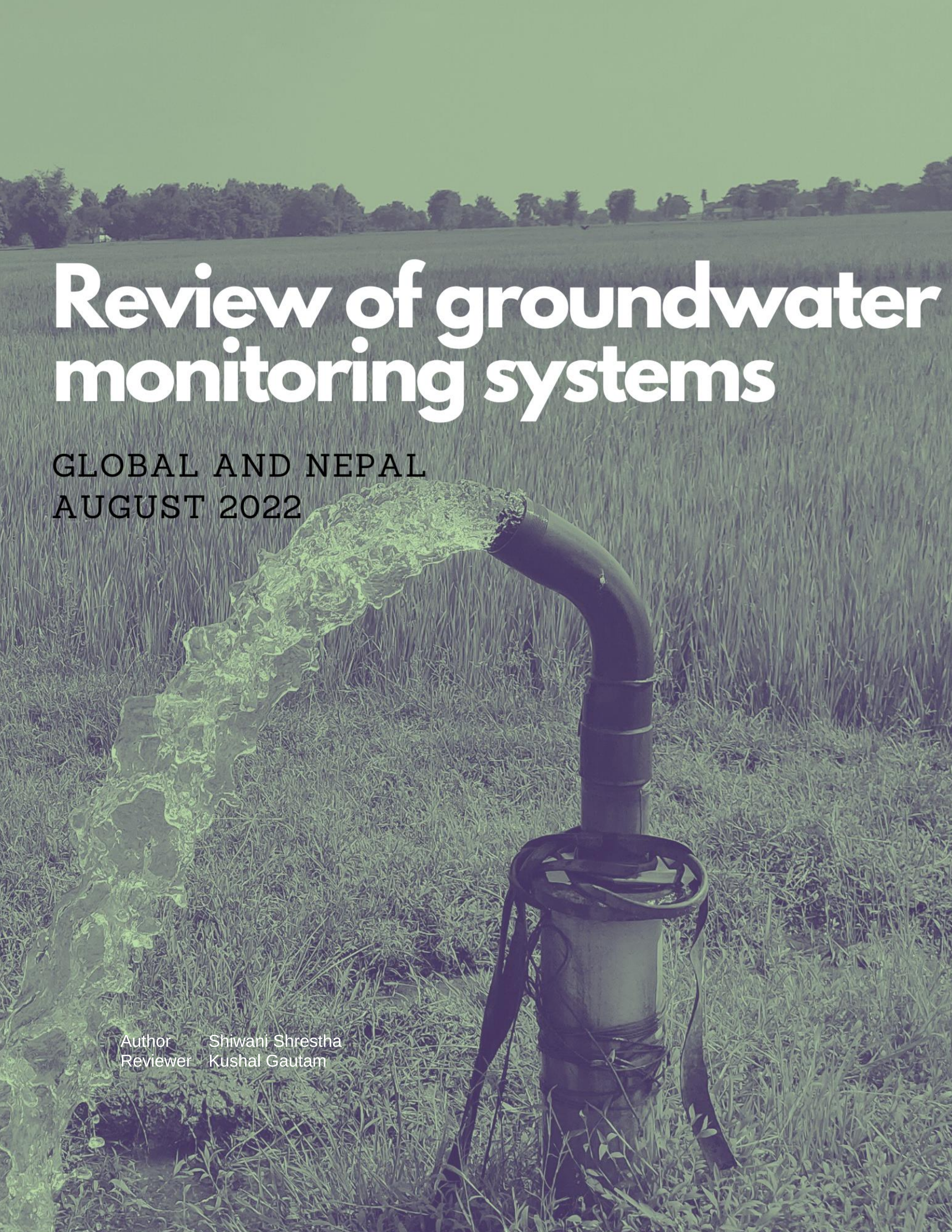

Review of groundwater monitoring systems

GLOBAL AND NEPAL
AUGUST 2022

Author Shiwani Shrestha
Reviewer Kushal Gautam

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1. Introduction

Groundwater (GW) is one of the greatest storage of water resources. However, in most cases it is inadequately understood, incompetently managed and improperly used. Groundwater monitoring is one of the vital tools that provide key information on the status of the resource and their response to natural and anthropogenic stressors like groundwater extraction, land use changes and climate change. The development of digitalized long-term monitoring data which can be presented spatially and temporally is indispensable for groundwater resource management.

Observation and measurement of groundwater levels from monitoring wells are crucial sources of information for any groundwater system (Taylor & Alley, 2002). For sustainable groundwater management, regular monitoring of groundwater levels is an essential element (Grieef & Hayashi, 2007). The aquifers' condition, their response to groundwater extraction, climate change and land use variation can only be comprehended through groundwater monitoring. Since groundwater systems are different from surface water systems, their response to external factors may vary. The distributed network of monitoring wells is a requirement for sustainable groundwater resource management (Little et al., 2016).

Objectives of this review report

- To identify organizations and institutes working on GW monitoring and management in Nepal.
- To understand the methods used for monitoring GW and how the acquired data is being utilized for sustainable planning and use of GW resources.
- To comprehend how GW monitoring and management is being conducted in the global context and what lessons can be attained from them.

In keeping with the objectives, firstly, a global scenario of GW monitoring and management is explored. Following this, the report converges on the Hindu Kush Himalayan region and finally focuses on Nepal's present state of monitoring efforts.

2. Global scenario

On a global scale, consistent data on aquifer storage, recharge, and use are extremely difficult to obtain. As a global apex body for GW, the **International Groundwater Resource Assessment Center (IGRAC)** is an organization working towards the international sharing of information and knowledge for sustainable GW development and management.

IGRAC has launched the **Global Groundwater Monitoring Network (GGMN)** project, which is set up to improve the accessibility and quality of GW monitoring information. It is a participatory program which is set to assist in refining the knowledge of groundwater resources on a global scale.

The following figure shows the snapshot of the GGMN portal showing Global GW monitoring networks and GW resources and recharge.

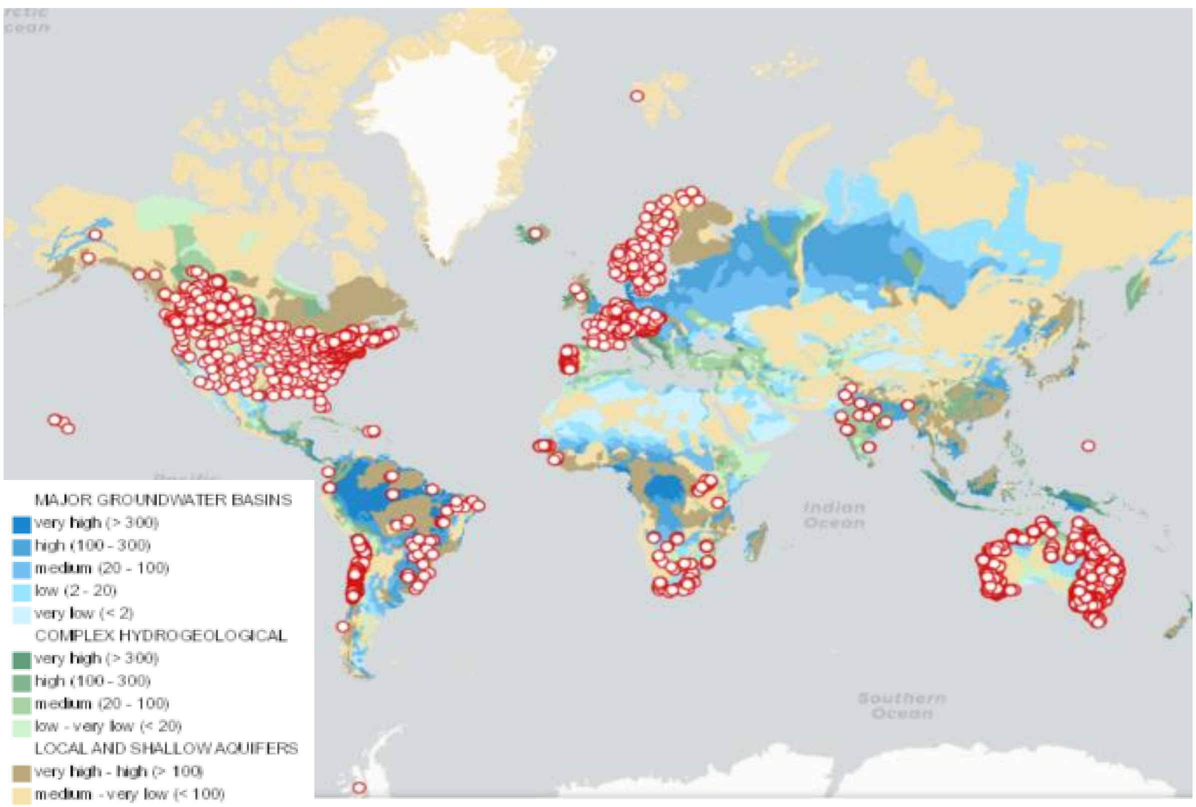


Figure 1 A snapshot of the GGMN portal showing Global GW monitoring networks and GW resources and recharge

Groundwater extraction in the global context

Despite the limits of global assessments, certain estimates do give a basic picture of the availability and usage of groundwater around the world. According to studies, groundwater makes up around one-third of the world's freshwater as well as the majority (96%) of the freshwater that is not confined in ice. It contributes significantly to the world's water use, making up around a quarter of all water withdrawals (Zektser, 2000).

According to estimates, **groundwater contributes about half of the world's current potable water supply, and between 1.5 and 2.8 billion people depend on groundwater as their major source of drinking water** (Morris et al., 2003).

Groundwater is currently one of the primary water sources in Austria, Belgium, Hungary, Germany, Denmark, Romania, Switzerland, and the former Yugoslavia, amounting to more than 70% of freshwater use. Groundwater is used by the majority of communities in Lithuania, Latvia, Estonia, Ukraine, Belorussia, Tajikistan, Armenia, and Georgia. Groundwater provides 75% of municipal water intake, supplying drinking water to more than half of the US population (Zektser et al., 2005).

Utilization has also increased for agricultural and urban purposes as surface sources have grown increasingly contaminated, and clean groundwater has served as an alternative (Morris et al., 2003).

Groundwater overdraft−global consequences

In many locations, groundwater levels have already decreased and are continuing to do so as a result of over-extraction (Konikow & Kendy, 2005). Reduced stream and wetland flow, stream-aquifer disconnection, water quality degradation due to the intrusion of salty or poor-quality surface or groundwater, reduced groundwater availability for consumptive purposes, land and aquifer subsidence, and higher pumping costs are just a few of the negative impacts of the overdraft that have been noted in several locations (Fitch et al., 2016).

Figure 2 depicts the exponentially growing trend of utilizing groundwater for agriculture worldwide.

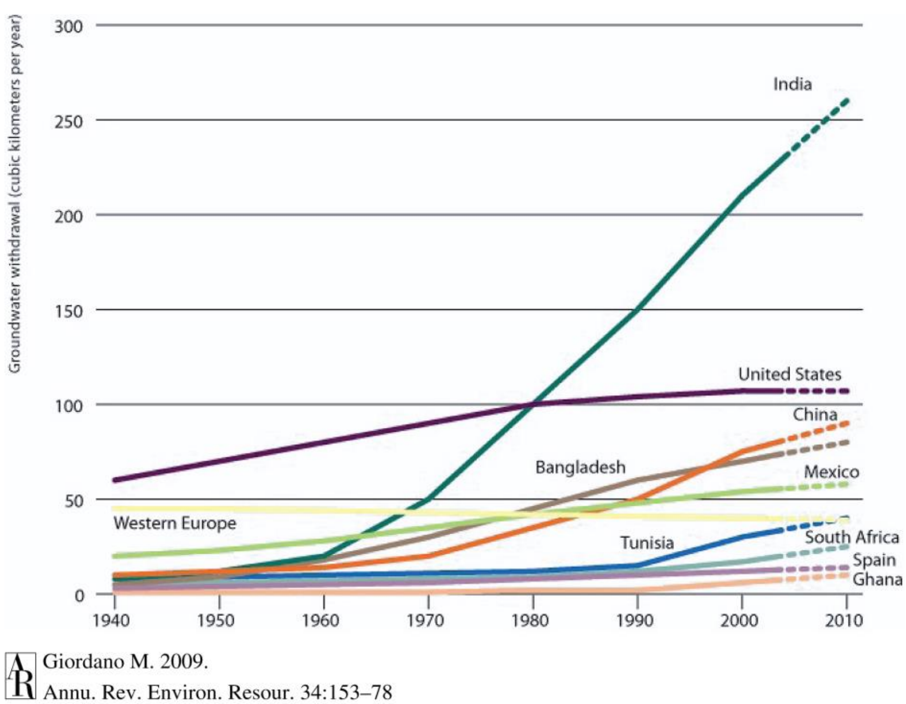


Figure 2 Trends in agriculture Groundwater use by country, in cubic kilometres per year, source: (Giordano, 2009)

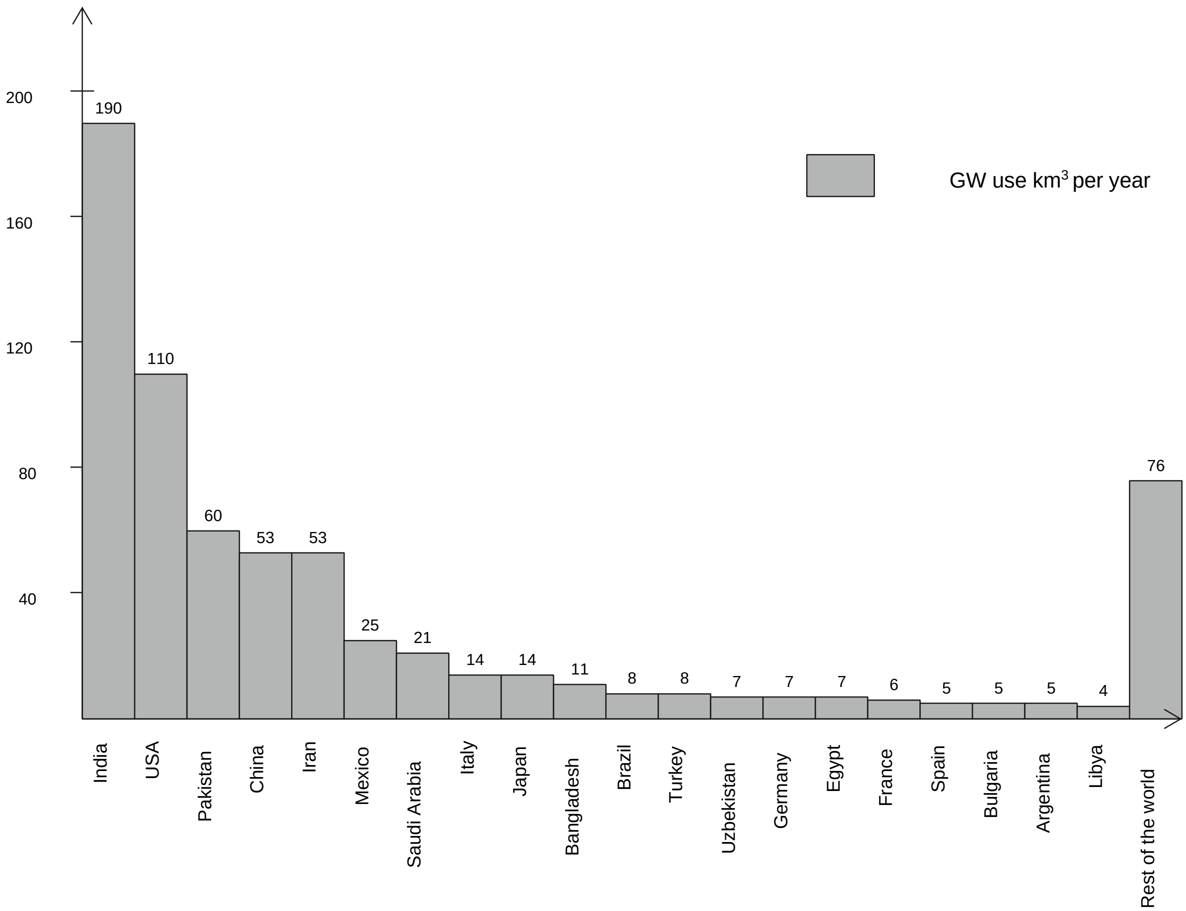


Figure 3 Groundwater use by country, in cubic kilometres per year (Adapted from Giordano, 2009)

According to Giordano, **global groundwater extraction exceeds 650 km^3 per year with India, the United States, China, Pakistan, Iran, Mexico, and Saudi Arabia accounting for 75% of total annual water extraction.** The nations that use the most groundwater are shown in Figure 3. Nearly 80% of all utilization is accounted for by the top five abstractors. Nearly 90% is accounted for by the top ten (Giordano, 2009).

Significance of GW monitoring: A case study of the United States and India

Case study: High Plains and Central Valley Aquifer, United States

One of the world's biggest freshwater groundwater systems, the **High Plains** (HP) aquifer spans eight states and more than 450,000 square kilometres (Alley & USGS, 2007). The HP aquifer is the most heavily exploited in the United States, accounting for over one-third of total groundwater extraction according to data obtained from over 3,000 monitoring wells of the High Plains Aquifer Monitoring Program. It provides drinking water to nearly 2.3 million people who live within the aquifer system's limits and proximity (Dennehy et al., 2002).

The Central Valley (CV) with a 52,000 km^2 area is second among aquifers in the United States for total groundwater withdrawals. 53% of CV is cropland with 90% of cropland and pastureland irrigated (Scanlon, Longuevergne, et al., 2012).

Cause of overdraft

- HP and CV area are renowned as the "breadbasket of the United States," which had an annual contribution of US $35 billion and $21 billion, respectively to the US $300 billion in overall agricultural production in 2007
- Groundwater is regarded as the primary economic driver for the HP area

Degree of impact

- **330 km^3** of groundwater decline from the HP based on **groundwater monitoring data** collected from **3,600 wells** between 1950 and 2007 (Scanlon, Faunt, et al., 2012)
- Degree of depletion in water level: Northern HP **Nebraska-0.3 m**, central HP **Kansas- 7 m**, southern HP **Texas-11m** and **30 m** in major regions of **Kansas and Texas**
- **GW depletion in CV:** Tulare Basin -30m (shallow unconfined aquifer), 120m (confined aquifer) (Scanlon, Longuevergne, et al., 2012).

Consequences

- Groundwater quality degradation, reduction of streamflow, lake levels,land subsidence ,seawater intrusion
- Disappearance of wetlands in Californais's Central Valley that covered 20% of the area
- **Santa Carla Valley** about 3.9m (13ft) land subsided at the begining of the 20th century

Mitigation efforts

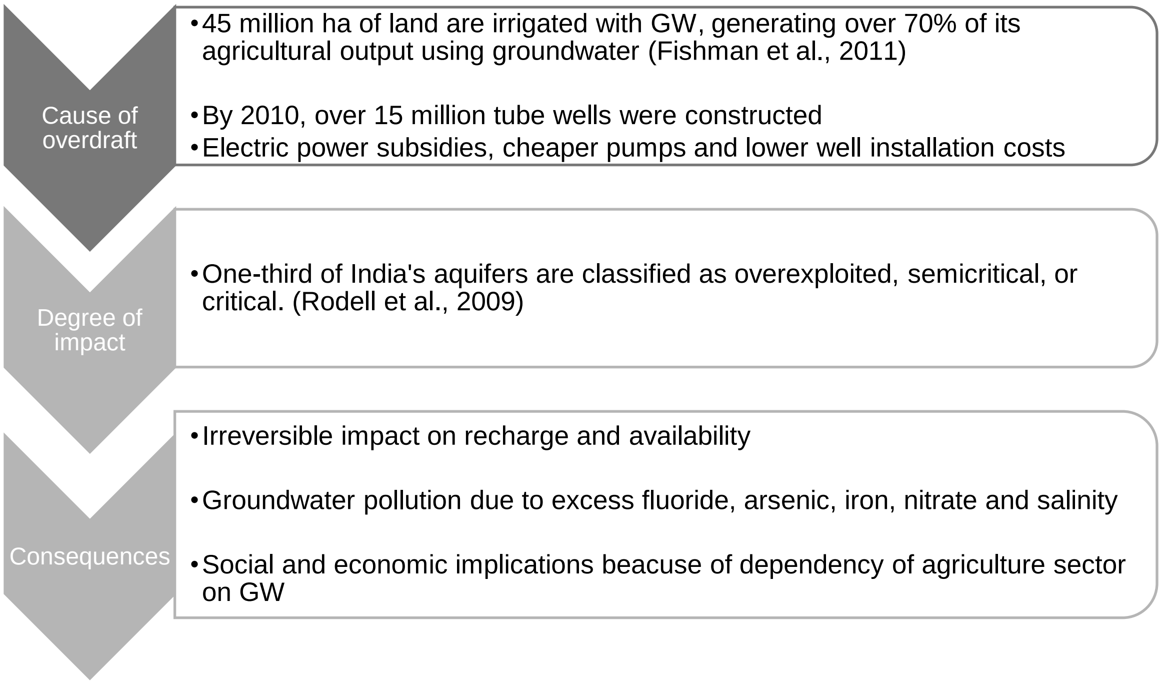
Amid drought, California state approved legislation to safeguard its aquifers in 2014. Since then, local water managers have produced sustainability plans for areas deemed most vulnerable (Stokstad, 2020). The Sustainable Groundwater Management Act (SGMA) established California's first statewide mandate for sustainable groundwater management. Several regions of the state had to utilize less water than they had in the past.

A pilot project, like the Terranova Ranch On-Farm Flood Capture and Recharge Project, started by an NGO in 2011 to disperse high-flow floods across farmland has the potential to increase the basin's average annual water supply by tens of thousands of acre-feet and has assisted in slowing the rate at which groundwater levels are declining (Babbitt et al., 2018).

Case study: Northwest India

With an estimated total yearly consumption of 230 km^3 per year or almost one-fourth of total worldwide groundwater extraction annually, **India has become the world's greatest consumer of groundwater.** India's yearly replenishable groundwater resources are estimated to be 433 km^3, with net availability of 399 km^3 (Chatterjee & Purohit, 2009). The Central Ground Water development board is the main department in charge of groundwater monitoring in India, which will be discussed in detail later in the review.

In 2002, it was projected that groundwater irrigation in India brought in $8 billion annually (World Bank, 2010). The construction of millions of irrigation wells has increased groundwater extraction in numerous Indian states during the past 50 years (Shah, 2009).



Mitigation efforts

According to a case study done by the World Bank in Punjab, measures for increasing crop-water productivity were applied in the groundwater-dependent irrigation sector of India. **The regulation was issued by the state government that delayed the transplantation of paddy rice by 35-40 days. The change didn't impact the crop yield but did assist in decreasing the groundwater overdraft by 50-65%. In addition, electricity savings amounted to 175 million kWh state-wide.** Given its effectiveness, this provision was adopted into the Punjab Preservation of Sub-Soil Water Act of 2009(Garduño et al., 2011).

Insights gained from USA and India case studies

The takeaway from the two case studies: Groundwater depletion has the potential to seriously disrupt society and ecological processes since it is a valuable resource for agriculture, ecosystem services, and domestic consumption. Groundwater supply is becoming increasingly important, but classification and measurement issues make management challenging. However, **improvements in data collection, analysis, and dissemination at regional to continental dimensions offer some promise for better planning, which may eventually result in sustainable and responsible management.**

Monitoring systems in Europe

According to an overview published by IGRAC, **Europe & Caucasus region** has the most GW monitoring networks per region as well as the countries that process the monitoring data (IGRAC, 2020). The purpose of monitoring is to establish the natural variability of water levels so that the drawdown caused by excessive pumping can be detected (Grieef & Hayashi, 2007).

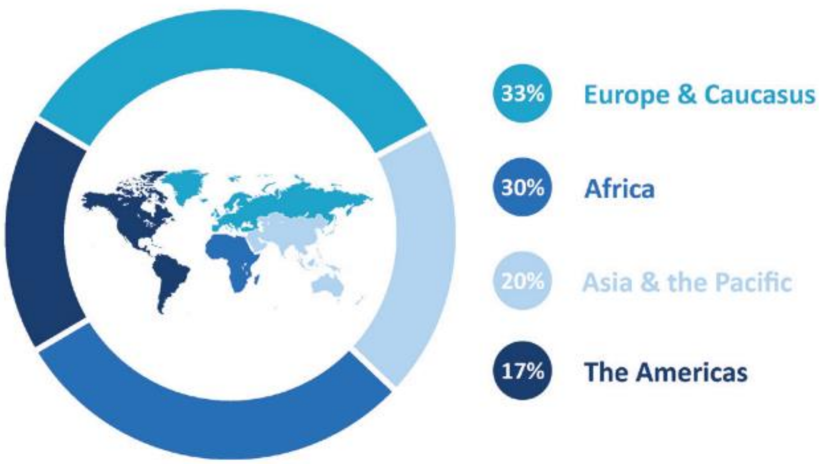
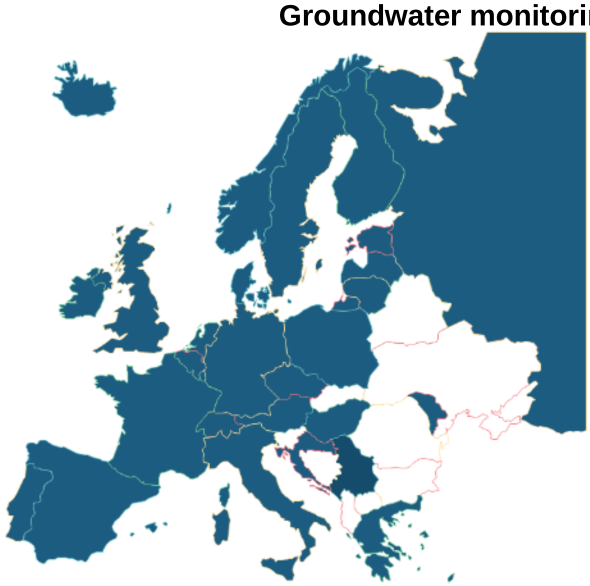


Figure 4 National monitoring network per region (in %), source: IGRAC,2020

In the context of Europe, **Water Framework Directive (WFD)** acted as the main building block for community action in the water policy field. Strict monitoring of all the water-types surface, ground and coastal was implemented for precise quality and quantity assessment (Winckel et al., 2022).

Groundwater monitoring snapshot of Europe



- **Monitoring networks density**: *0.004 sites/km² to 7.3 /km²*
- **Frequency of measurement**: *Variation from weekly to two times a year*
- **Quantitative variables observed:**
  - *Groundwater level*
  - *Temperature*
  - *Spring level*
  - *Spring Discharge*
- **Method of data collection:** *Both automated and manual*

Figure 5 GW monitoring in Europe

Groundwater quantitative monitoring has been conducted in Europe for a long time with the **oldest networks being in operation since 1845**, and most of the other networks from the 20th century. The monitoring networks comprise various types of observation points such as **bored and dug wells**, which are mostly used but also driven wells and spring wells (Koreimann et al., 1996).

Most countries have groundwater information available publicly through a web-based GIS portal.

In Northern and Central Europe, the principal use of groundwater is for public drinking supplies, whereas, agriculture is predominately dependent on rainfall. However, **in Southern European countries groundwater use is chiefly used for agriculture** (Ribeiro & Cunha Da, 2010).

Table 1 Main countries in Europe those dependent on GW for Agriculture (Ribeiro & Cunha Da, 2010)

Countries	Percentage of groundwater use in Agriculture
France	17
Greece	86
Italy	57
Portugal	88.5
Spain	75

Given that predominantly Southern European countries use groundwater mostly for irrigation, a comprehensive view of France and Portugal's monitoring systems is considered for review as they reflect the minimum and maximum use of GW for agriculture.

France

In France, The Ministry of the Ecological and Inclusive Transition (MTES) is in charge of water management and implements the WFD. National Quantitative Monitoring Network for Groundwater (RNESP) monitors the number of aquifers of national interest.
The National Portal for Access to Groundwater Data (ADES), is the national database of public quantitative and qualitative groundwater data for metropolitan France and overseas departments. It is maintained by the French Geological Survey (BRGM) and is the product of the Water Information System (SIE).
Through ADES portal online metadata and data of groundwater level monitoring stations can be accessed and visualized.

Groundwater monitoring snapshot of France

- **No of Monitoring stations: 1,843**
- **No of monitoring points: 14,815**
- **Monitoring point density:**
  - One every 500 km^2 in unconfined aquifers
  - One every 1,000 km^2 *(small confined aquifers < 1000 km^2)*
  - One every 3,000 km^2 *(large confined aquifers > 1000 km^2)*
  - One every 7,000 km^2 in deep

Figure 6 GW monitoring snapshot of France

GW information dissemination: Every month, BRGM releases press materials about the state of groundwater levels in France, including a groundwater trend map. The papers provide information on the changes in groundwater levels and anticipated trends.

Indicators that depict the typical variations in the water levels over the preceding two months are displayed on the map (stable –square, levels go up –triangle or levels go down -inverted triangle). The colours depict how much the present values deviate from the historical mean.

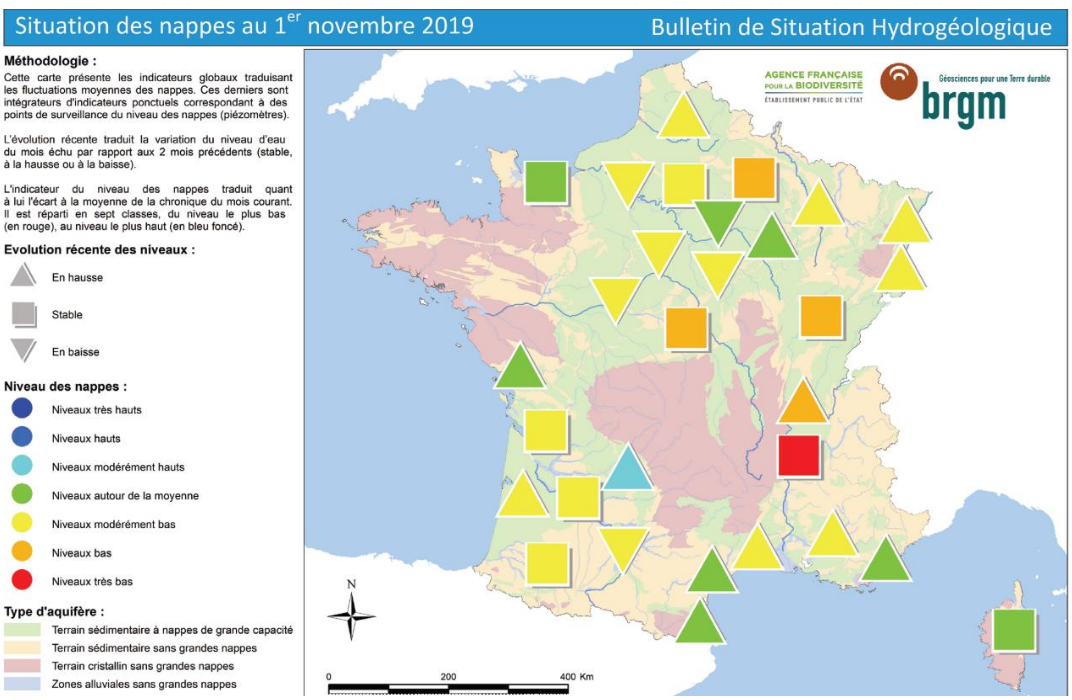


Figure 7 State of groundwater in France in November 2019. Source: BRGM

Portugal

The Portuguese Environmental Agency (APA) is in charge of the National Groundwater Monitoring Network of Portugal.

Groundwater monitoring snapshot of Portugal

- **No of monitoring points: 22,639**
- **Monitoring Frequency: Monthly and daily**

  *Daily in piezometers with sensors**

Figure 8 Snapshot of GW monitoring points of Portugal Source (SNIRH)

GW information dissemination: Every month from the start of the measurements to the conclusion of the preceding hydrological year, the average groundwater level and the 20%-percentile are determined for each well. When compared to prior statistics, the value from the studied month is classified into three categories: above average, between average and the 20% percentile, and below the 20% percentile. Values that fall under the 20% percentile are regarded as being "extremely low." A groundwater body is finally categorized by the class that occurs most frequently (Figure 8).

If two classes have an equal number of occurrences, the classification uses the precautionary principle to evaluate the worst-case situation. Using this concept, a piezometric level map for Portugal is created. In 44 groundwater bodies, piezometric levels were measured at 232 locations in October 2019 (Figure 9).

Every month, all of the individual ground-water bodies are subjected to this examination, which includes a graph showing the hydrological year's monthly progression.

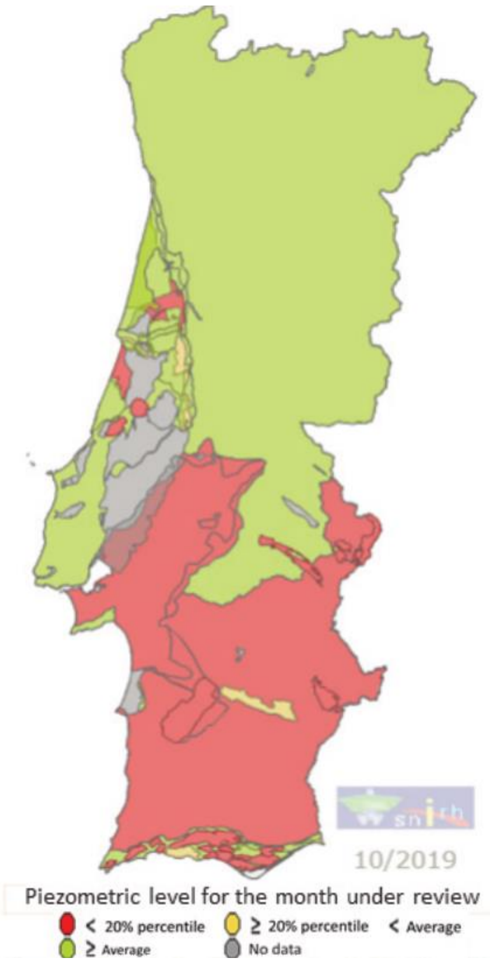


Figure 9 State of groundwater levels in Portugal for October 2019. Source: SNIRH, monthly bulletin

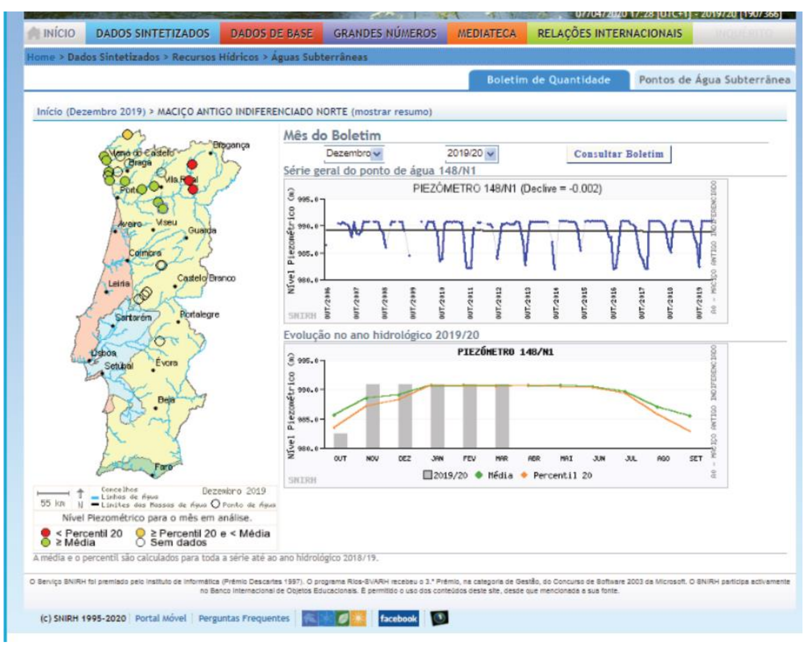


Figure 10 Groundwater level analyses for selected monitoring point. Source: SNIRH, monthly bulletin

3. The Hindu Kush Himalayan Region

The **Hindu Kush Himalayan (HKH) Region** is home to four biodiversity hotspots as well as a climate hot spot. Since Nepal lies within this region and shares close borders with these countries as well as transboundary aquifers, an overview of the GW monitoring systems of these countries is important.

The Hindu Kush Himalayan Region

Countries

- Afghanistan
- Pakistan
- India
- Nepal
- Bhutan
- Bangladesh
- China
- Myanmar

Figure 11 Countries in the Hindu Kush Himalayan region

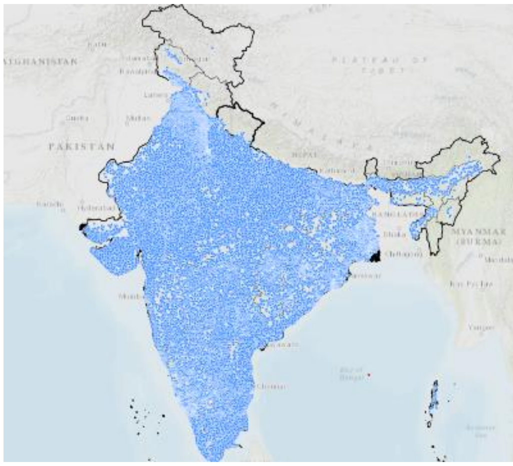
India

In India many of the states and Union territories (UT) have their groundwater departments and groundwater monitoring mechanisms and coordinate at the country level with the **Central Ground Water Board (CGWB)** under the Department of Water Resources, River Development and Ganga Rejuvenation, **Ministry of Jal Shakti which is the apex organization dealing with monitoring, assessment and management of groundwater resources.**

International Water Management Institute (IWMI)

IWMI has been working in water and agriculture-related research in India for two decades, with the main goal being to improve agriculture with proper water use and management. One of the key programs in groundwater management in India is the IWMI-TATA Water Policy project which identified 112 irrigation-deprived districts with potential for groundwater and small-scale irrigation development.

Groundwater monitoring snapshot of India



- **Field offices:** 29 (Headquarter: Faridabad & Haryana)
- **Monitoring stations:** 23,000 with reliable data (total 87,183 wells)
  - Dug wells: 16,500
  - Piezometers: 6,500
- **Methods of measurement:** Manual and few automatic
- **Measurement frequency:** Four times a year *(dry & wet season)*

Figure 12 Snapshot of India-WIRS showing monitoring points

The custom-made software **Ground Water Estimation and Management System** (GEMS) is used for storage, retrieval and analysis of all kinds of groundwater-related data collected. **India Water Resource Information System (India-WRIS)**, is a web-based information system which provides a GIS-based interface for visualization and analysis of water level data (Sishodia et al., 2016).

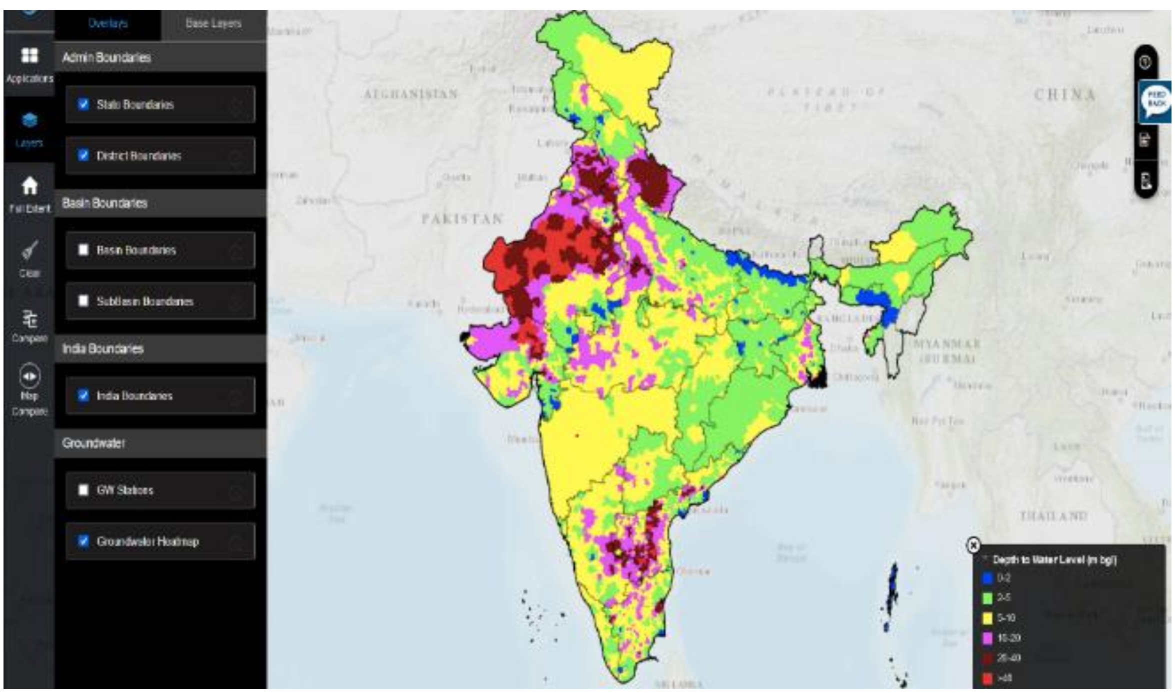
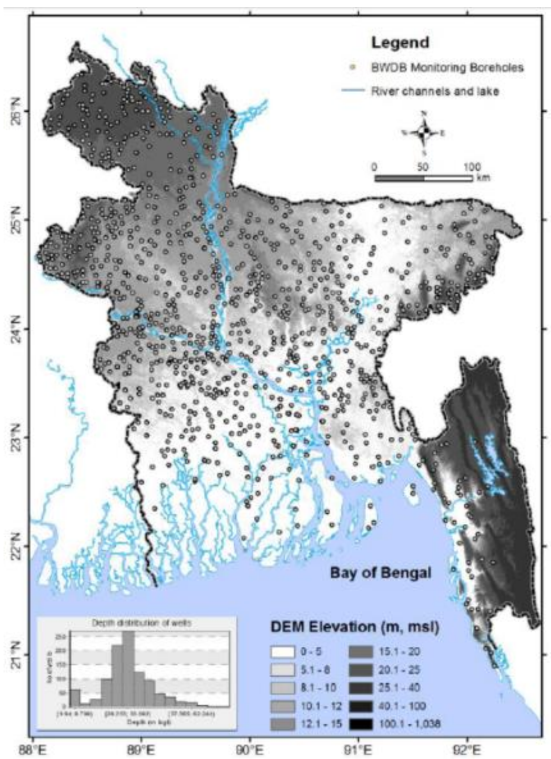


Figure 13 Output of India-WRIS showing spatial variation in depth to water level (post-monsoon)

Bangladesh

Ground-water-level monitoring networks have been set up by several institutions in Bangladesh, including the Bangladesh Agricultural Development Corporation, the Department of Public Health Engineering, and the Bangladesh Water Development Board (BWDB) (BADC). The **Barind Multipurpose Authority (BMDA)** is a governmental organization that is also in charge of gathering and monitoring groundwater data. Among these, BWDB is the principal agency responsible for carrying out water-related development projects in Bangladesh and monitoring surface and groundwater resources. Figure 14 shows the characteristics of GW networks in Bangladesh.

Groundwater monitoring snapshot of Bangladesh



Organizations involved:

- Bangladesh Water Development Board (BWDB)
- Department of Public Health Engineering (DPHE)
- Bangladesh Agricultural Development Corporation (BADC)
- Barind Multipurpose Development Authority *(BMDA)*

BWDB

- National Scale monitoring of shallow aquifres
- No of monitoring points: 1,250
- Monitoring point density: 120/km^2
- Monitoring frequency: Weekly

DPHE

- No of monitoring points: 4,500
- Monitoring frequency: Once per year during dry season

BADC

- No. of monitoring points: 3,000
- Ground water zoning map *(not available online)*

BMDA

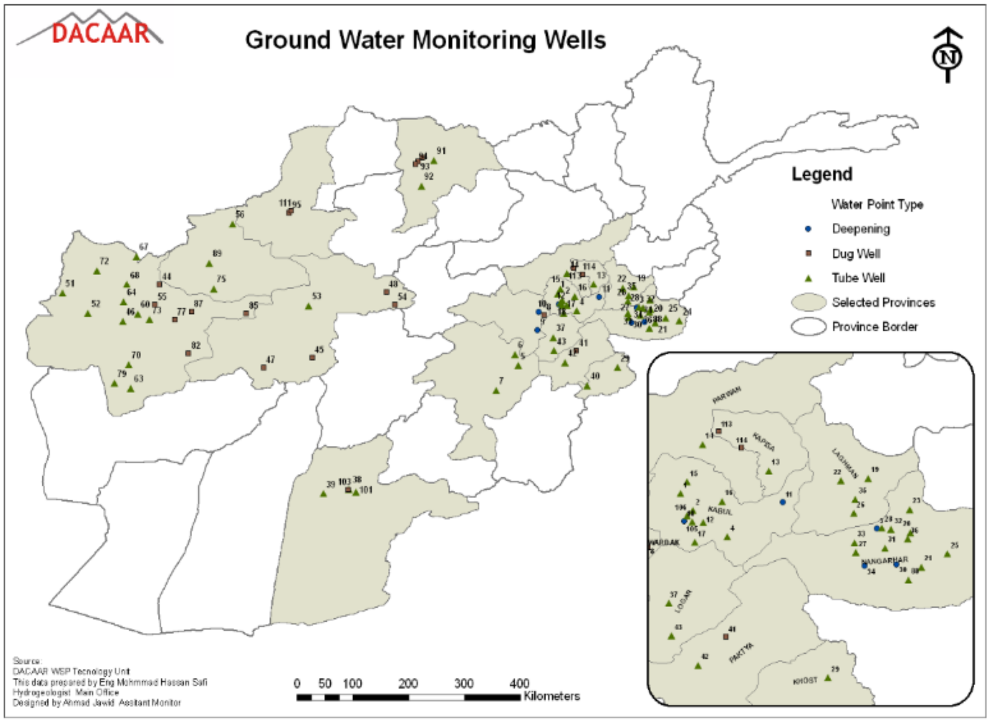
- No. of monitoring points: 1,400 deep tube wells
- For irrigation and monitoring Water levels

Figure 14 Distribution of BWBD GW monitoring points (Shamsudduha, 2013)

Afghanistan

The **Hydrogeology Department of the Ministry of Energy and Water** (MEW) is the main department responsible for the management and monitoring of GW. Other institutions engaged in GW monitoring are The Danish Committee for Aid to Afghan Refugees (DACAAR) and Afghanistan Geological Survey (AGS)

Groundwater monitoring snapshot of Afghanistan



DACAAR:

Focus on quality and quantity

- Collecting data since 2003 from 29 provinces
- No. of monitoring wells: 363
- Method of measurement: Manual
- Frequency of measurement: Monthly

AGS

Focus on assessment of seasonal, areal, and potentially climatic variations in the Kabul Basin

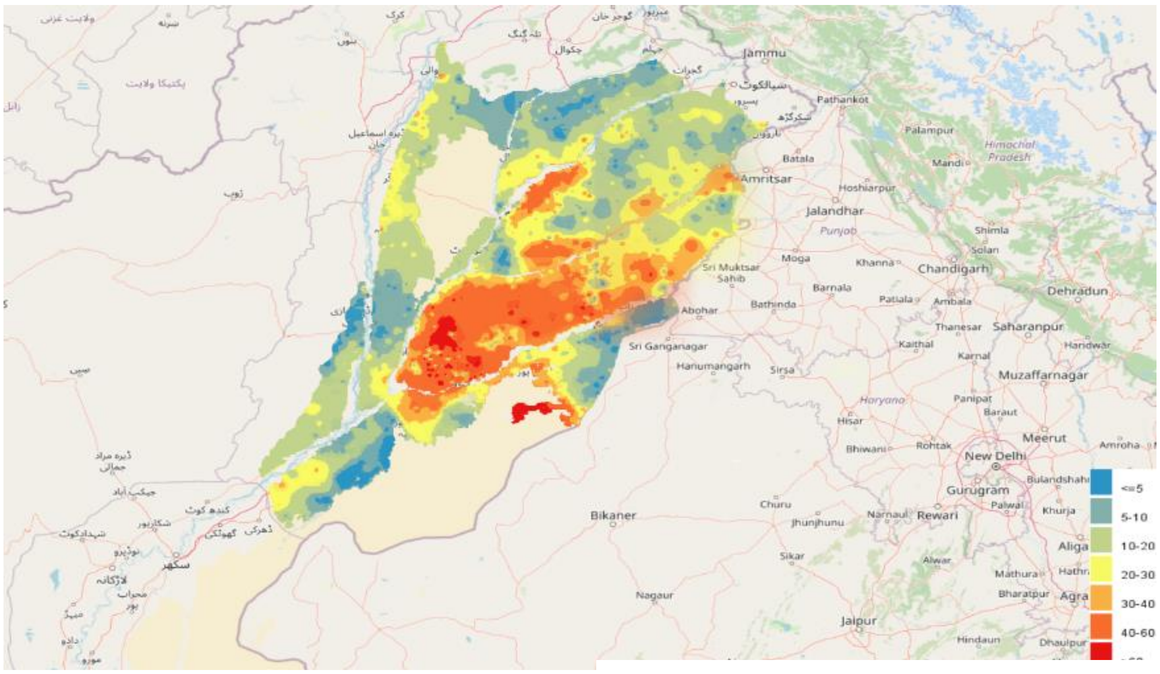
- No of monitoring wells: 71
- Method of measurement: Manual
- Frequency of measurement: Monthly

Figure 15 Map showing monitoring wells in Afghanistan, source Campbell, 2015

Pakistan

The **Ministry of Water Resources** is the main department responsible for overseeing the water sector. Other institutions engaged in GW monitoring are the Water and Sanitation Agency (WASA), the Pakistan Council of Research in Water Resources (PCRWR), Geological Survey of Pakistan, Scarp Monitoring Organization (SMO) and the Punjab Irrigation Department-Directorate of Land Reclamation (DLR).

Groundwater monitoring snapshot of Pakistan



Punjab Irrigation department

Interactive map on website, however no time series of data available

No of monitoring wells: 3,000

Method of measurement: Manual with piezometers

Measurement frequency: Biannual

SMO: In Indus Basin Irrigation System

- Hydrological monitoring
- Measurement characteristics: depth to water table and water quality *(data unavailable)*
- Measurement frequency: Biannual
- No of observation wells: 9000 Punjab, 3000 Sindh

WASA: GW monitoring in several municipalities mostly urban centers

PCRWR: working on the observation of water table depth

Geological Survey of Pakistan: Ground water resource exploration

Figure 16 Snapshot of an interactive map on GW monitoring in Punjab

4. Nepal

Government bodies active in groundwater management and monitoring in Nepal

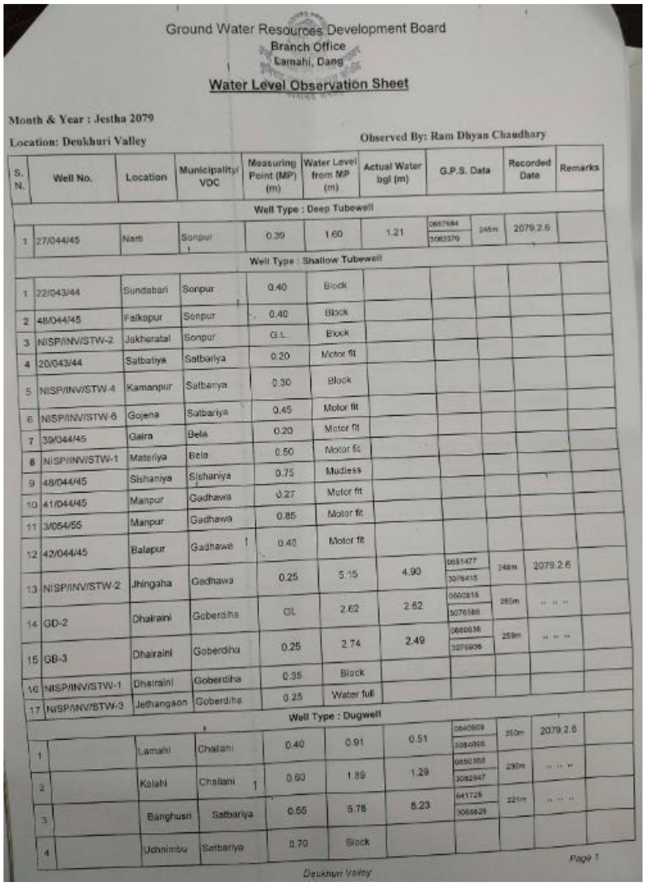
Groundwater Research Development Board (GWRDB)

GWRDB is under the Ministry of Energy, Water Resources and Irrigation. It is one of the main institutes working on groundwater investigation and exploration In Nepal. It conducts several programs such as:

- Projects related to **deep and shallow tube well irrigation.**
- **Groundwater investigation** program: qualitative as well as quantitative monitoring of groundwater resources for irrigation purposes.
- **Expansion of irrigation** project for proper utilization of available resources.

Field offices under GWRDB are located in **Biratnagar, Lahan, Mahottari, Birganj, Butwal, Dang, Nepalganj and Dhangadhi.**

According to the information on the GRDWB website, each of the branch offices per district employs **one data collector** who measures the groundwater level of **20 investigation wells per district** monthly. **The measurements are recorded manually and transcribed into an excel worksheet that is stored with the GWRDB in hard copy. There are a total of 657 investigation wells across Nepal mostly concentrated in the Terai region.**



Ground Water Resources Development Board
Branch Office
Lamahi, Dang

Water Level Observation Sheet

Month & Year : Jestha 2079

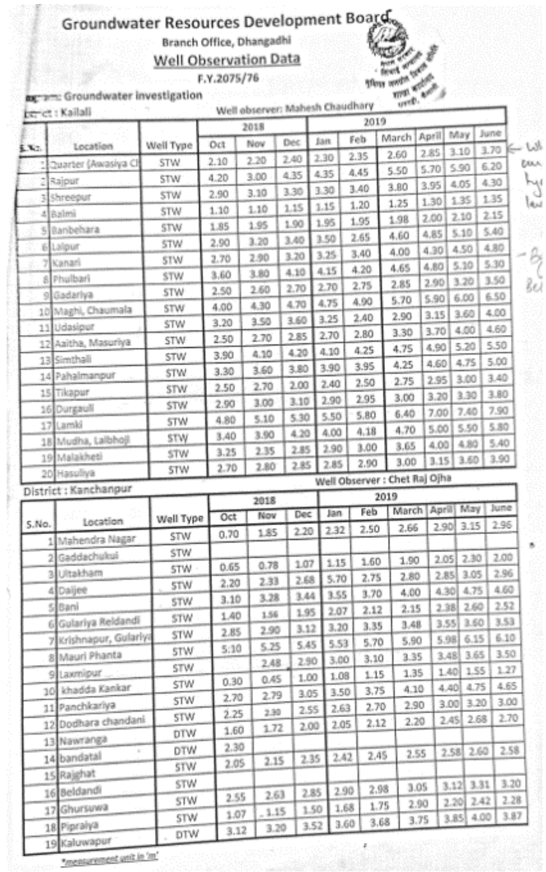
Location: Deukhuri Valley

Observed By: Ram Dhyan Chaudhary

S. N.	Well No.	Location	Municipality/ VDC	Measuring Point (MP) (m)	Water Level from MP (m)	Actual Water bgl (m)	G.P.S. Data		Recorded Date	Remarks
Well Type : Deep Tubewell										
1	27/044/45	Narti	Sonpur	0.39	1.60	1.21	0657684 3062370	245m	2079.2.6	
Well Type : Shallow Tubewell										
1	22/043/44	Sundabari	Sonpur	0.40	Block					
2	48/044/45	Falkapur	Sonpur	0.40	Block					
3	NISP/INV/STW-2	Jakheratal	Sonpur	G.L.	Block					
4	20/043/44	Satbatiya	Satbariya	0.20	Motor fit					
5	NISP/INV/STW-4	Kamanpur	Satbariya	0.30	Block					
6	NISP/INV/STW-6	Gojena	Satbariya	0.45	Motor fit					
7	39/044/45	Gaira	Bela	0.20	Motor fit					
8	NISP/INV/STW-1	Materiya	Bela	0.50	Motor fit					
9	48/044/45	Sishaniya	Sishaniya	0.75	Mudless					
10	41/044/45	Manpur	Gadhawa	0.27	Motor fit					
11	3/054/55	Manpur	Gadhawa	0.85	Motor fit					
12	42/044/45	Balapur	Gadhawa	0.40	Motor fit					
13	NISP/INV/STW-2	Jhingaha	Gadhawa	0.25	5.15	4.90	0651477 3076415	248m	2079.2.6	
14	GD-2	Dhairaini	Goberdiha	GL	2.62	2.62	0660815 3076588	285m	" " "	
15	GB-3	Dhairaini	Goberdiha	0.25	2.74	2.49	0660938 3076936	259m	" " "	
16	NISP/INV/STW-1	Dhairaini	Goberdiha	0.35	Block					
17	NISP/INV/STW-3	Jethangaon	Goberdiha	0.25	Water full					
Well Type : Dugwell										
1		Lamahi	Chailahi	0.40	0.91	0.51	0640609 3084090	250m	2079.2.6	
2		Kolahi	Chailahi	0.60	1.89	1.29	0650358 3082947	236m	" " "	
3		Banghusri	Satbariya	0.55	5.78	5.23	641725 3065829	221m	" " "	
4		Uchnimbu	Satbariya	0.70	Block					

Page 1

Deukhuri Valley



Groundwater Resources Development Board
Branch Office, Dhangadhi

Well Observation Data

F.Y.2075/76

Groundwater investigation

District : Kailali

Well observer: Mahesh Chaudhary

S.No.	Location	Well Type	2018 Oct	2018 Nov	2018 Dec	2019 Jan	2019 Feb	2019 March	2019 April	2019 May	2019 June
1	Quarter (Awasiya C	STW	2.10	2.20	2.40	2.30	2.35	2.60	2.85	3.10	3.70
2	Rajpur	STW	4.20	3.00	4.35	4.35	4.45	5.50	5.70	5.90	6.20
3	Shreepur	STW	2.90	3.10	3.30	3.30	3.40	3.80	3.95	4.05	4.30
4	Balmi	STW	1.10	1.10	1.15	1.15	1.20	1.25	1.30	1.35	1.35
5	Banbehara	STW	1.85	1.95	1.90	1.95	1.95	1.98	2.00	2.10	2.15
6	Lalpur	STW	2.90	3.20	3.40	3.50	2.65	4.60	4.85	5.10	5.40
7	Kanari	STW	2.70	2.90	3.20	3.25	3.40	4.00	4.30	4.50	4.80
8	Phulbari	STW	3.60	3.80	4.10	4.15	4.20	4.65	4.80	5.10	5.30
9	Gadariya	STW	2.50	2.60	2.70	2.70	2.75	2.85	2.90	3.20	3.50
10	Maghi, Chaumala	STW	4.00	4.30	4.70	4.75	4.90	5.70	5.90	6.00	6.50
11	Udasipur	STW	3.20	3.50	3.60	3.25	2.40	2.90	3.15	3.60	4.00
12	Aaitha, Masuriya	STW	2.50	2.70	2.85	2.70	2.80	3.30	3.70	4.00	4.60
13	Simthali	STW	3.90	4.10	4.20	4.10	4.25	4.75	4.90	5.20	5.50
14	Pahalmanpur	STW	3.30	3.60	3.80	3.90	3.95	4.25	4.60	4.75	5.00
15	Tikapur	STW	2.50	2.70	2.00	2.40	2.50	2.75	2.95	3.00	3.40
16	Durgauli	STW	2.90	3.00	3.10	2.90	2.95	3.00	3.20	3.30	3.80
17	Lamki	STW	4.80	5.10	5.30	5.50	5.80	6.40	7.00	7.40	7.90
18	Mudha, Lalbhoji	STW	3.40	3.90	4.20	4.00	4.18	4.70	5.00	5.50	5.80
19	Malakheti	STW	3.25	2.35	2.85	2.90	3.00	3.65	4.00	4.80	5.40
20	Hasuliya	STW	2.70	2.80	2.85	2.85	2.90	3.00	3.15	3.60	3.90

District : Kanchanpur

Well Observer : Chet Raj Ojha

S.No.	Location	Well Type	2018 Oct	2018 Nov	2018 Dec	2019 Jan	2019 Feb	2019 March	2019 April	2019 May	2019 June
1	Mahendra Nagar	STW	0.70	1.85	2.20	2.32	2.50	2.66	2.90	3.15	2.96
2	Gaddachukui	STW									
3	Ultakham	STW	0.65	0.78	1.07	1.15	1.60	1.90	2.05	2.30	2.00
4	Daijee	STW	2.20	2.33	2.68	5.70	2.75	2.80	2.85	3.05	2.96
5	Bani	STW	3.10	3.28	3.44	3.55	3.70	4.00	4.30	4.75	4.60
6	Gulariya Reldandi	STW	1.40	1.56	1.95	2.07	2.12	2.15	2.38	2.60	2.52
7	Krishnapur, Gulariya	STW	2.85	2.90	3.12	3.20	3.35	3.48	3.55	3.60	3.53
8	Mauri Phanta	STW	5:10	5.25	5.45	5.53	5.70	5.90	5.98	6.15	6.10
9	Laxmipur	STW		2.48	2.90	3.00	3.10	3.35	3.48	3.65	3.50
10	khadda Kankar	STW	0.30	0.45	1.00	1.08	1.15	1.35	1.40	1.55	1.27
11	Panchkariya	STW	2.70	2.79	3.05	3.50	3.75	4.10	4.40	4.75	4.65
12	Dodhara chandani	STW	2.25	2.30	2.55	2.63	2.70	2.90	3.00	3.20	3.00
13	Nawranga	DTW	1.60	1.72	2.00	2.05	2.12	2.20	2.45	2.68	2.70
14	bandatal	DTW	2.30								
15	Rajghat	STW	2.05	2.15	2.35	2.42	2.45	2.55	2.58	2.60	2.58
16	Beldandi	STW									
17	Ghursuwa	STW	2.55	2.63	2.85	2.90	2.98	3.05	3.12	3.31	3.20
18	Pipraiya	STW	1.07	1.15	1.50	1.68	1.75	2.90	2.20	2.42	2.28
19	Kaluwapur	DTW	3.12	3.20	3.52	3.60	3.68	3.75	3.85	4.00	3.87

*measurement unit in 'm'

Figure 17 Snapshots of GWRDB data collection

Besides GW monitoring, GWRDB supports the Department of Irrigation in implementing shallow and deep tube-well projects.

Other institutions involved in water resource management (not necessarily GW) are the **Department of Water resource and Irrigation (DWRI),** which mainly focuses on water resource management for irrigation purposes. **Bhumigat Jalsrot Tatha Sichai Bikash Division** is one of the divisions under DWRI operating at the provincial level. The key efforts concerning GW of the department and division are identification, management, policy-making and providing support for groundwater irrigation in Nepal.

Kathmandu Valley Water Supply Management Board (KVWSMB)

KVWSMB was established by the Government of Nepal as the institution responsible for groundwater regulation and management in Kathmandu Valley. KVWSMB was created to address overlaps in responsibilities between GWRDB and the Water and Energy Commission Secretariat (WECS), which is in charge of performing water resource research for the government of Nepal, several ministries and other associated organizations. KVWSMB is responsible for groundwater data collection and processing, groundwater development planning, monitoring, regulation and research of Kathmandu Valley.

Non-profit institutes active in groundwater management and monitoring in Nepal

International Maize and Wheat Improvement Center (CIMMYT)

An organization focused on non-profit agriculture research and training to tackle global food crises through an innovative agri-food system.

CIMMYT Nepal has launched the **Digital GW monitoring pilot program** in Banke and Bardiya in Nepal in response to the lack of a comprehensive system of GW monitoring.

Groundwater dashboard

The GW dashboard supported by CIMMYT and owned by GWRDB is an **initial version** that is designed to provide rapid interactive access to the data that the GWRDB is collecting. It provides an overview of the CIMMYT pilot project activity and can be considered a foundation for digitization GW monitoring in Nepal.

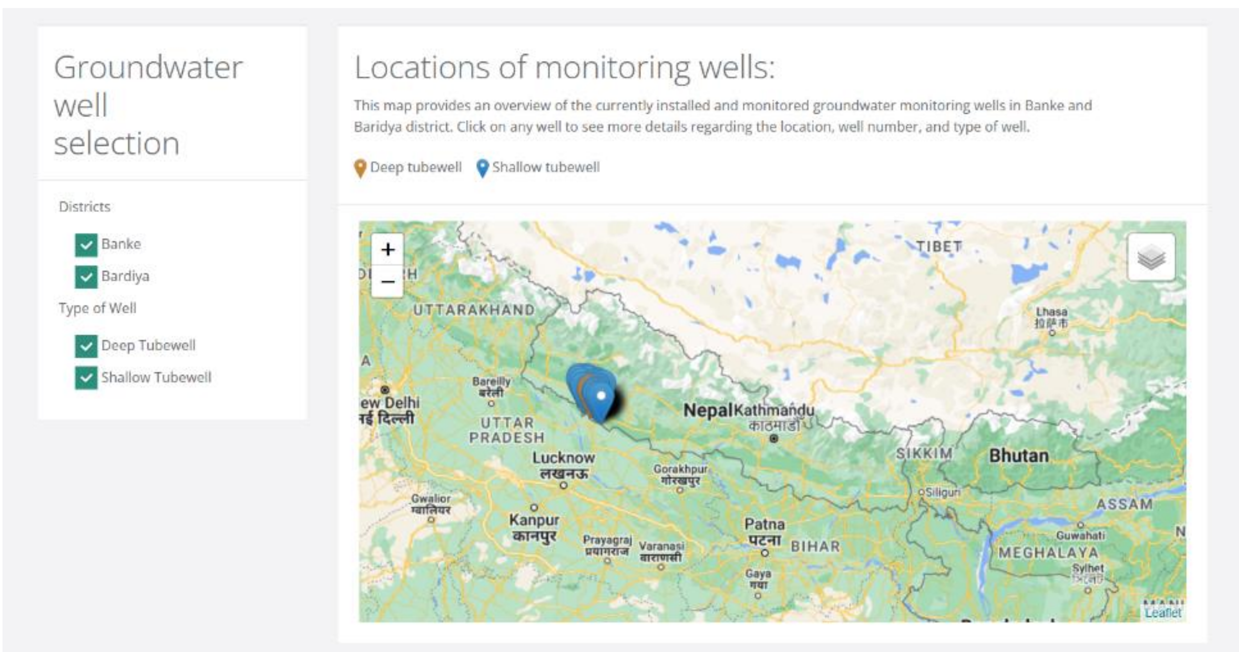


Figure 18 Snapshot of the GW monitoring dashboard

International Water Management Institute (IWMI)

IWMI solves water-related problems through collaboration with governments, farmers, development partners and businesses.

IWMI is working in collaboration with CIMMYT and GWRDB for the GW monitoring pilot project.

Smartphones4Nepal

Smartphone4Nepal is an organization working on understanding and management of water through the mobilization of citizen scientists, young researchers and mobile technologies.

A study in the **Kathmandu Valley watershed** was conducted to establish a citizen science-based groundwater monitoring network **using existing wells**, whereby local citizen scientists measure shallow groundwater levels in public or private wells of their community.

GPS and high-resolution camera technology in smartphones were used to collect verifiable records in the field, and cellular networks were used to transmit collected data to a central repository (Prajapati et al., 2021). This study included data from **45 wells in Kathmandu Valley.** The recordings were done two times a year during pre-monsoon and post-monsoon seasons.

5. Conclusions

From the review of GW from the global perspective and funnelling the review toward Nepal, interactive digitization of national GW data is a gap that remains to be filled in Nepal (which is established in neighbouring countries in varying degrees). Other countries have been recording various water quality-related parameters such pH, conductivity, arsenic levels etc. (in addition to GW level) which aren't being recorded or reflected in the consolidated GW level monthly report.

Furthermore, as shown in Figure 17, the format of GW data recorded in Nepal is not consistent across districts and data analysis is limited. Based on conversations with GWRDB, one-off projects in Nepal have accessed and digitized GW data for specific purposes which remains within the scope of the project and not available to the public. Projects, such as the one supported by CIMMYT, have created an online GW monitoring platform, currently limited to data of two districts but has the potential for national expansion.

The case studies of the United States and India emphasize the challenges of the groundwater issue globally. Groundwater monitoring in the United States reveals that the intensive use of groundwater for irrigation in the High Plains has resulted in a significant water-level decrease over the years. Groundwater levels, for example, have dropped more than 30 meters in regions of Kansas, New Mexico, Oklahoma, and Texas (Scanlon, Faunt, et al., 2012). Such variations were identified and could be followed over time throughout the whole High Plains area thanks to the multi-state groundwater level monitoring program. Similarly, in India, one CGWB monitoring unit is available for every 100-150 square kilometres, with statistics indicating that India is at the forefront of groundwater exploitation for agriculture. The monitoring program's records are vital for assessing various groundwater levels, and management alternatives as well as for demonstrating the results of conservation measures.

Digitization and public access to GW data can contribute to improved national water management planning and research activities across sectors. Some of the advantages are, but are not limited to, as follows,

- Systematic planning of investigation wells installed by GWRDB.
- Systematic recording of field data directly to the online platform by GWRDB will result in efficient data management.
- Efficient evaluation of conservation efforts.
- Analysis and research on GW status by GWRDB, research institutions (such as CIMMYT) and non-profits.
- Systematic planning of SIP promotion by AEPC.
- Cross-cutting sectors and institutions that will benefit from GW data.

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