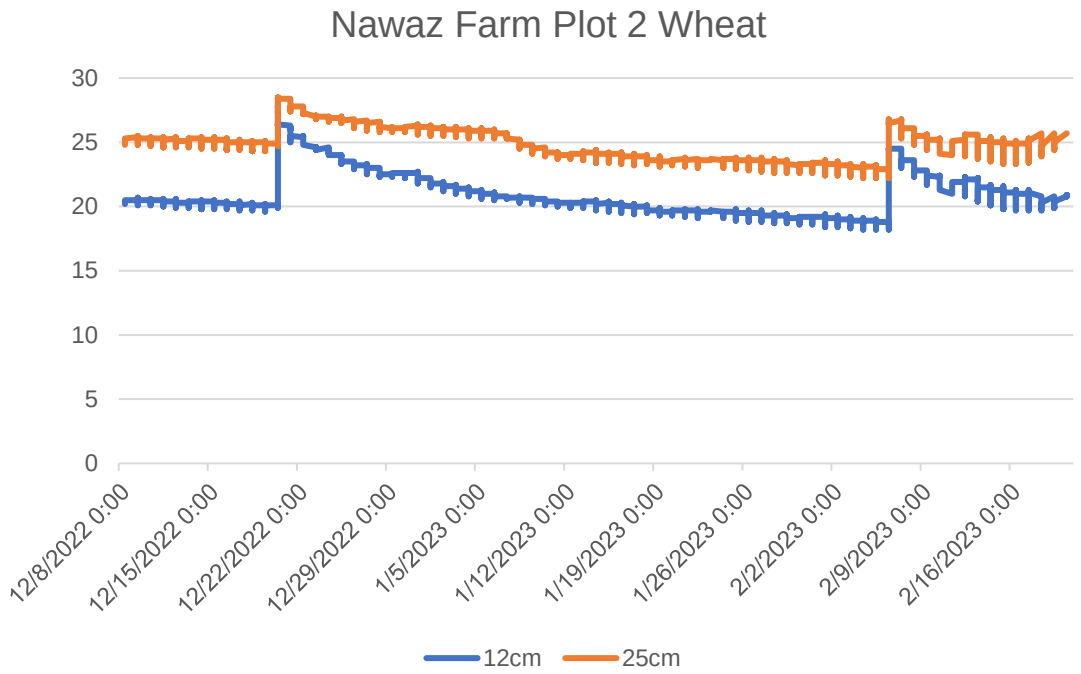
- **Plot 1:** Lat 30.356225 Long 72.367665
- **Plot 2 :** Lat 30.357446 Long 72.368343
- **Plot 3 :** Lat 30.357590 Long 72.367132
- **Plot 4:** Lat 30.358749 Long 72.368497

Nawaz Agri Farm, Khanewal



GPS Coordinates

- **Plot 1:** Lat 30.136101 Long 71.786412
- **Plot 2 :** Lat 30.136402 Long 71.790045
- **Plot 3 :** Lat 30.134628 Long 71.786106
- **Plot 4:** Lat 30.136972 Long 71.789796
- **Plot 5:** Lat 30.137610 Long 71.789206


Nawaz Farm Plot 2 Wheat
30
25
20
15
10
5
0
12/8/2022 0:00
12/15/2022 0:00
12/22/2022 0:00
12/29/2022 0:00
1/5/2023 0:00
1/12/2023 0:00
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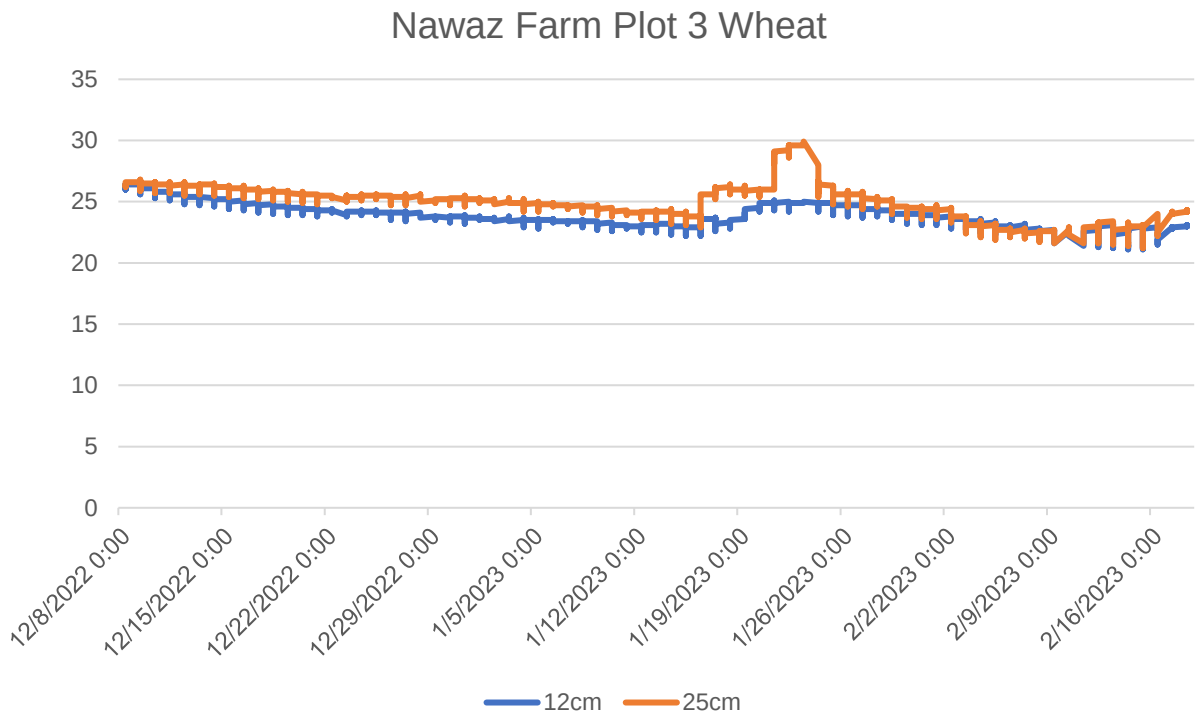
1/26/2023 0:00
2/2/2023 0:00
2/9/2023 0:00
2/16/2023 0:00
12cm
25cm


Nawaz Farm Plot 3 Wheat
35
30
25
20
15
10
5
0
12/8/2022 0:00
12/15/2022 0:00
12/22/2022 0:00
12/29/2022 0:00
1/5/2023 0:00
1/12/2023 0:00
1/19/2023 0:00
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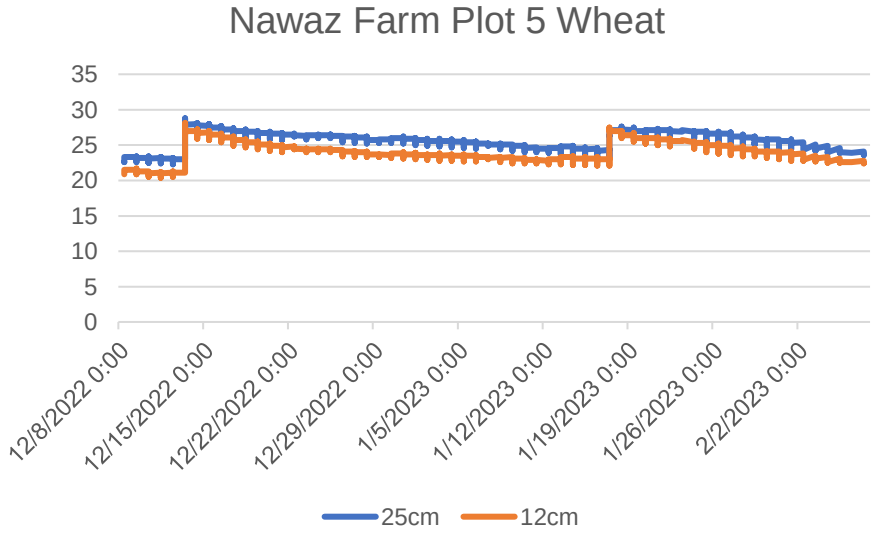
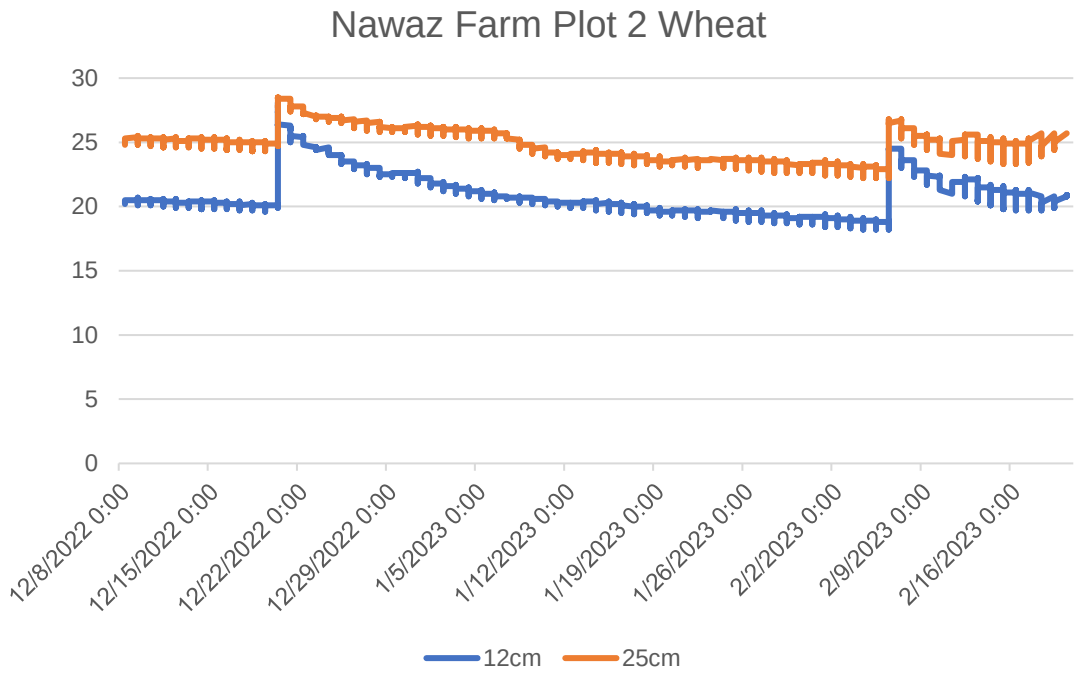
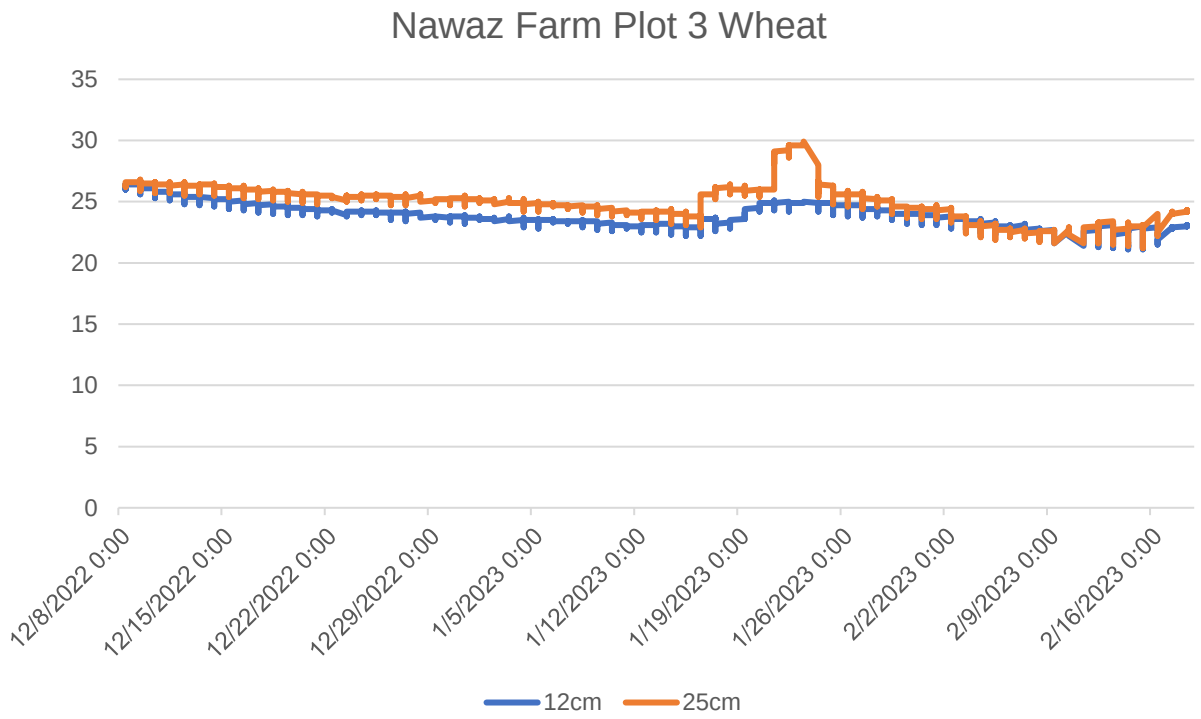
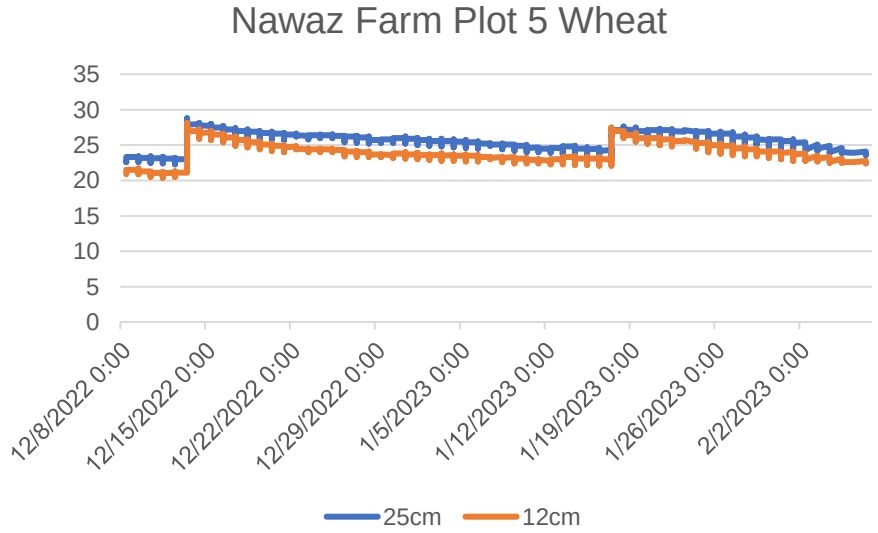
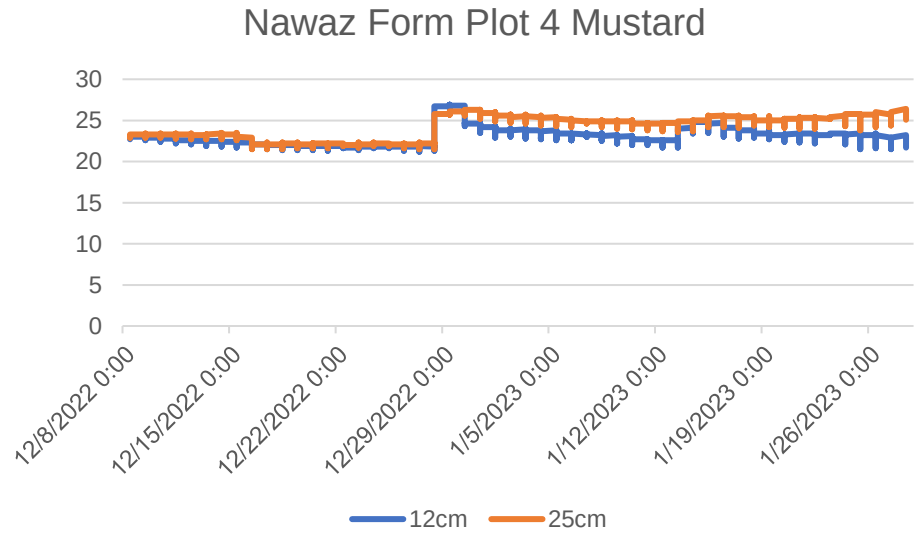
2/2/2023 0:00
2/9/2023 0:00
2/16/2023 0:00
12cm
25cm


Nawaz Farm Plot 5 Wheat
35
30
25
20
15
10
5
0
12/8/2022 0:00
12/15/2022 0:00
12/22/2022 0:00
12/29/2022 0:00
1/5/2023 0:00
1/12/2023 0:00
1/19/2023 0:00
1/26/2023 0:00
2/2/2023 0:00
25cm
12cm


Nawaz Farm Plot 2 Wheat
30
25
20
15
10
5
0
12/8/2022 0:00
12/15/2022 0:00
12/22/2022 0:00
12/29/2022 0:00
1/5/2023 0:00
1/12/2023 0:00
1/19/2023 0:00
1/26/2023 0:00
2/2/2023 0:00
2/9/2023 0:00
2/16/2023 0:00
12cm
25cm


Nawaz Farm Plot 3 Wheat
35
30
25
20
15
10
5
0
12/8/2022 0:00
12/15/2022 0:00
12/22/2022 0:00
12/29/2022 0:00
1/5/2023 0:00
1/12/2023 0:00
1/19/2023 0:00
1/26/2023 0:00
2/2/2023 0:00
2/9/2023 0:00
2/16/2023 0:00
12cm
25cm


Nawaz Farm Plot 5 Wheat
35
30
25
20
15
10
5
0
12/8/2022 0:00
12/15/2022 0:00
12/22/2022 0:00
12/29/2022 0:00
1/5/2023 0:00
1/12/2023 0:00
1/19/2023 0:00
1/26/2023 0:00
2/2/2023 0:00
25cm
12cm


Nawaz Form Plot 4 Mustard
30
25
20
15
10
5
0
12/8/2022 0:00
12/15/2022 0:00
12/22/2022 0:00
12/29/2022 0:00
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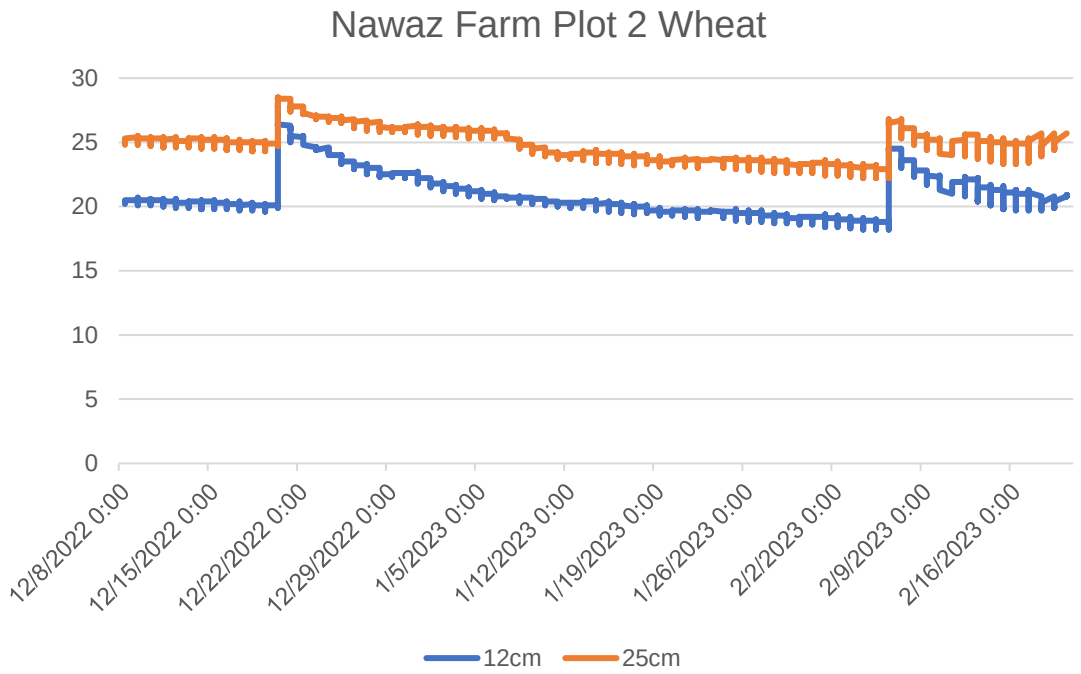
1/19/2023 0:00
1/26/2023 0:00
12cm
25cm


Nawaz Farm Plot 2 Wheat
30
25
20
15
10
5
0
12/8/2022 0:00
12/15/2022 0:00
12/22/2022 0:00
12/29/2022 0:00
1/5/2023 0:00
1/12/2023 0:00
1/19/2023 0:00
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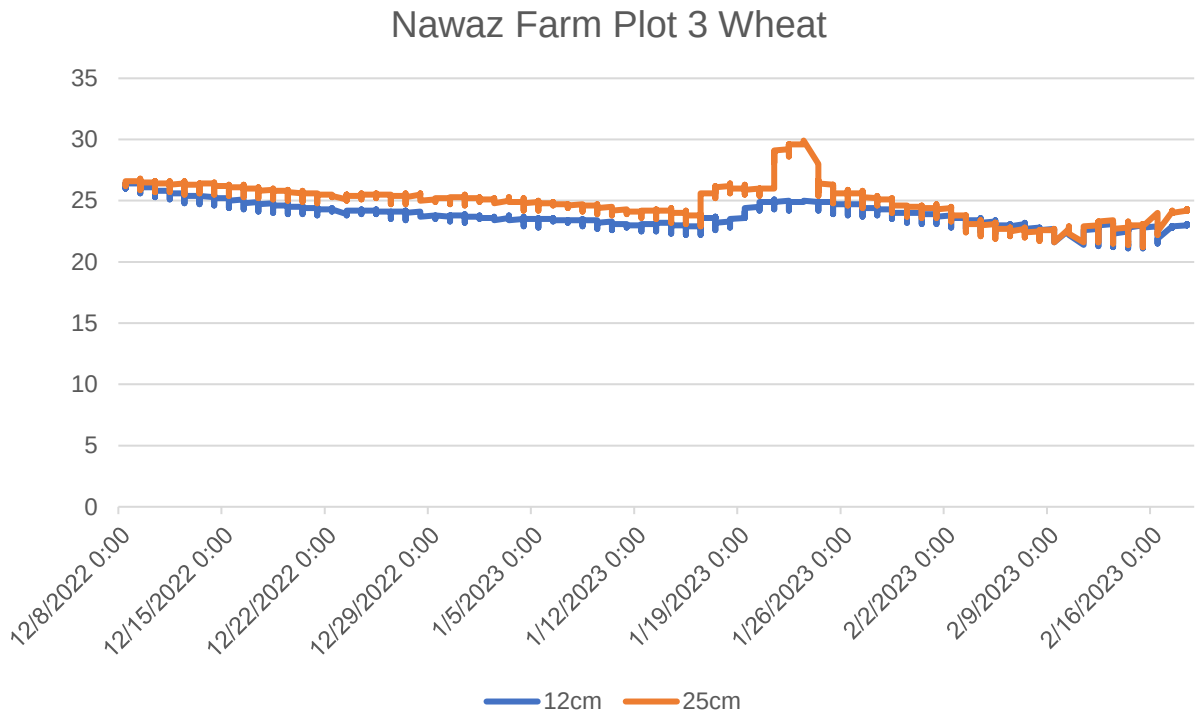
2/2/2023 0:00
2/9/2023 0:00
2/16/2023 0:00
12cm
25cm


Nawaz Farm Plot 3 Wheat
35
30
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15
10
5
0
12/8/2022 0:00
12/15/2022 0:00
12/22/2022 0:00
12/29/2022 0:00
1/5/2023 0:00
1/12/2023 0:00
1/19/2023 0:00
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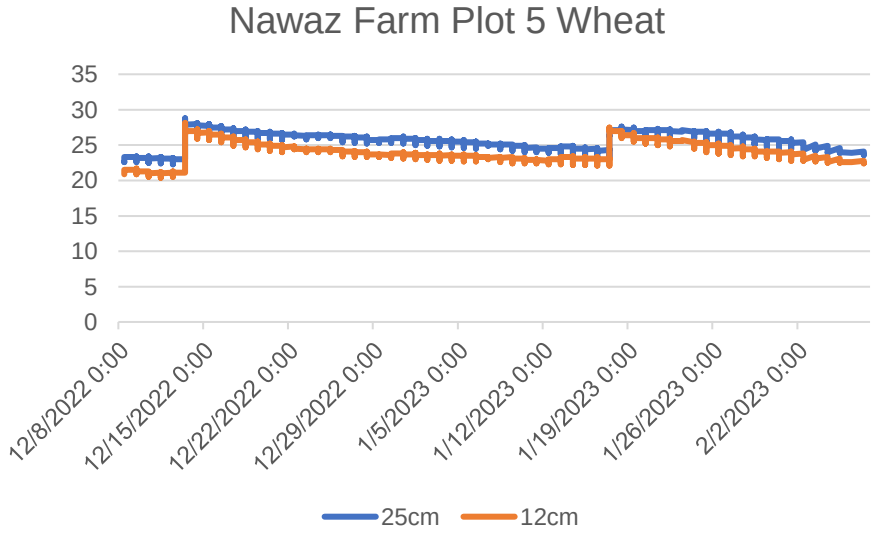
2/9/2023 0:00
2/16/2023 0:00
12cm
25cm


Nawaz Farm Plot 5 Wheat
35
30
25
20
15
10
5
0
12/8/2022 0:00
12/15/2022 0:00
12/22/2022 0:00
12/29/2022 0:00
1/5/2023 0:00
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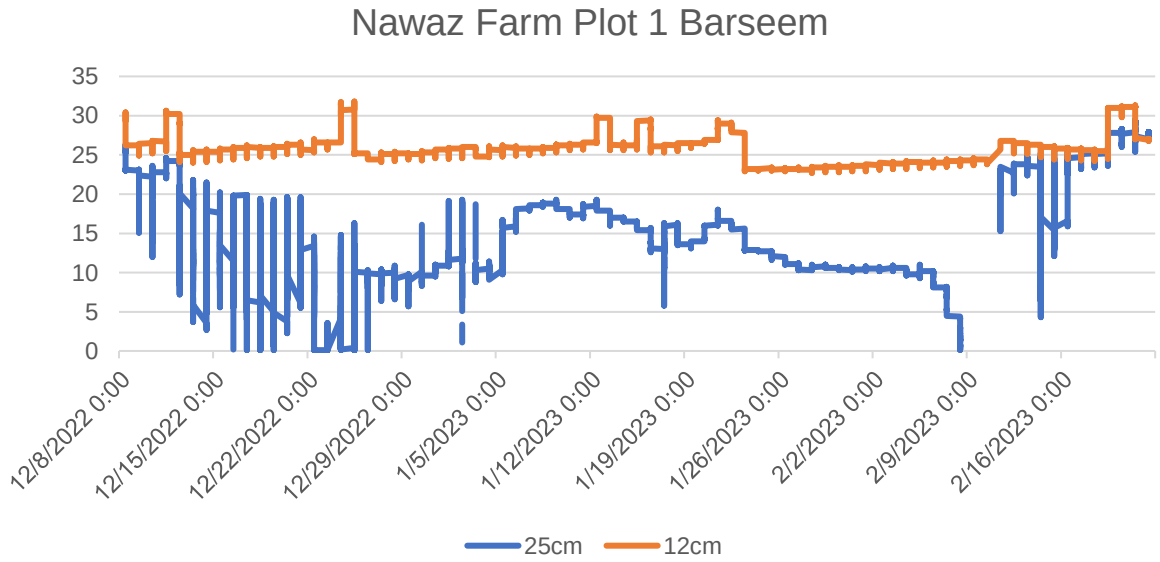
1/26/2023 0:00
2/2/2023 0:00
25cm
12cm


Nawaz Farm Plot 1 Barseem
35
30
25
20
15
10
5
0
12/8/2022 0:00
12/15/2022 0:00
12/22/2022 0:00
12/29/2022 0:00
1/5/2023 0:00
1/12/2023 0:00
1/19/2023 0:00
1/26/2023 0:00
2/2/2023 0:00
2/9/2023 0:00
2/16/2023 0:00
25cm
12cm

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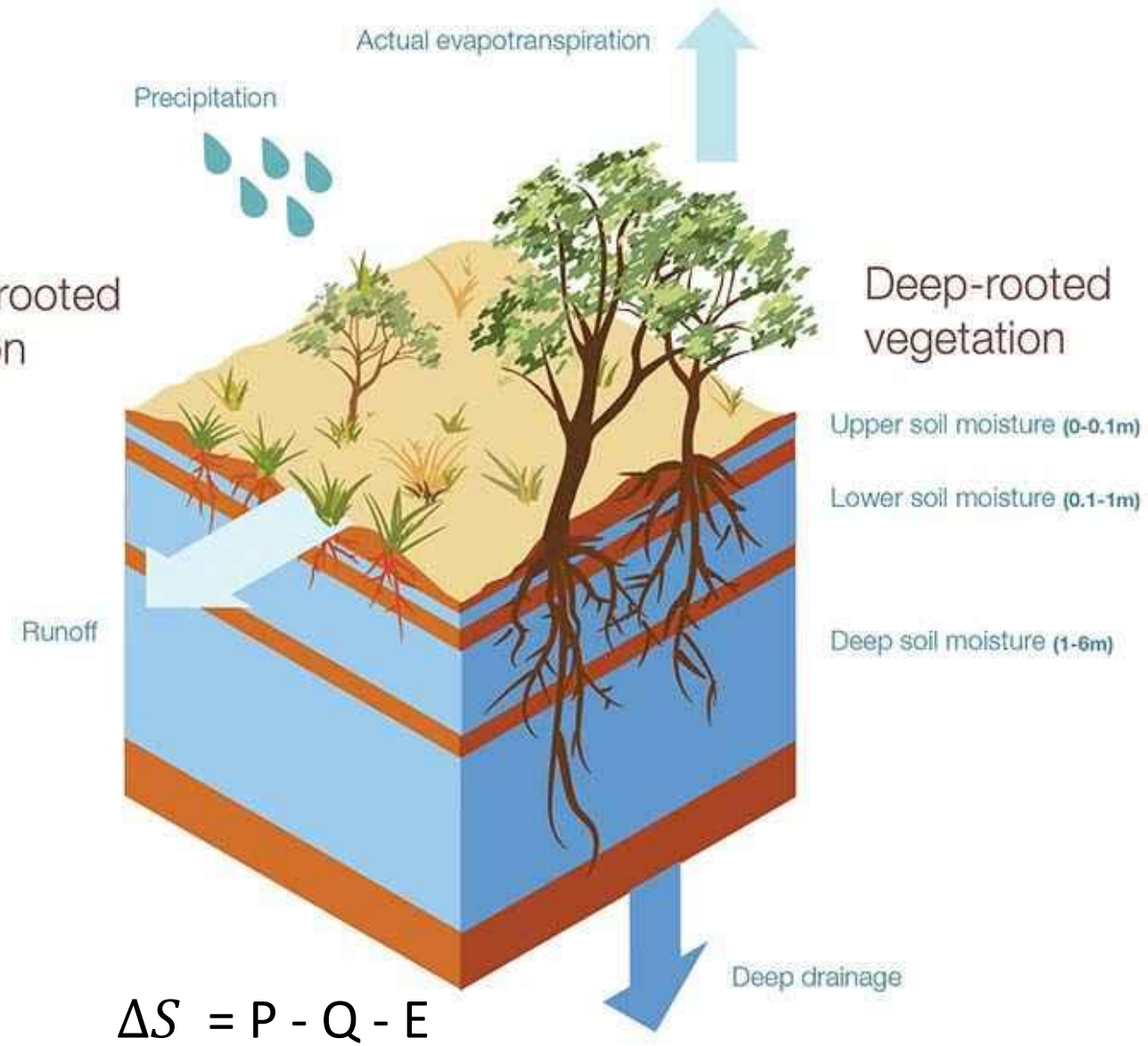
Water Balance

A general water balance equation is:

$$P = Q + E + \Delta S$$

where

P is precipitation
Q is runoff
E is evapotranspiration
ΔS is the change in storage (in soil or the bedrock)



ΔS = P - Q - E

https://www.landcarevic.org.au/landcare-magazine/summer-2018/landscape-model-provides-water-balance-picture/

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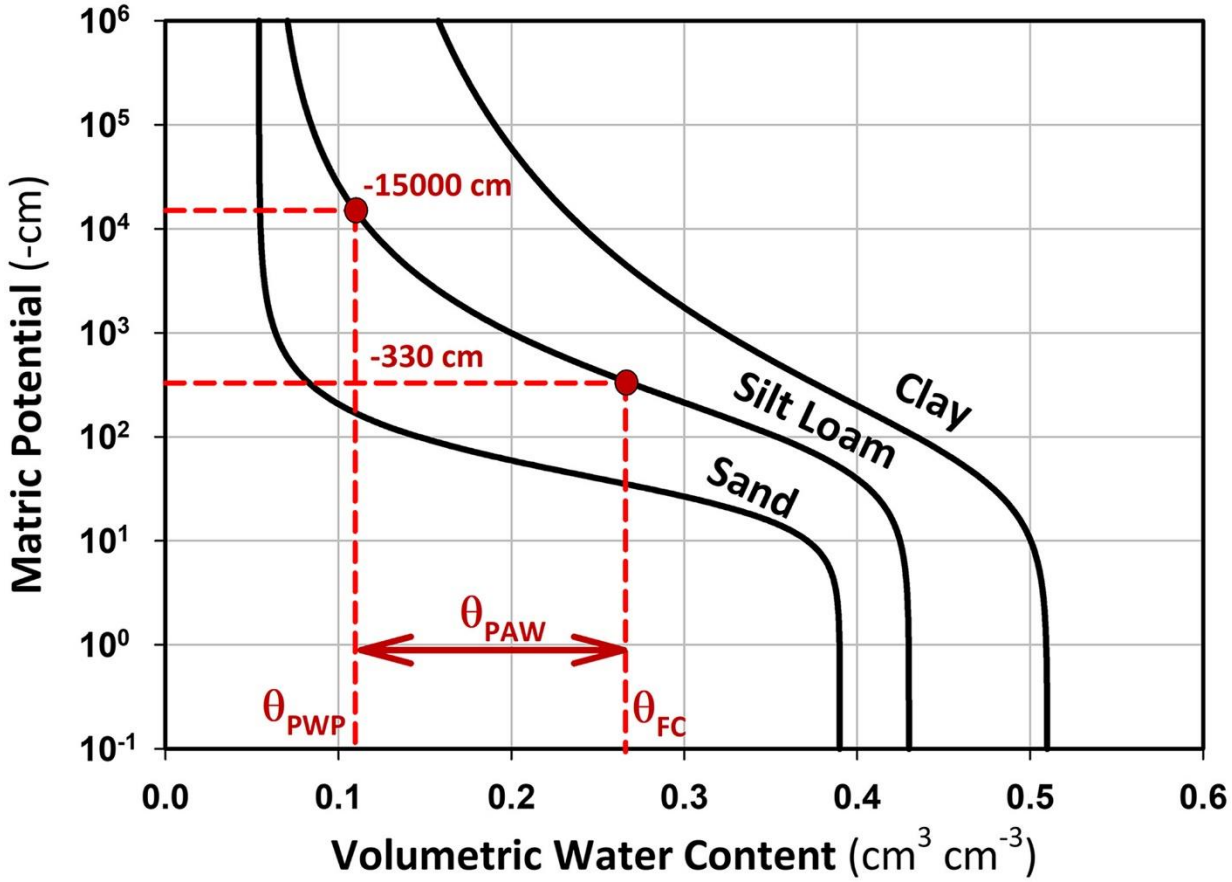
What is Soil Moisture?

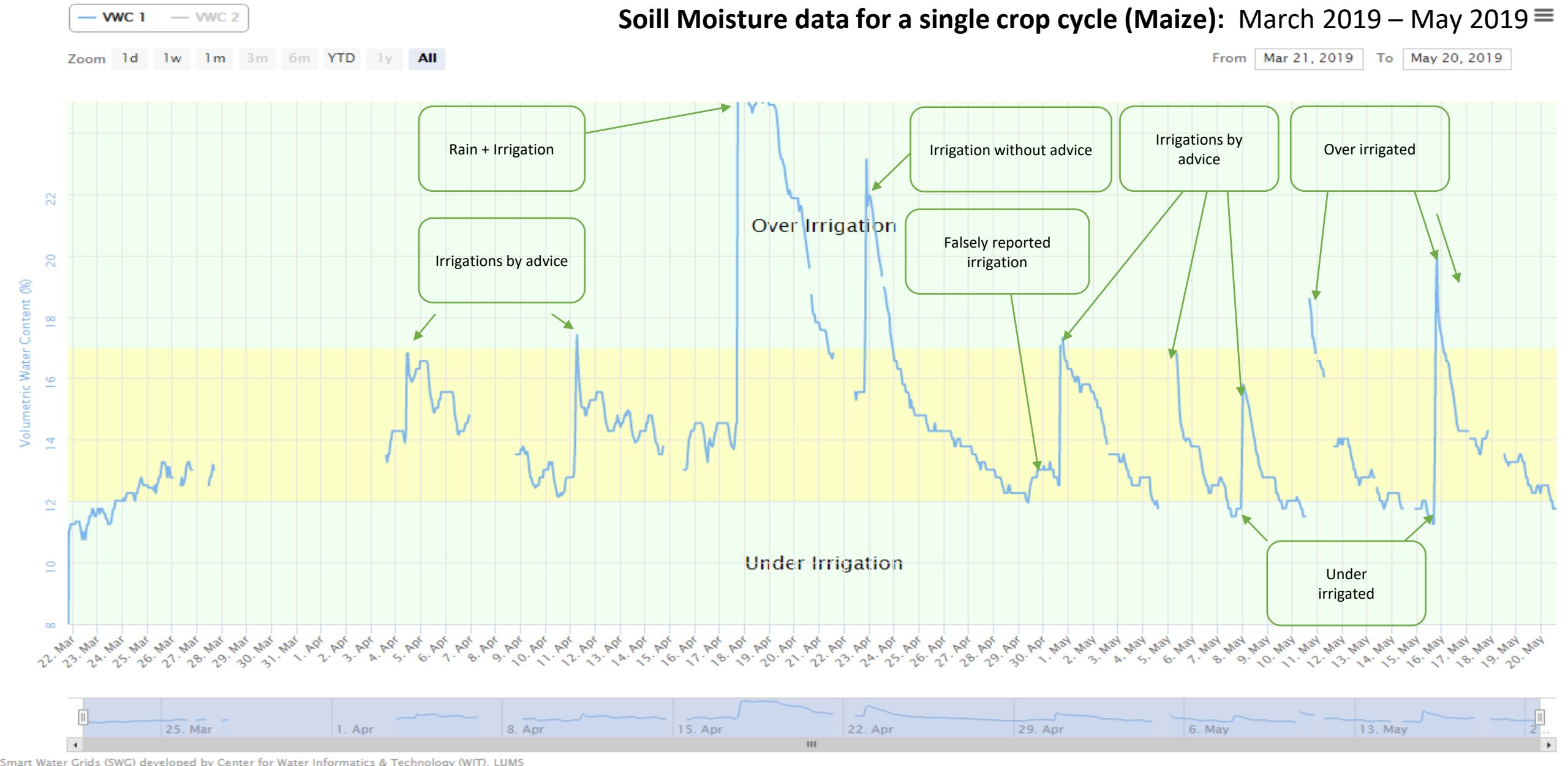
- The SM or soil water content, which may be expressed on a gravimetric, θ_m, or volumetric, θ_v, basis represents the amount of water present in the soil at a given matric potential.
- The matric potential, Ψ_m (or matric head, h), is synonymous with the combined capillary and adsorptive surface forces that hold water within the solid soil matrix and are uniquely related to SM under hydrostatic conditions.
- The highly nonlinear relationship between SM and Ψ_m is termed the soil water characteristic and exhibits a very distinctive shape for each individual soil texture



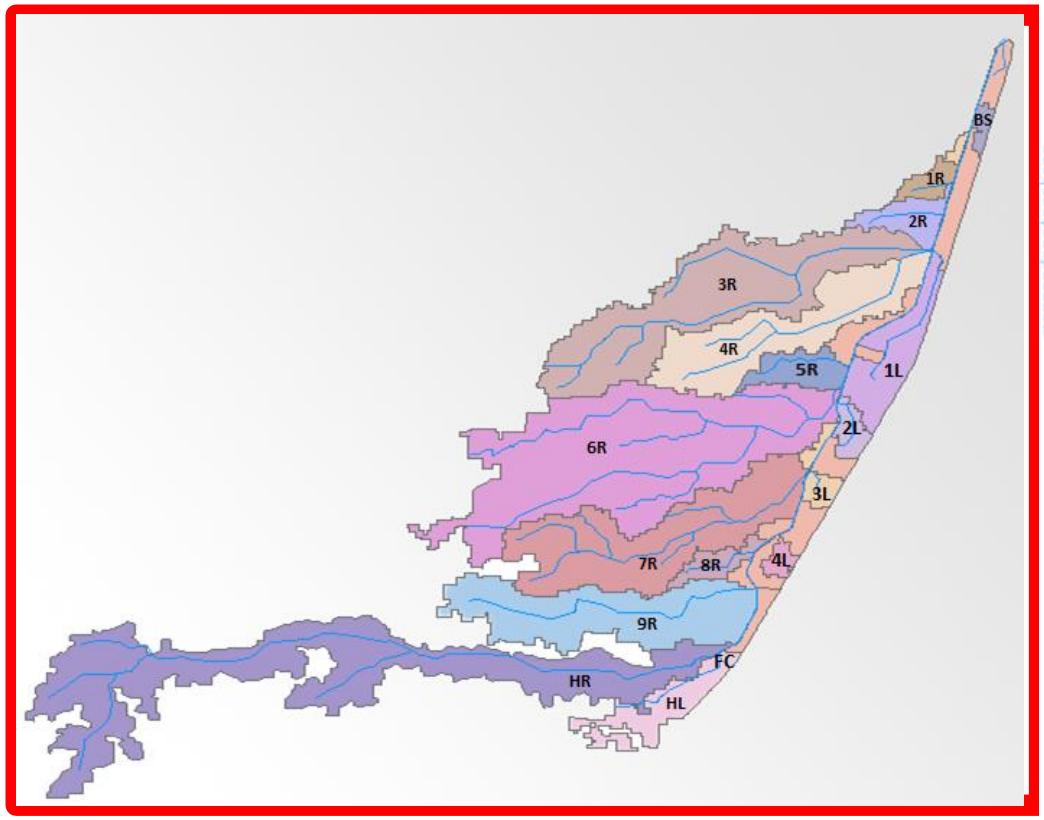
Babaeian, E., Sadeghi, M., Jones, S. B., Montzka, C., Vereecken, H., & Tuller, M. (2019). Ground, Proximal, and Satellite Remote Sensing of Soil Moisture. *Reviews of Geophysics*, *57*(2), 530-616. https://doi.org/10.1029/2018RG000618

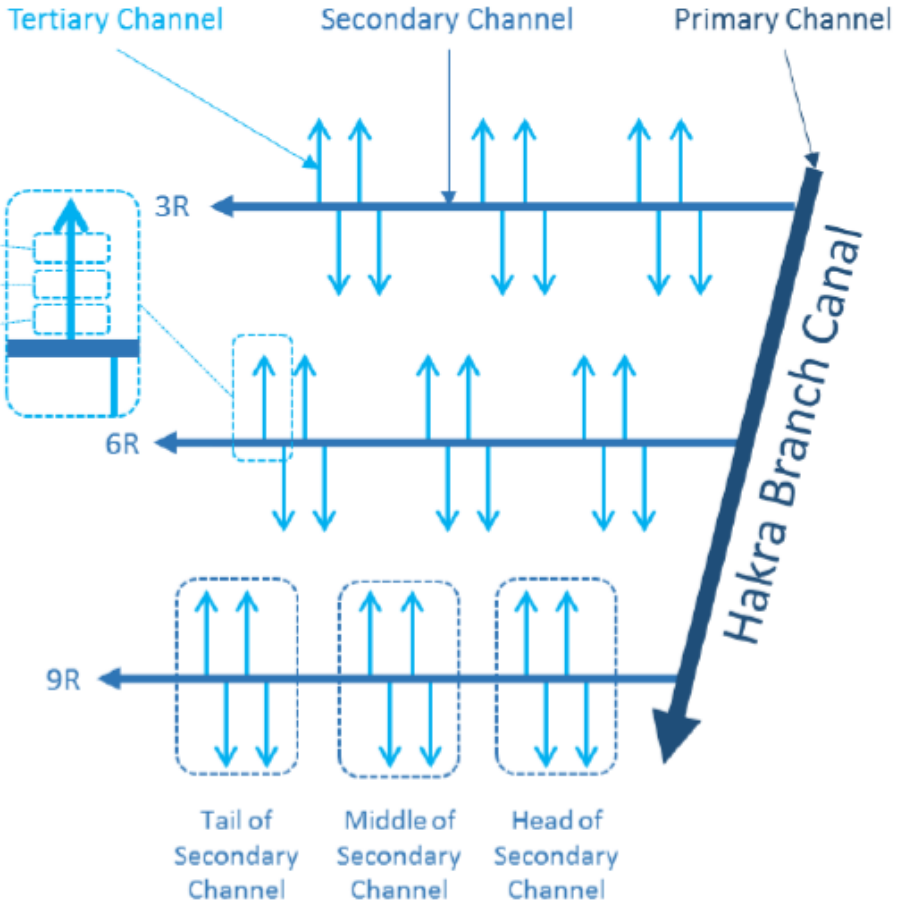
Farmer Behavior & Technology Adoption

Soill Moisture data for a single crop cycle (Maize): March 2019 – May 2019



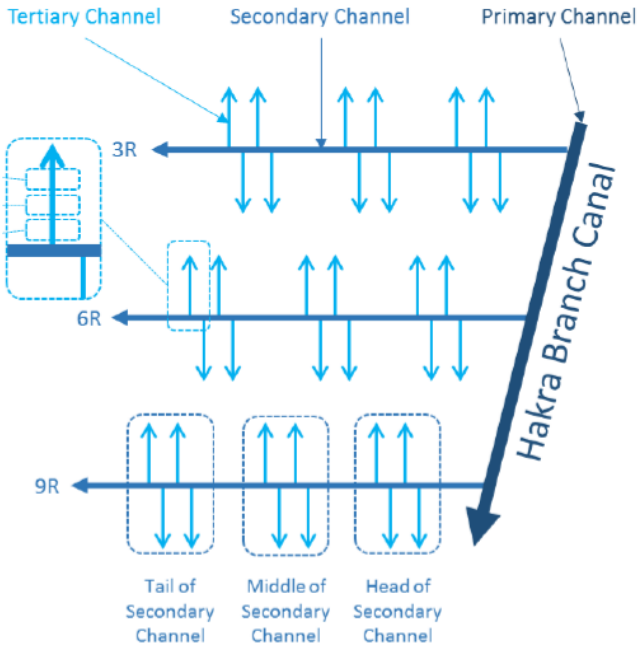
Bulk Irrigation Delivery to Farms: Canal commands





Bulk Irrigation Delivery to Farms: Canal commands

- 45 canal commands



- 43, 561Km of canals
- 18,884Km of seapage-cum-storm water drains
- 12,612Km of tiled drains

- Each canal command ~ 10-20 secondary channels (distributary)
- Each secondary channel ~ 10-20 tertiary channels (outlets)
- **107,000 outlets**
  - Proportional type (mostly)
  - Fixed type

Farmer-Farmer Interaction

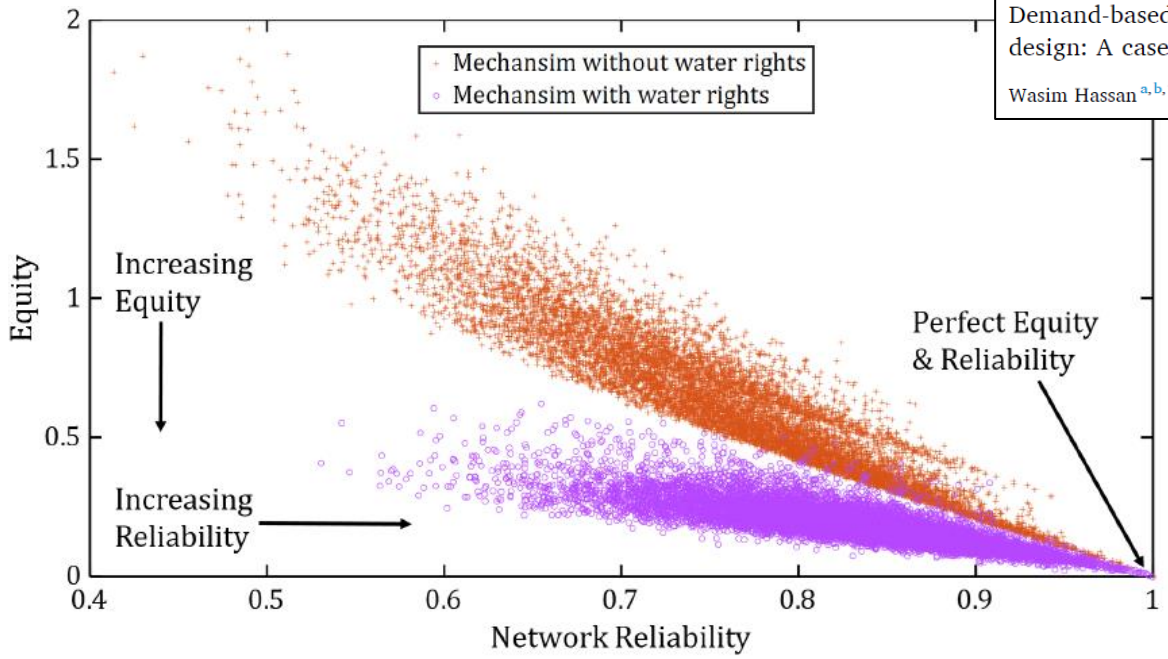
Contents lists available at ScienceDirect

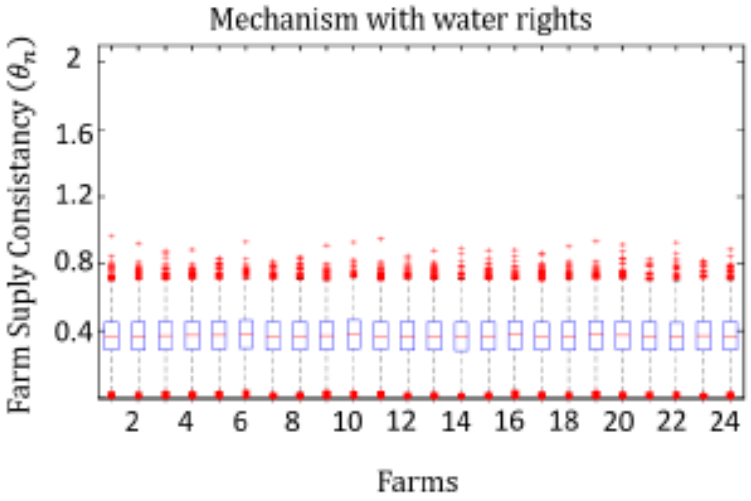
Agricultural Water Management

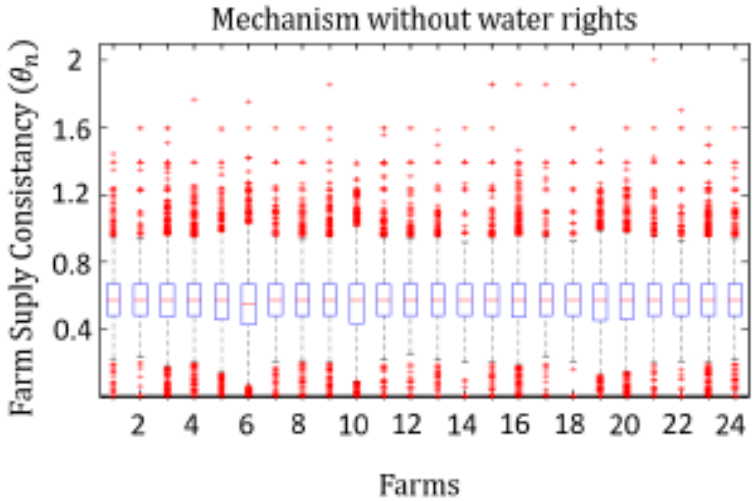
journal homepage: www.elsevier.com/locate/agwat

Demand-based water allocation in irrigation systems using mechanism design: A case study from Pakistan★

Wasim Hassan [a,b,*], Talha Manzoor [a], Hassan Jaleel [b], Abubakr Muhammad [a,b]







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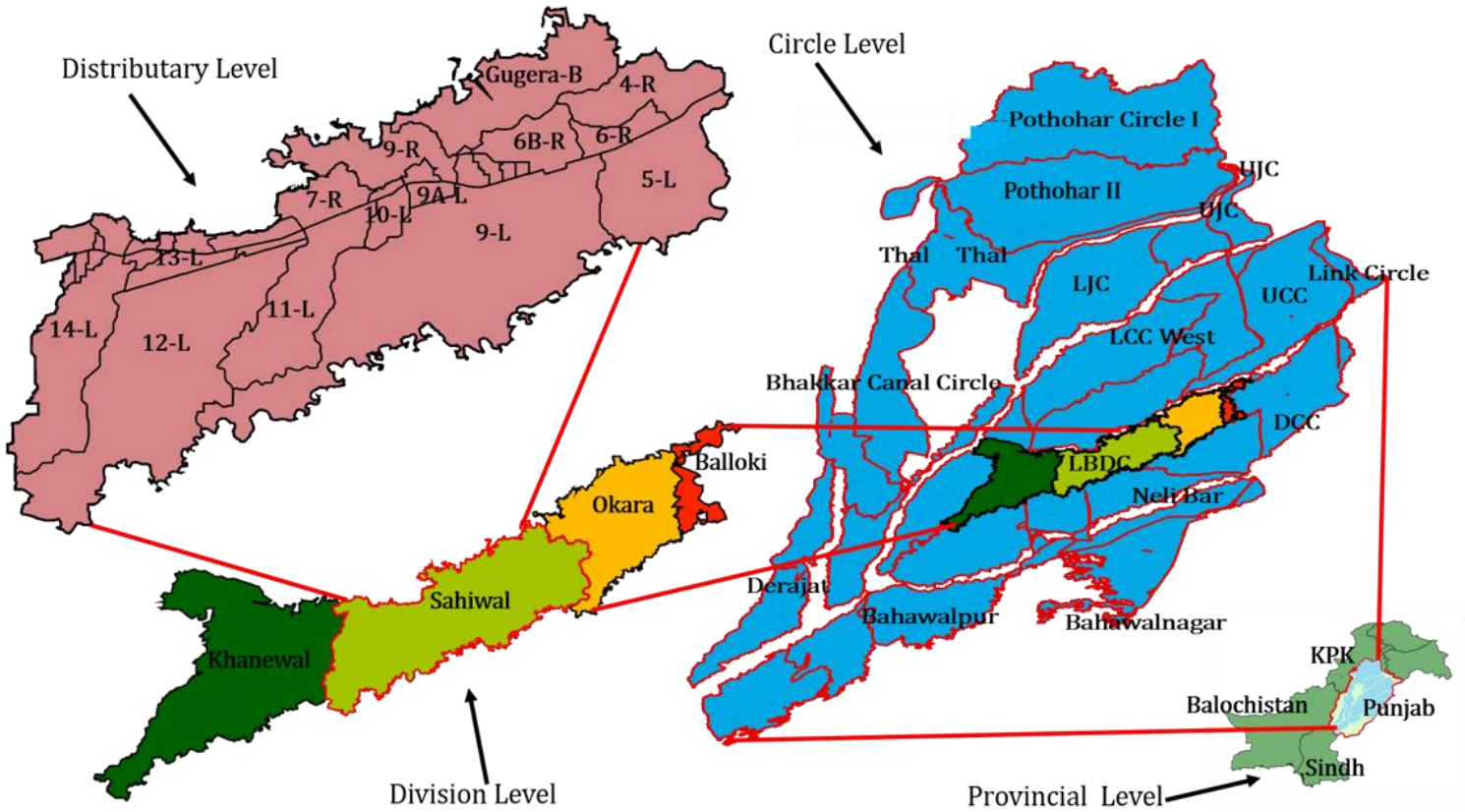
Improving Canal Irrigation Management through Remote Sensing Based Decision Support Tool

Demand management by technology driven
Water accounting Precision irrigation advisory services

Poor water management costs 4 percent of GDP or around $12 billion per year. (WB)

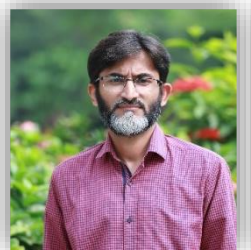
1 MAF = economic worth $1 billion

LBDC (10,000 Cusecs) ~ 7 MAF
Punjab SW ~ 56 MAF







IRRIGATION Department Punjab

ADB

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Irrigation Decision support system

Real-Time Flow Telemetry

Weather Stations

Soil Moisture Network

INPUTS

Satellite Imagery
Climatic Data
Land use Maps
Soil Properties
Canal Supply
Command Area Boundaries

PROCESSING

ET LOOK Modelling &
SEBAL Calibration

OUTPUTS

Crop Water Demand
Crop Water Consumption
Soil Moisture
Biomass
Irrigated Land etc.

IPIs

Equity
Adequacy
Reliability
Productivity

OPTIMIZATION

INDENT
RECOMMENDATION

DISEMMINATION

WEB APPLICATION TO
SUPPORT DECISION
MAKING

Soil Moisture Network

Weather Stations

Real-Time Flow Telemetry

LUMS SWG SERVER

RTFM

PID Water Information Systems

ALL

PROJECT DSS

International Soil Moisture Network (e.g. SNOTEL, TWENTE)

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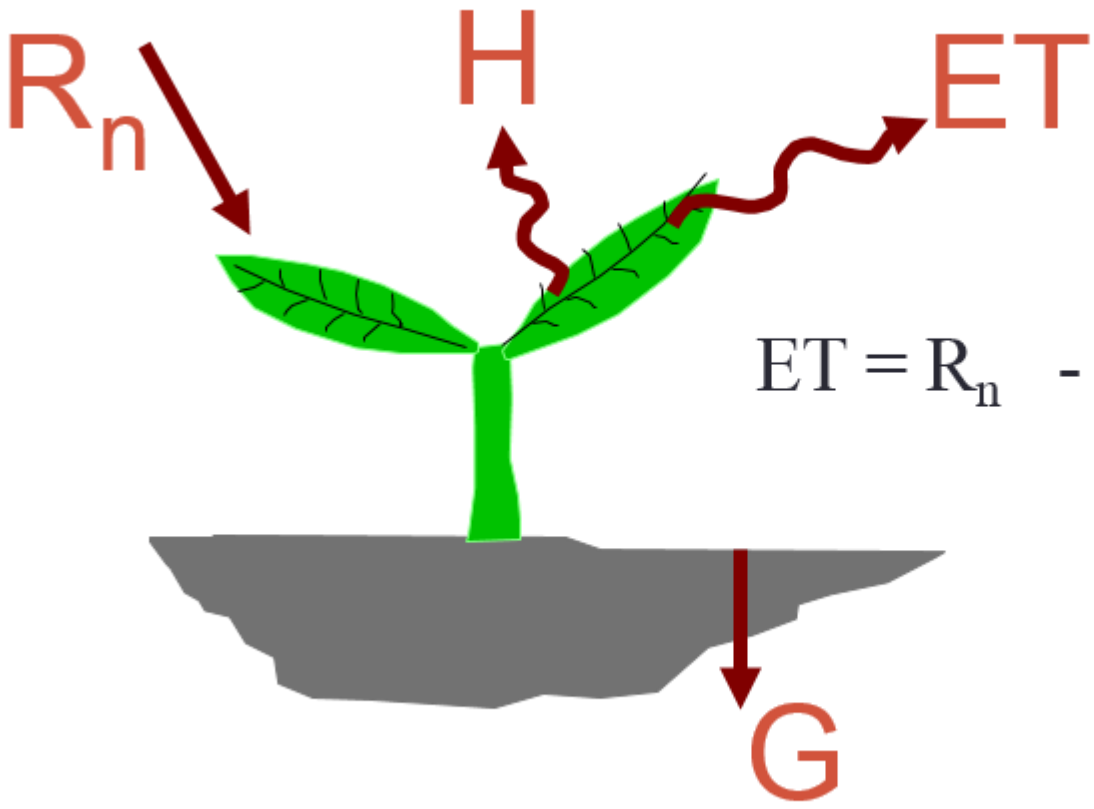
Surface Energy Balance

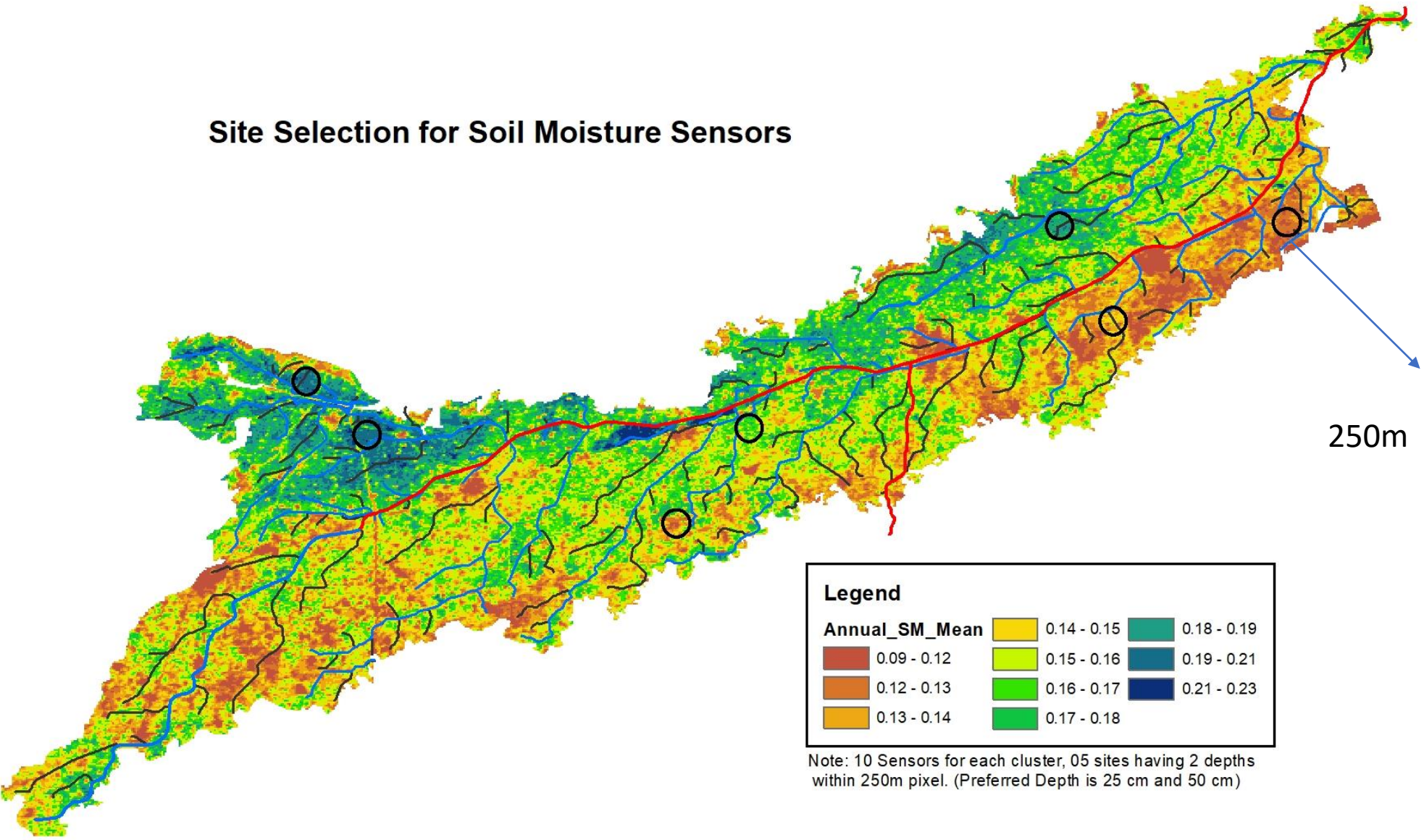


$$ET = R_n - G - H$$

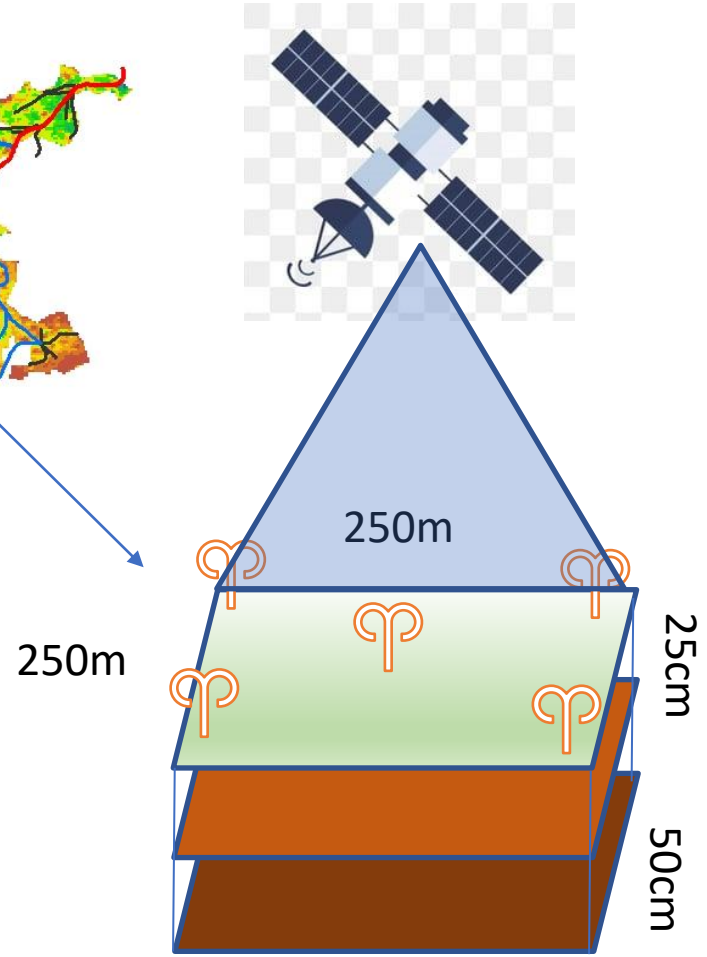
FACT: Evaporation consumes Energy.

R_n is net radiation;
H is sensible heat flux;
G is heat conduction to the ground;
ET is energy consumed by evapotranspiration.

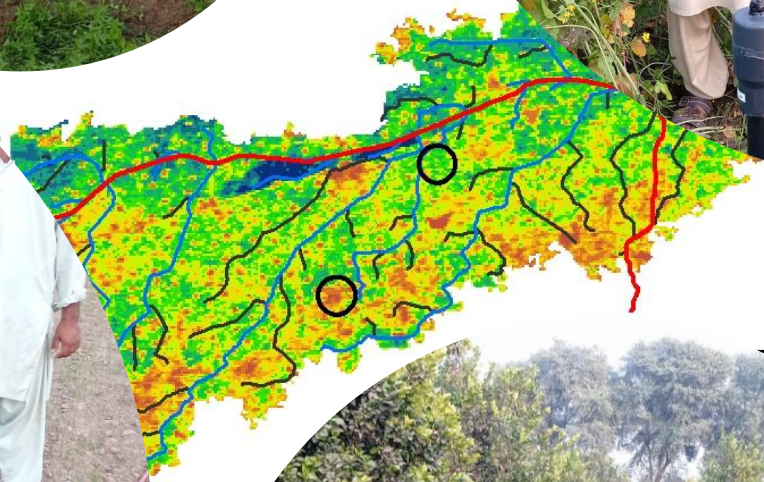
Site Selection for Soil Moisture Sensors

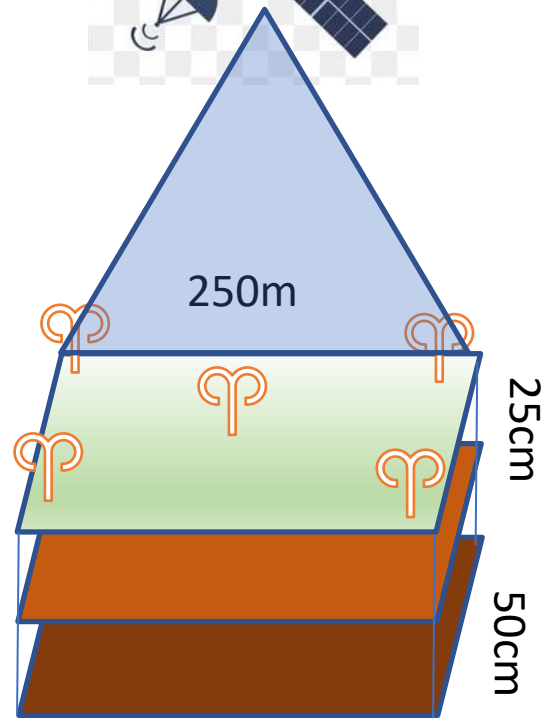


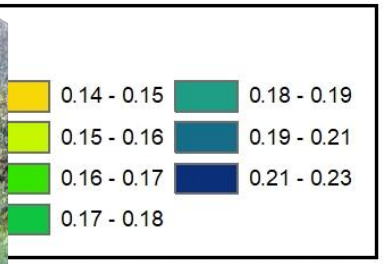
Note: 10 Sensors for each cluster, 05 sites having 2 depths within 250m pixel. (Preferred Depth is 25 cm and 50 cm)



7 clusters x **5** probes x **2** depths = **70** points
at 15 min intervals

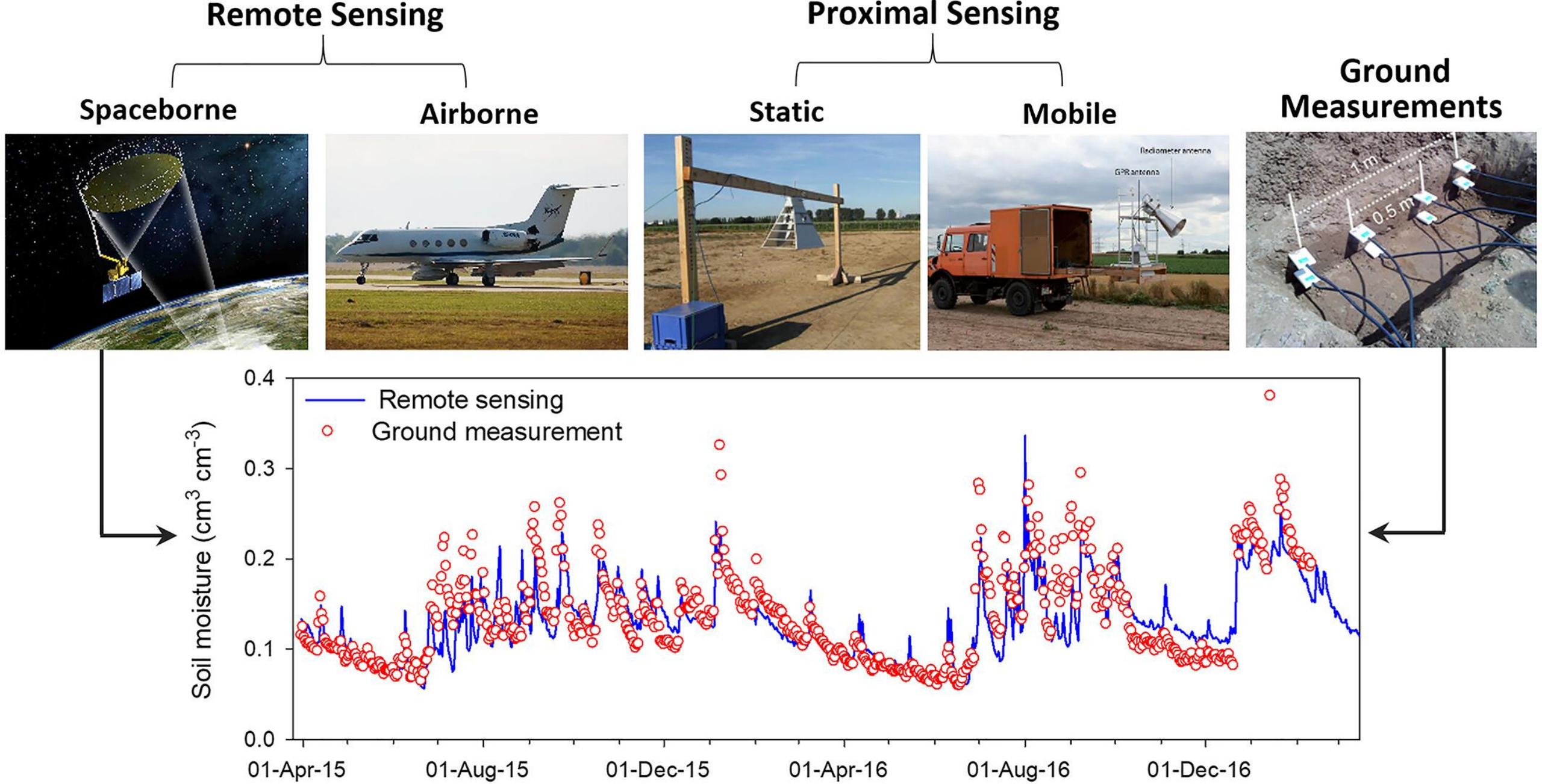






cluster, 05 sites having 2 depths
red Depth is 25 cm and 50 cm)

7 clusters x **5** probes x **2** depths = **70** points
at 15 min intervals



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Leveraging Multi-source Data Fusion to Build a Multi-scale Soil Moisture Monitoring Network in Pakistan