

GMIS AS A CATALYST FOR SUSTAINABLE GROUNDWATER GOVERNANCE IN PUNJAB, PAKISTAN

LE GMIS COMME CATALYSEUR D'UNE GOUVERNANCE DURABLE DES EAUX SOUTERRAINES AU PENDING, PAKISTAN

Mohsin Hafeez¹, Kaleem Ullah¹, Naveed Iqbal¹, Jehanzaib Cheema¹, Hafsa Aeman¹,
Habib Ullah Bodla¹, Salman Siddiqui¹, Zohaib Shahid¹, and Mohammad Ashraf¹

ABSTRACT

Groundwater is a critical yet largely invisible component of global water security, underpinning food systems, urban supply, and climate resilience. Across many regions, unsustainable abstraction, declining water quality, and fragmented governance threaten the long-term sustainability of aquifers. Pakistan exemplifies these challenges: groundwater supplies over 60 percent of irrigation water, approximately 90% of domestic supply, and nearly all industrial demand, yet regulation and monitoring remain weak. Nowhere are these pressures more acute than in Punjab, Pakistan's agricultural heartland, where intensive cropping systems, rapid expansion of tubewells from approximately 4,500 in 1960 to more than 1.36 million by 2024, climate variability, and urban growth have driven widespread depletion and localized degradation of quality.

This paper presents the Groundwater Management Information System (GMIS), developed under the FCDO-funded Water Resource Accountability in Pakistan (WRAP) Program and CGIAR Policy Innovations Science Program, as a governance-enabling response to Punjab's groundwater crisis. GMIS integrates heterogeneous datasets, including approximately 1.32 million geotagged tubewells, over 2,000 piezometer sites, near-real-time data from 182 Conductivity–Temperature–Depth (CTD) sensors installed in Okara, Chakwal, and Rahim Yar Khan districts, groundwater quality records covering more than 60,000 locations, aquifer and soil characteristics, approximately 1,500 lithological borehole logs, 8,000 geophysical surveys, and remote-sensing products from global datasets into a centralized, decision-support platform. The paper documents the pilot districts where primary monitoring infrastructure was deployed, the secondary data sources at the province level, the integration methodology, the system's core modules, and the governance applications that have enabled evidence-based implementation of the Punjab Water Act 2019. GMIS was formally handed over to the Punjab Irrigation Department (PID) on 18 September 2024. By bridging data, policy, and governance, GMIS offers a blueprint for sustainable groundwater management in water-stressed regions, underscoring the urgency of holistic frameworks to balance agricultural demand with long-term aquifer sustainability.

Keywords: GMIS, groundwater governance; decision-support systems; water policy; hotspot identification; Punjab Water Act.

RÉSUMÉ

Les eaux souterraines constituent une composante essentielle, quoique largement invisible, de la sécurité hydrique mondiale, dont dépendent les systèmes alimentaires, l'approvisionnement urbain et la résilience climatique. Dans de nombreuses régions, les prélèvements non durables, la dégradation de la qualité de l'eau et la fragmentation de la gouvernance menacent la pérennité des aquifères. Le Pakistan illustre ces difficultés : les eaux souterraines fournissent plus de 60 % de l'eau d'irrigation, environ 90 % de l'approvisionnement domestique et la quasi-totalité de la demande industrielle, alors que la réglementation et le suivi demeurent insuffisants. Ces pressions sont particulièrement fortes au Pendjab, cœur agricole du Pakistan, où les systèmes de culture intensive, l'augmentation rapide du

¹ International Water Management Institute (IWMI), Lahore, Pakistan

nombre de puits tubulaires — d'environ 4 500 en 1960 à plus de 1,36 million en 2024 —, la variabilité climatique et la croissance urbaine ont entraîné une baisse généralisée des niveaux et une dégradation localisée de la qualité.

Cet article présente le Groundwater Management Information System (GMIS), développé dans le cadre du programme Water Resource Accountability in Pakistan (WRAP), financé par le FCDO, et du CGIAR Policy Innovations Science Program, comme une réponse permettant de renforcer la gouvernance face à la crise des eaux souterraines au Pendjab. Le GMIS intègre des ensembles de données hétérogènes, notamment environ 1,32 million de puits tubulaires géoréférencés, plus de 2 000 sites piézométriques, des données en temps quasi réel provenant de 182 capteurs de conductivité, température et profondeur (CTD) installés dans les districts d'Okara, de Chakwal et de Rahim Yar Khan, des relevés de qualité des eaux souterraines couvrant plus de 60 000 emplacements, les caractéristiques des aquifères et des sols, environ 1 500 diagraphies lithologiques de forages, 8 000 levés géophysiques et des produits de télédétection issus d'ensembles de données mondiaux, le tout au sein d'une plateforme centralisée d'aide à la décision. L'article décrit les districts pilotes dans lesquels l'infrastructure principale de suivi a été déployée, les sources de données secondaires à l'échelle provinciale, la méthode d'intégration, les modules centraux du système et les applications de gouvernance qui ont permis une mise en œuvre fondée sur des données probantes du Punjab Water Act 2019. Le GMIS a été officiellement remis au Punjab Irrigation Department (PID) le 18 septembre 2024. En reliant les données, les politiques et la gouvernance, le GMIS offre un modèle de gestion durable des eaux souterraines dans les régions soumises au stress hydrique et souligne l'urgence d'adopter des cadres globaux permettant d'équilibrer la demande agricole et la durabilité à long terme des aquifères.

Mots-clés : GMIS; Gouvernance des eaux souterraines; Systèmes d'aide à la décision; Politique de l'eau; Identification des points chauds; Loi d'eau de Pendjab.

1. INTRODUCTION

Groundwater constitutes approximately 30% of global freshwater resources, supplies drinking water to over 2 billion people, and supports around 40% of global agricultural water demand (Margat and van der Gun, 2013). Despite this importance, groundwater management faces persistent challenges: over-extraction beyond sustainable yields, declining water tables, degradation of water quality from salinity and anthropogenic pollution, weak regulatory enforcement, and chronic data scarcity (Famiglietti, 2014; Gleeson et al., 2012). Because groundwater is largely invisible and spatially heterogeneous, governance failures are often detected only after aquifer degradation has become severe and prohibitively costly to reverse (Foster and MacDonald, 2014).

Pakistan ranks as the fourth-largest groundwater user globally (Wada et al., 2010). Groundwater meets over 60% of irrigation demand, approximately 90% of domestic water supply, and nearly all industrial water use (Government of Pakistan, 2018). Per-capita water availability has declined from 5,260 cubic meters in 1951 to approximately 1,010 cubic meters in 2021, pushing the country below the international water-scarcity threshold (Pakistan Bureau of Statistics, 2022). Projections indicate that water demand will increase by 16-25% by 2050, further straining already overstressed aquifers (Asian Development Bank, 2019). This crisis is compounded by rapid population growth, climate variability manifested in increasingly erratic monsoon patterns, and structural over-dependence of agriculture on groundwater as a buffer against unreliable canal water deliveries (Qureshi et al., 2010). Policy responses have emerged at national and provincial levels. The National Water Policy 2018 (NWP-18) represents Pakistan's first comprehensive federal water governance framework, introducing prioritized water use and mandating the development of provincial groundwater atlases documenting quality, depth, and aquifer characteristics (Government of Pakistan, 2018, Clause 16.6).

Punjab Province represents the epicenter of Pakistan's groundwater challenge. Punjab sustains the country's most intensive agricultural systems, producing more than 60% of national agricultural output, and accounts for approximately 90% of Pakistan's total groundwater abstraction (Pakistan Bureau of Statistics, 2021). The province hosts approximately 1.32 million tubewells, expanding from around

4,500 in 1960 (Qureshi et al., 2010). This explosive growth has been driven by water-intensive cropping patterns, particularly sugarcane, rice, and cotton; unreliable canal water deliveries; subsidized electricity tariffs; and the absence of effective regulation (Shah, 2009; Basharat and Tariq, 2015). After the NWP-18, the Punjab Water Act 2019 (Act XXI of 2019) was officially passed by the Provincial Assembly of the Punjab and assented to on December 13, 2019. The Punjab Water Act 2019 established a formal licensing regime for groundwater abstraction (Section 25), mandated abstraction regulation (Section 43), and set quality compliance standards (Section 28), whilst creating a 22-member Punjab Water Resources Commission and designating Water Resource Zones under the Punjab Irrigation Department (PID) as operational units for district-level enforcement (Government of Punjab, 2019). However, implementation has been constrained by fragmented institutional mandates, limited monitoring infrastructure, and, most critically, the absence of integrated, spatially explicit datasets required for regulatory enforcement (Basharat, 2019).

In Punjab, groundwater tables are declining at 0.5 to 1.0 meters per year across many canal command areas, with localized rates of 2 to 3 meters per year in critical hotspots, including Lahore, Multan, Lodhran, and Okara (Basharat, 2012). Groundwater quality degradation presents an equally severe challenge. Arsenic contamination, mobilized by reducing conditions in alluvial aquifers and exacerbated by wastewater infiltration, now affects more than 20% of Punjab's population, with concentrations frequently exceeding the WHO guideline of 10 micrograms per liter (Podgorski and Berg, 2020; Tayyab et al., 2023). In southern and southwestern districts, naturally occurring salinity renders groundwater unusable even where water is accessible at moderate depths, with electrical conductivity values often exceeding 2,000 micro siemens per centimeter (Basharat, 2012). Nitrate contamination from excessive fertilizer applications presents an additional public health risk (Azizullah et al., 2011). The spatial distribution of these quality problems is highly heterogeneous, varying at sub-district scales, yet existing monitoring systems lack the spatial resolution to identify contamination hotspots or guide targeted interventions.

The governance crisis is characterized by six interlocking challenges.

1. Groundwater abstraction substantially exceeds natural recharge, driven by the absence of effective controls and subsidized electricity tariffs. The rapid proliferation of private tubewells has occurred in a regulatory vacuum, with no requirement for permits, no volumetric limits, and no monitoring of abstraction rates.
2. Quality degradation requires localized monitoring and management responses that existing systems cannot provide.
3. Groundwater monitoring has been fragmented across multiple departments within the Punjab Irrigation Department (PID), Pakistan Council of Research in Water Resources (PCRWR), and Water and Power Development Authority (WAPDA), each operating independent networks with overlapping mandates, inconsistent methodologies, incompatible data formats, and minimal inter-agency data sharing (Afzal et al., 2023). The result is an information landscape characterized by abundant but isolated 'data islands' and a critical shortage of integrated, spatially explicit intelligence.
4. Even where data exists, they have rarely been used systematically to inform regulatory decisions. The Punjab Water Act 2019's licensing regime requires spatial evidence identifying where depletion is severe, where quality is unacceptable, and where tubewell density exceeds sustainable limits, evidence that no single agency possesses.

5. Governance fragmentation arising from divided institutional responsibilities persists among PID, PCRWR, WAPDA, the Agriculture Department, and the Energy Department, with no formal data-sharing protocols.
6. The absence of spatially explicit decision-support tools means that piezometric data remain in spreadsheets, quality surveys in laboratory reports, and tubewell inventories in district registers are operationally useless for targeted regulation.

This paper addresses how data integration and spatial decision-support systems can enable the transition from fragmented, reactive groundwater governance to coordinated, evidence-based management. It presents the Groundwater Management Information System (GMIS) in Punjab, Pakistan, as a case study in institutional capacity building for data-driven water governance. GMIS was developed under the UK Foreign, Commonwealth and Development Office (FCDO)- funded Water Resource Accountability in Pakistan (WRAP) Program and the CGIAR Policy Innovations Science Program by the International Water Management Institute (IWMI), in partnership with PID. GMIS was formally handed over to PID on 18 September 2024.

2. STUDY AREA AND DATA COLLECTION

The study was conducted in the province of Punjab, Pakistan (Figure 1), using both primary and secondary datasets. Primary data were collected from selected pilot districts through field surveys, groundwater monitoring, stakeholder consultations, and installation of monitoring instruments. In addition, secondary data for the remaining districts of Punjab were compiled from relevant government departments, published reports, existing databases, and remote sensing sources to support province-wide analysis and assessment. Rahim Yar Khan, Okara, and Chakwal districts were selected in the Punjab Province to represent contrasting hydrogeological settings.

Okara District represents intensively irrigated central Punjab with fresh groundwater under heavy abstraction. The district experiences a mean annual rainfall of 297 mm, compared with a reference evapotranspiration of 1,437 mm. As one of Pakistan's leading producers of maize, potatoes, rice, and vegetables, Okara hosts 50,028 geotagged tubewells and was selected because it demonstrates over-abstraction creating localized depletion hotspots and anthropogenic contamination. To monitor groundwater, 102 CTD sensors were installed in Okara and the surrounding area.

Chakwal District represents the rainfed Pothohar Plateau, with limited recharge conditions and reliance on shallow aquifers fed by monsoon rainfall. There are 40 CCTD installed in Chakwal (Figure 1) to provide continuous monitoring of water levels, temperature, and salinity levels at half-hourly intervals. It also hosts 8,537 tubewells, with very limited recharge to the groundwater aquifer.

Rahim Yar Khan (RYK) district, located in southernmost Punjab, is characterized by flat alluvial plains served by the Punjnad and Abbasia Canal systems. Although the canal systems operate under the Warabandi allocation system, rigid scheduling fails to meet peak crop water demands, leading farmers to depend extensively on groundwater.

Demand is intensified by the dominance of water-intensive crops, particularly sugarcane and cotton. RYK hosts 104,153 tubewells, the highest in Punjab. Unlike Okara, much of RYK's aquifer is saline or brackish. Although water is accessible at moderate depths, it is unusable. It demonstrates that quality-based monitoring is also essential in saline-aquifer districts, rather than relying solely on depth-to-water-table tracking. For groundwater, 40 CTD sensors were strategically installed to capture spatial variability in water levels and salinity (Figure 1).

Water quality sampling campaigns analyzed 151 samples in Okara, 58 in Chakwal, and 91 in RYK for physicochemical parameters, toxic contaminants (arsenic, fluoride, nitrate), and microbiological indicators. These primary data sources collected in pilot districts provide continuous, near-real-time monitoring of depth to the water table, temperature, and salinity. The spatial variation of groundwater

tables in the Okara district is shown in Figure 2. These primary datasets were generated specifically to fill spatial and temporal data gaps that existing secondary sources could not address.

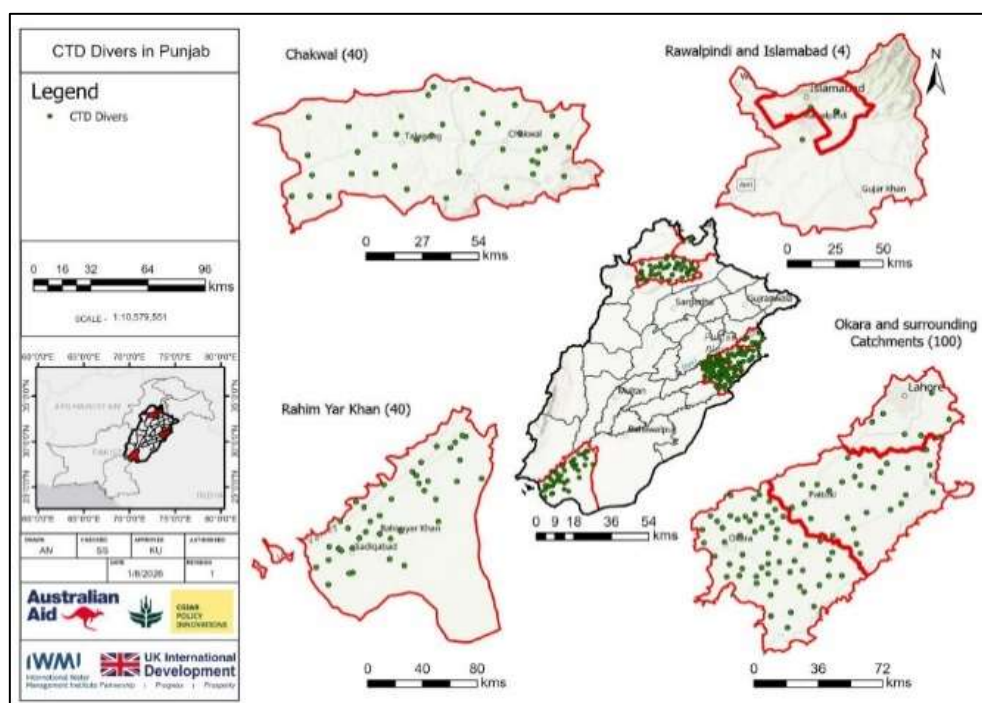


Figure 1: Study Area with Location of CTD in Pilot Districts, Punjab, Pakistan

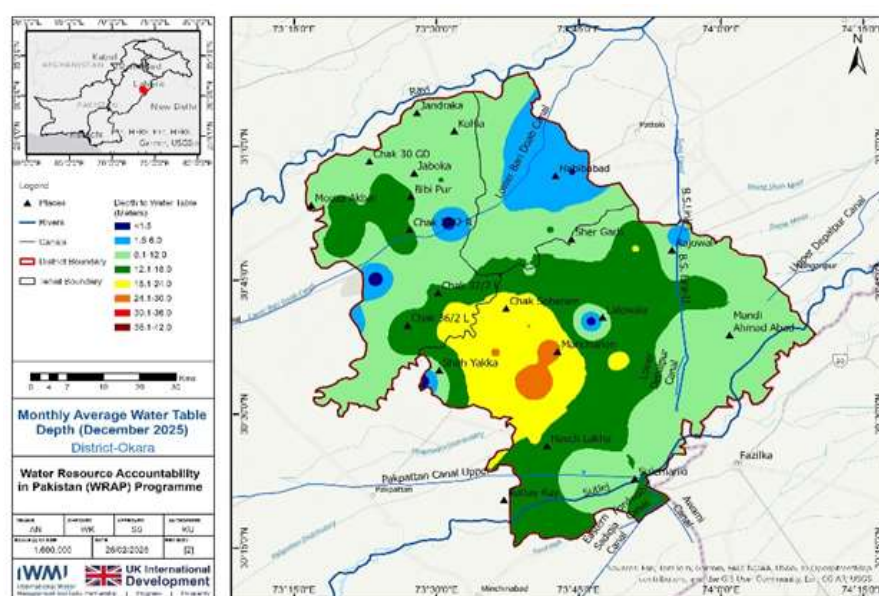


Figure 2: Spatial Variation of Water Table in Okara (December 2025)

The secondary data sources include: (i) PID's province-wide geotagged tubewell inventory with attributes including depth, discharge capacity, and ownership status (Figure 3(a) ; (ii) PID's historical piezometric database containing bi-annual water-level measurements from over 2,000 monitoring sites spanning multiple decades (Figure 3(b); (iii) PID water quality surveys covering over 60,000

geotagged locations across Punjab, providing baseline data on arsenic, salinity, nitrate, and other contaminants; (iv) CSIRO compiled borehole logs documenting subsurface lithology and aquifer stratigraphy for approximately 1,500 wells investigated by WAPDA; (v) electrical resistivity surveys from approximately 8,000 locations conducted by PCRWR and other agencies, providing spatial mapping of aquifer geometry and salinity; (vi) Landsat-derived land use and land cover classifications enabling estimation of crop water demand and recharge potential; and (vii) WAPDA historical aquifer studies and pumping test data.

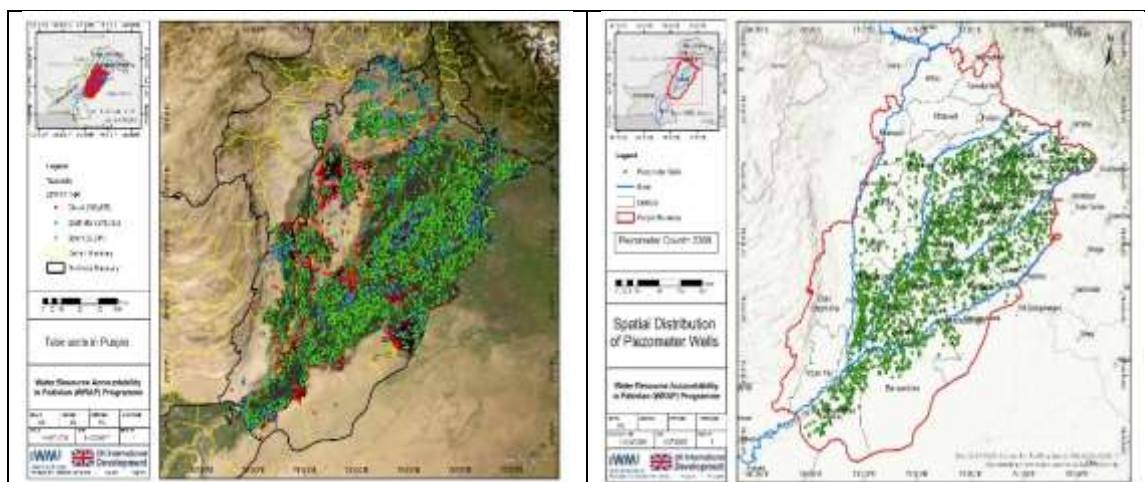


Figure 3 (a & b): Location of Geotagged Tubewells & Piezometer Sites

3. GMIS DEVELOPMENT: ARCHITECTURE AND INTERFACE

The Groundwater Management Information System (GMIS) was developed to address data fragmentation and support evidence-based decision-making. The system was designed to serve multiple institutional stakeholders: PID as the primary regulatory authority; the Punjab Public Health Engineering Department in rural areas; Water and Sanitation Agencies managing urban groundwater; the PCRWR providing water quality monitoring; the Agriculture and Energy Departments; and provincial planning agencies. GMIS directly supports hotspot identification, monitoring, and enforcement under the Punjab Water Act 2019 and the Punjab Irrigation and Drainage Authority Act 2023.

GMIS consolidates eight core data components accessible through standard internet browsers (Figure 4): (i) Geotagged Tubewells (ii) Piezometer Information; (iii) Groundwater Quality; (iv) Aquifer Characteristics; (v) Soil Properties; (vi) bore logs; (vii) Resistivity; and (viii) Spatial Atlas integrating groundwater data with land use, cropping patterns, canal command areas, and administrative boundaries. All datasets were harmonized using a common spatial reference system (WGS 84 / UTM Zone 42N), temporally aligned, and documented with metadata.

This standardization enabled integration of data from PID, PCRWR, WAPDA, and other agencies that previously existed in incompatible formats, transforming isolated 'data islands' into a coherent evidence base. Data flows operate on multiple temporal scales: historical piezometric records enable long-term trend analysis; bi-annual manual measurements track seasonal variability; half-hourly CTD sensor readings provide near-real-time alerts when thresholds are breached; and periodic quality surveys capture spatial contamination patterns.

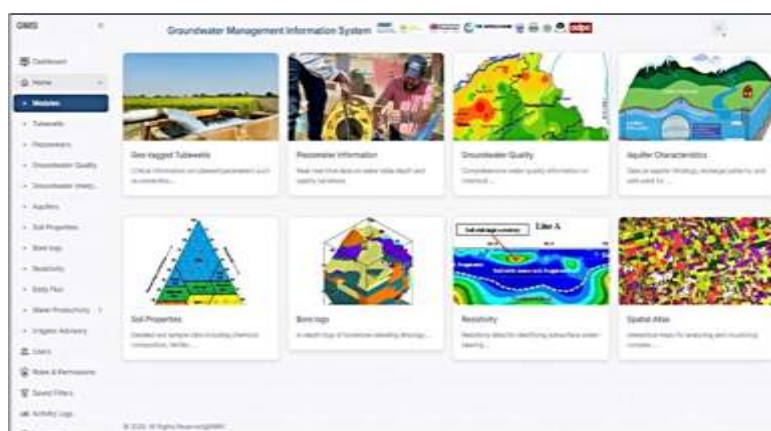


Figure 4: GMIS Interactive interface

The user interface provides three primary modes: an interactive map interface allowing users to overlay depth-to-water-table maps with tubewell density, groundwater quality parameters and administrative boundaries; pre-generated dashboards providing summary statistics and trend analysis for each district/tehsil/ canal command, including current water-table status, annual change rates, quality compliance against WHO and national guidelines, and rankings of priority intervention zones derived from identified hotspots; and automated alert notifications triggered when monitored zones breach pre-defined thresholds. The platform includes a reporting module that generates standardized reports (Figure 5) for submission to the Punjab Water Resources Commission, the district administration, and planning agencies. This integrated design fulfills the monitoring requirements of the National Water Policy 2018 (Clause 16.6) and the Punjab Irrigation and Drainage Authority Act 2023 (Sections 97–100).



Figure 5: GMIS Analytics and Reporting

GMIS was formally handed over to PID, marking the transition from a donor-funded pilot to a government-owned operational system. The handover included a capacity-building program that trained 163 officials (21% women) in system use, data interpretation, and report generation.

4. RESULTS: GMIS APPLICATIONS FOR EVIDENCE-BASED GROUNDWATER GOVERNANCE

The Punjab Water Act 2019 mandates licensing, abstraction regulation, and quality compliance, but can function only if regulators know where depletion is severe, where quality is unacceptable, and where tubewell density exceeds sustainable limits. GMIS provides exactly this capability by integrating the various data types and sources relevant to groundwater into a unified platform that transforms fragmented data into spatially explicit intelligence. PID can now apply depth-based licensing to over-extracted zones without imposing blanket restrictions overall. PID can enforce stricter licensing and mandate High-Efficiency Irrigation Systems for new permits in areas where the groundwater table is declining rapidly. In areas where heavy metal contamination exceeds WHO guidelines, relevant departments can prioritize deploying filtration plants and restrict new tubewell permits.

GMIS-derived hotspot rankings give the Punjab Water Resources Commission a transparent methodology for designating priority zones, replacing contested political allocation with evidence-led prioritization. Southern Punjab districts were identified as the most vulnerable based on indicators of integrated depth to the water table, water quality, and tubewell density. This evidence-informed revision of ecological zones, canal reallocation proposals targeting hotspot areas, and enforcement prioritization enable PID to concentrate inspections rather than spread resources uniformly. GMIS introduces quality-based governance for the first time. In Rahim Yar Khan, PID can condition new tubewell permits on water-quality thresholds rather than on depth alone, thereby restricting sugarcane cultivation in severely saline zones. GMIS data can inform policies that couple solar subsidies with mandatory adoption of drip or sprinkler irrigation.

Two practical use cases demonstrate GMIS's value in governance. In Okara, arsenic contamination affects 32.5% of sampled wells, peaking at 171.8 micrograms per liter near Renala Khurd. PID used GMIS quality analytics to produce a sub-tehsil arsenic hotspot map. Punjab Public Health Engineering Department prioritizes community arsenic filtration plants in the three most affected union councils. PID may restrict new shallow tubewell permits in contaminated zones and encourage deeper installations. In Rahim Yar Khan, PID integrated GMIS hotspot maps with canal allocation data to identify zones where groundwater is saline, but canal supply is available, and zones where groundwater is fresh but declining rapidly. In saline zones, PID may reallocate additional canal water during peak irrigation periods to reduce reliance on brackish groundwater. In freshwater-declining zones, PID may introduce seasonal restrictions on tubewell operation and promote managed aquifer recharge pilots. Following successful piloting, GMIS was expanded to cover the entire Punjab Province. Approximately 95% of province-wide data collection is complete. A Community of Practice was established to facilitate multi-departmental collaboration. GMIS is now accessible via PID (Figure 6), PCRWR, and Living Indus Initiative websites.

6. DISCUSSION: GOVERNANCE IMPLICATIONS, LIMITATIONS, AND LESSONS

Punjab's groundwater crisis is not a single problem but a convergence of over-abstraction, deteriorating quality, fragmented monitoring, and governance failure. These challenges created the conditions that made GMIS necessary, and they define the standard against which it must be judged. GMIS meets that standard by integrating primary IWMI monitoring data and CTD sensors with secondary data from PID, PCRWR, WAPDA, and remote sensing into a single governance-focused platform. By identifying priority hotspot zones, and by mapping quantity and quality stress at sub-tehsil resolution. GMIS converts fragmented data into ranked, actionable intelligence for regulators. The system's governance value is demonstrated through spatially explicit licensing that enables depth- and quality-based tubewell permitting. Transparent prioritization of hotspot rankings replaces political contestation with evidence; interdepartmental coordination, where a single timestamped, auditable platform removes information barriers that have paralyzed coordinated governance; and proactive regulation before crises escalate.



Figure 6: Accessibility of GMIS on PID Websites (<https://irrigation.punjab.gov.pk>)

Despite its successes, GMIS faces several limitations. First, whilst GMIS integrates extensive data on abstraction, water levels, and quality, comprehensive water-balance calculations that quantify recharge, abstraction, and outflows at basin and sub-basin scales are still in development. Second, data quality and gaps persist near-real-time CTD sensors cover only 182 locations in three pilot districts, whilst over 60,000 locations have quality records, many are one-time samples, and continuous quality monitoring is not yet systematic. Third, institutional responsibilities remain divided among PID, PCRWR, WAPDA, and the Agriculture and Energy Departments, whilst GMIS provides evidence; enforcement of the Punjab Water Act requires field inspections and coordination with district administrations. Although 163 officials have been trained, capacities remain under-resourced, and sustained use depends on institutional culture change and political commitment to evidence-based regulation. Fourth, GMIS had not been directly linked to farmer-facing advisory services; however, the Scaling for Impact workshops (December 2025) in Okara and Rahim Yar Khan marked the first structured engagement with farmers, indicating that bridging the gap between institutional monitoring and farm-level decision-making is essential for long-term impact.

Five lessons emerge from Punjab's experience. First, data integration is necessary but not sufficient: GMIS demonstrates that technical integration of heterogeneous datasets is feasible and valuable, but data alone does not drive governance change; effective governance requires clear institutional mandates, political will to enforce regulations, and capacity to act on evidence. Second, quality and quantity must be managed jointly: the Rahim Yar Khan experience confirms that volume-based regulation misses the dominant stress mechanism in saline-aquifer districts, and GMIS's integration of quality analytics (electrical conductivity, arsenic) with quantity indicators (depth to water table) is essential for effective management in hydrogeologically diverse basins.

Third, farmer engagement is essential for scale: the positive response to advisory services in the December 2025 workshops (over 90% perceived usefulness) underscores that institutional data platforms must be linked to farmer-facing services to achieve behavioral change at scale. Fourth, transparency builds trust: making GMIS publicly accessible via PID, PCRWR, and Living Indus Initiative websites, and establishing a multi-departmental Community of Practice (CoP) demonstrates that transparency and stakeholder inclusion strengthen legitimacy and uptake.

7. CONCLUSIONS AND POLICY RECOMMENDATIONS

Punjab's groundwater crisis is characterized by over-abstraction, deteriorating quality, fragmented monitoring, and governance failure, which demands a coordinated, evidence-based response. GMIS is essential because it makes groundwater 'visible' by integrating various datasets, promotes transparency and accountability through a single, timestamped, auditable platform, supports adaptive management through continuous monitoring updates, and facilitates inter-departmental coordination. Punjab's experience demonstrates that GMIS is not merely a data platform but a governance enabler, a system that translates fragmented information into ranked, actionable intelligence for regulators.

To realize the full potential of the Groundwater Management Information System (GMIS), Punjab should strengthen the Water Resources Zone with the legal mandate, staff, and budget for groundwater regulation, monitoring, and enforcement. Basin-scale water balance assessments should be conducted and integrated into GMIS for improved planning and decision-making. Building on December 2025 workshops in pilot districts, area-specific advisory services should provide farmers with regular guidance on groundwater and irrigation via WhatsApp and automated voice messages in local languages. The CTD monitoring network should also be expanded across Punjab using scientifically optimized site selection methods. In addition, formal data-sharing mechanisms among PID, PCRWR, WAPDA, Agriculture, and Energy Departments should be established under a GMIS Steering Committee chaired by the Water Resources Regulatory Authority (WRRRA), Punjab.

The GMIS framework should further be adapted and scaled to Khyber Pakhtunkhwa, Sindh, and Balochistan through technical support, capacity building, and investment in automated monitoring and decision-support systems.

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