

TECHNOLOGY ADOPTION AND DATA-DRIVEN IRRIGATION MANAGEMENT IN NEPAL: STATUS, BARRIERS, AND A ROADMAP FOR WATER-USE EFFICIENCY

ADOPTION DES TECHNOLOGIES ET GESTION DE L'IRRIGATION FONDÉE SUR LES DONNÉES AU NEPAL : ÉTAT DES LIEUX, OBSTACLES ET FEUILLE DE ROUTE POUR L'EFFICACITÉ D'UTILISATION DE L'EAU

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ABSTRACT

Nepal's irrigation sector is central to agricultural productivity, rural livelihoods, and climate adaptation, yet it operates within one of the world's most demanding hydro-geomorphic contexts: steep hills, sediment-laden rivers, highly seasonal flows, and increasing climate variability. The Department of Water Resources and Irrigation (DWRI) manages 32 Agency-Managed Irrigation Systems (AMIS) alongside over 16,000 Farmer-Managed Irrigation Systems (FMIS), collectively covering approximately 1.5 million hectares of the 2.5 million hectare irrigable potential. Major investments have improved infrastructure; however, the transition toward a measure-manage-improve paradigm remains uneven. This paper assesses the current status of technology adoption and data-driven practices across Nepal's irrigation landscape and documents DWRI's concrete steps toward digital transformation—specifically the Nepal Irrigation Management Information System (NIMIS) and the Nepal Irrigation Infrastructure Monitoring System (NIIMS). The paper further identifies persistent barriers and proposes a practical modernization roadmap. Farm-level adoption is progressing, but system-level monitoring and institutional use of data remain weak. Key constraints include supply-driven operations, weak O&M financing, fragmented datasets, skill deficits, and insufficient performance-oriented incentives. Nepal's modernization must prioritize closing the data-to-decision gap through minimum monitoring packages, interoperable data systems, remote sensing, participatory monitoring, and selective automation—treating digital irrigation as a service transformation rather than a technology rollout.

Keywords: Irrigation modernization; Water-use efficiency; Nepal; FMIS; IMIS; Remote sensing, Performance assessment; Digital irrigation.

RÉSUMÉ

Le secteur de l'irrigation au Népal joue un rôle central dans la productivité agricole, les moyens de subsistance ruraux et l'adaptation au climat, mais il évolue dans l'un des contextes hydrogéomorphologiques les plus exigeants au monde : versants abrupts, rivières fortement chargées en sédiments, débits très saisonniers et variabilité climatique croissante. Le Département des ressources en eau et de l'irrigation (DWRI) gère 32 systèmes d'irrigation administrés par l'État (AMIS), parallèlement à plus de 16 000 systèmes d'irrigation gérés par les agriculteurs (FMIS) ; ensemble, ils couvrent environ 1,5 million d'hectares sur un potentiel irrigable de 2,5 millions d'hectares. D'importants investissements ont amélioré les infrastructures ; toutefois, la transition vers un paradigme « mesurer-gérer-améliorer » reste inégale. Cet article évalue l'état actuel de l'adoption des technologies et des pratiques fondées sur les données dans l'ensemble du secteur népalais de

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l'irrigation. Il présente également les mesures concrètes prises par le DWRI en faveur de la transformation numérique, notamment le Système népalais d'information sur la gestion de l'irrigation (NIMIS) et le Système népalais de suivi des infrastructures d'irrigation (NIIMS). L'article recense en outre les obstacles persistants et propose une feuille de route pratique pour la modernisation. L'adoption progresse à l'échelle des exploitations, mais le suivi à l'échelle des systèmes et l'utilisation institutionnelle des données restent faibles. Les principales contraintes comprennent une exploitation guidée par l'offre, un financement insuffisant de l'exploitation et de la maintenance (O&M), des jeux de données fragmentés, un déficit de compétences et des incitations trop peu axées sur les performances. La modernisation du Népal doit en priorité combler l'écart entre les données et la décision grâce à des dispositifs minimaux de suivi, des systèmes de données interopérables, la télédétection, le suivi participatif et une automatisation sélective, en considérant l'irrigation numérique comme une transformation des services plutôt que comme un simple déploiement technologique.

Mots-clés : Modernisation de l'irrigation; Efficacité de l'utilisation de l'eau; Népal; FMIS, IMIS, Télédétection; Evaluation des performances; Irrigation numérique.

1. Introduction

Globally, irrigation modernization increasingly emphasizes service orientation, data systems, performance benchmarking, and informed operational control. Modern irrigation is not defined only by concrete structures, pumps, or automated gates. It is defined by the ability of institutions to know how much water is available, how much is being delivered, whether services are timely and equitable, where losses occur, what crops are demanding, and how operations should respond. In this sense, modernization is as much institutional and informational as it is physical.

Irrigation remains one of the most critical foundations of Nepal's agricultural system, influencing crop intensity, yield stability, food security, rural employment, and resilience to increasingly erratic rainfall. Over 100 years of modern irrigation development—from the Chandra Nahar Irrigation System in Saptari to the Sunkoshi Main Diversion Multipurpose Project—has built a substantial infrastructure base. Yet coverage remains at approximately 1.5 million hectares out of a 2.5 million hectare irrigable potential, with service quality often falling short of the reliability and equity that farmers need (IMP, 2019).

Nepal's irrigation sector operates under unusually demanding conditions. Its topography ranges from high mountains and fragile mid-hills to the alluvial Terai plains. Water availability is highly seasonal, rivers carry heavy sediment during the monsoon, and recurrent floods, landslides, and infrastructure damage are persistent challenges. The Department of Water Resources and Irrigation (DWRI) serves as the central institution responsible for irrigation development and management, with a mandate spanning infrastructure development, policy formulation, water management, multi-purpose planning, and disaster mitigation.

Historically, Nepal's irrigation performance has been assessed primarily in terms of physical expansion—hectares covered, structures built, canals lined. This infrastructure-led approach has not consistently translated into reliable irrigation service, improved water productivity, or stronger agricultural outcomes. The next phase must therefore focus on how water is measured, managed, delivered, monitored, and continuously improved.

This paper assesses the current status of technology adoption and data-driven irrigation management in Nepal. It asks three central questions: (i) Where does Nepal currently stand in technology adoption and data systems across different system types? (ii) What major barriers prevent technology from translating into sustained operational improvement? (iii) What practical roadmap, including existing DWRI digital initiatives, can guide Nepal toward context-appropriate, institutionally sustainable modernization?

2. Conceptual Framework: From Construction to Measure-Manage-Improve

This paper is grounded in a central proposition: irrigation modernization should be understood as a transition from infrastructure-led expansion to a measure-manage-improve approach. Under a construction-dominated model, success is measured in physical outputs. Under a measure-manage-improve model, it is measured in service quality—reliability, adequacy, timeliness, equity, and water productivity.

The goals of irrigation management, as framed by DWRI and consistent with FAO guidance, center on four outcomes: enhancing water productivity, improving service delivery, ensuring equitable water distribution, and enabling proper scientific irrigation scheduling (FAO, 2016). Achieving these outcomes requires irrigation institutions to not only build systems but also observe, diagnose, and adapt them.

- To assess Nepal's position within this transition, the analysis uses a technology and data maturity framework across five components of the irrigation service chain:
- Measurement and monitoring: routine flow, groundwater, soil moisture, and climate observation—the foundation of performance-oriented management.
- Operational control and delivery: canal regulation, scheduling, rotational distribution, and maintenance timing supported by reliable data.
- IMIS and digital asset management: GIS-based inventories, digital maps, scheme condition records, and interoperable information systems.
- Performance assessment and benchmarking: adequacy, reliability, equity, timeliness, and water productivity indicators used for continuous improvement.
- Decision support systems: remote sensing-based ET estimation, water accounting, crop water analysis, and scenario-based planning tools.

Nepal needs differentiated modernization grounded in both technical feasibility and institutional realism—not a single template applied uniformly across diverse system types.

3. Nepal's Irrigation Context and the Case for Data-Driven Management

3.1 Sector Overview

Nepal's irrigation sector encompasses over a century of development and is institutionally and geographically diverse. Key statistics are summarized in Table 1.

Table 1. Nepal's Irrigation coverage

Indicator	Value / Description
Total irrigable area	2.5 million hectares
Currently irrigated area	~1.5 million hectares (IMP, 2019)
Agency-Managed Irrigation Systems (AMIS)	32 systems; gross command area ~400,618 ha
Farmer-Managed Irrigation Systems (FMIS)	16,000+ systems; gross command area ~668,677 ha
Groundwater irrigation systems (in NIMIS)	876 systems
Governance structure	Multi-tier: Federal, Provincial, and Local
Key contribution	Food security, rural livelihoods, climate risk reduction

3.2 System Types

Hill irrigation is dominated by farmer-managed systems that evolved through local knowledge, collective labor, and location-specific design. These systems exhibit strong social organization and low-cost management traditions, but remain vulnerable to source depletion, structural fragility, and declining labor availability due to rural out-migration.

In the Terai, larger agency-managed surface schemes feature longer canals, formal engineering structures, and greater administrative complexity. Operations in these systems are currently supply-driven, relying on manual gate operation by field staff (chaukidars and dhalpas) and rotational water supply based on Water User Association (WUA) agreements. Lower-order canal management is largely dependent on WUAs, with limited use of hydro-meteorological data, weather forecasting, or crop-based irrigation planning.

Groundwater and lift-based systems represent a third dimension. Where market access, water sources, and energy availability converge, pump-based and localized irrigation methods are increasingly influencing practice—partly explaining why farm-level adoption consistently outpaces system-level modernization.

3.3 The Management Gap

Current irrigation management is characterized by weak or outdated databases, manual record-keeping with minimal analysis, lack of asset management plans, unscientific inventory and maintenance records, non-scientific budget allocation, and fragmented data systems that impede tracking and evaluation of maintenance records. These weaknesses collectively prevent Nepal from converting available technologies into sustained gains in water-use efficiency.

4. Current Status of Technology Adoption

4.1 Farm-Level Adoption: Visible but Uneven Progress

The most visible technology adoption is occurring at the farm or plot level. Farmers in selected areas have adopted pumps, plastic conveyance, localized irrigation methods, and emerging advisory tools linked to weather and market signals. Adoption is strongest where individual or group incentives are clear, where water access is tied directly to crop income, and where users control operation without depending on larger institutions. However, farm-level gains do not automatically transform overall irrigation performance when bulk water delivery remains unreliable or system-level allocation stays opaque.

4.2 Measurement and Monitoring: The Weakest Foundational Layer

Routine measurement is one of Nepal's weakest irrigation management elements. In many schemes, flow measurement at intakes, branch points, and outlets is not consistently institutionalized. Measurement structures may be absent, poorly maintained, uncalibrated, or not routinely used for decisions. Groundwater monitoring is limited in most local contexts. Soil moisture observations are rarely integrated into routine operations. Climate data, though increasingly available through hydro-meteorological networks, are seldom translated into practical irrigation scheduling.

This structural weakness is critical: without dependable measurement, services cannot be benchmarked, distribution disputes cannot be resolved transparently, losses cannot be properly diagnosed, and water productivity cannot be meaningfully assessed.

4.3 Operational Control and Delivery: Partial Modernization without System Intelligence

Many schemes have undergone physical rehabilitation—canal lining, structural improvements, partial control infrastructure—yet operational control often remains weaker than the physical appearance of

the system suggests. Rotational schedules may not be based on verified flow data, and canal operations depend on individual field staff experience rather than explicit service standards. Maintenance tends to be reactive rather than preventive. Automation, telemetry, and SCADA-type systems remain rare outside pilots.

4.4 IMIS and Digital Asset Management: Fragmented Progress

GIS mapping, digital inventories, and project-based databases have expanded over time but remain fragmented across projects, offices, and donor-supported initiatives. Data may exist in pieces but not as a functioning management ecosystem—a scheme may be mapped, yet its delivery performance is not linked to its asset record. This is a common pattern of partial digitalization without institutional integration.

4.5 Performance Assessment: Still Not Institutionalized

Schemes are rarely benchmarked for adequacy, reliability, equity, timeliness, or water productivity. When assessment occurs, it is typically project-driven, consultant-led, or episodic rather than embedded in normal operations. Without performance assessment, data remain unused, field problems remain poorly prioritized, and modernization becomes indistinguishable from mere technology procurement.

4.6 Decision Support Systems: Promising but Underused

Remote sensing, evapotranspiration estimation, crop water analysis, and water accounting offer strong potential in Nepal, particularly where ground measurement density is limited. These tools can support command area verification, relative performance diagnosis, and seasonal planning. However, integration into routine agency practice remains limited, constrained not only by technical capacity but by institutional readiness to act on analytical outputs.

5. DWRI's Digital Transformation Initiatives

The Department of Water Resources and Irrigation (DWRI) has recognized these gaps and is actively pursuing digital transformation through two complementary systems—NIMIS and NIIMS—that together form the information backbone for technology-enabled irrigation management.

5.1 Nepal Irrigation Management Information System (NIMIS)

NIMIS is a static database system focused on documenting information related to irrigation systems, including canal networks, command areas, and detailed asset inventories. Its main goal is to integrate a web-based MIS database with GIS and online reporting capabilities. The system covers both FMIS and AMIS databases and is accessible at <https://nimis.dwri.gov.np/>.

As of the most recent update, NIMIS contains:

- 6,040 Farmer-Managed Irrigation Systems (FMIS) with a gross command area of 668,677 ha
- 32 Agency-Managed Irrigation Systems (AMIS) with a gross command area of 400,618 ha
- Asset inventory completed for 7 AMIS (Chandra Nahar, Koshi Pump, Koshi Distribution, Kamala, Manusmara, Jhajh, and Narayani Irrigation Systems), with 2 more systems currently being updated
- 876 groundwater irrigation systems

A NIMIS Mobile Application has been developed to facilitate data collection and updates from the field level. This supports both viewing and updating of information across user levels, enabling semi-real-time data capture for lower-order canals and field reporting. The system demands continuous operation and regular database updating, particularly for asset inventory ratings that contribute to asset management and maintenance planning.

5.2 Nepal Irrigation Infrastructure Monitoring System (NIIMS)

NIIMS is a dynamic real-time monitoring system designed to track the status of irrigation water flow through main canals at major irrigation systems across the country. It is accessible at <http://niims.dwri.gov.np/>.

Key features of NIIMS include:

- 15 telemetry systems (radar-level water sensors) installed across various AMIS, including Kamala IS, Narayani IS, and Gandak IS, measuring water levels in main canals
- Integration of sensor data into a centralized platform providing shared visibility across federal, provincial, and local levels
- A decision support function for irrigation scheduling and water balancing
- Capacity to transform monitoring data into operational choices supporting timely delivery and equitable allocation

DWRI is currently monitoring data and finalizing system development before formal handover to respective projects. The overarching integration ambition is to unify all fragmented telemetry systems into NIIMS as a national monitoring backbone.

5.3 Integration Architecture and Future Plans

Together, NIMIS and NIIMS are designed to provide a two-tier information architecture: NIMIS as the static, asset-oriented layer and NIIMS as the dynamic, real-time monitoring layer. The technology-driven improvement pathway flows from data capture (sensors and mobile apps) through connectivity (telemetry) and spatial context (GIS asset mapping) to integrated digital platform (dashboards, MIS integration) and ultimately to decision support (irrigation scheduling and water balancing) and planning and evaluation (performance analysis and maintenance prioritization).

DWRI's near-term plans include:

- Capacity-building training for field staff at projects where telemetry systems are already installed, to translate real-time data into improved water management decisions
- Extension of at least one telemetry system per major federal irrigation project, with mobile-application-based semi-real-time observations for secondary canals
- Installation of soil moisture sensors at field level to support basic decision support for irrigation scheduling
- Providing provincial governments with login credentials for direct data entry into NIMIS/NIIMS (access already provided to Gandaki Province)
- Formal establishment of a dedicated MIS Division under the Irrigation Management Division (IMD), approved under recent O&M restructuring, to ensure sustained system operations and coordination across all divisions and field offices

6. Key Barriers to Technology Adoption and Data-Driven Management

Weak measurement culture and infrastructure: Many schemes were designed or rehabilitated without strong emphasis on operational measurement. Even where devices are installed, calibration, maintenance, and routine use are inconsistent. A sector that does not routinely measure water cannot efficiently manage it.

Supply-driven operations and limited scheduling intelligence: Current AMIS operations are predominantly supply-driven, relying on manual gate operation and rotational schedules based on

WUA agreements rather than verified flow data or crop-based demand assessment. This operational culture limits the value that monitoring infrastructure can deliver.

Hydro-geomorphic and disaster challenges: Sedimentation, erosion, flood damage, and source instability increase maintenance burdens and can render sophisticated installations unsustainable. Technologies must be robust, simple, and maintainable to succeed in Nepal's conditions.

Limited and uncertain O&M financing: Devices, sensors, and data systems require ongoing cleaning, calibration, replacement, and trained attention. Where O&M budgets are weak or uncertain, modernization often becomes short-lived—a frequent outcome when project-supported digital components fade after the project period ends.

Procurement bias toward hardware: Procurement systems often favor visible hardware acquisition over whole-life functionality. Agencies acquire devices without securing maintenance arrangements, spare parts, calibration protocols, staff training, or data governance frameworks. True digital modernization requires service ecosystems, not isolated equipment.

Human resource and skill gaps: The sector has limited capacity in instrumentation, sensor maintenance, database management, GIS integration, remote sensing interpretation, water accounting, and operational analytics. Engineering capacity remains predominantly construction-oriented. DWRI's recent capacity-building initiatives for NIIMS field staff represent a step in the right direction.

Fragmented institutional responsibility: Data relevant to irrigation are distributed across multiple agencies, projects, and administrative levels—water, agriculture, meteorology, groundwater, local governance—with weak coordination, differing standards, and limited interoperability. This is what NIMIS and NIIMS are designed to address, but institutional buy-in across levels remains a challenge.

Weak performance-based incentives: If service providers are not evaluated on reliability, equity, adequacy, or responsiveness, there is limited institutional motivation to invest seriously in measurement and performance systems. A sector cannot become data-driven unless data matter to accountability.

Farmer trust, usability, and adoption: DWRI's own lessons from digital implementation recognize that farmer participation is essential from design to operation. Technologies that farmers do not understand, trust, or find useful will not be maintained or acted upon at the local level.

7. A Practical Roadmap for Irrigation Modernization

Nepal does not need a single grand modernization package. It needs a staged, differentiated roadmap that starts with essentials, builds on existing initiatives like NIMIS and NIIMS, and expands institutional confidence over time. DWRI's own lessons from digital implementation converge on a key principle: treat digital irrigation as a service transformation—not only a technology rollout.

7.1 Institutionalize Minimum Monitoring Packages

Every significant scheme should have a basic monitoring backbone: simple flow measurement at key control points, basic climate information, groundwater observation where relevant, and clear field protocols for recording and validation. Building on NIIMS' 15 installed telemetry systems, the priority is to extend coverage to at least one main canal offtake per major federal project, while using the NIMIS Mobile Application for semi-real-time data capture at secondary canals. A simple device that is maintained and used is far more valuable than an advanced device that fails after installation.

7.2 *Build an Interoperable IMIS and GIS Asset Framework*

NIMIS provides the foundation. The next step is ensuring continuous operation and regular updating of existing databases—particularly asset inventory ratings that support maintenance planning—and extending coverage to provincial systems through the login-credential access model already piloted with Gandaki Province. The newly established MIS Division under IMD should be resourced to coordinate data standards, interoperability, and system governance across all divisions and field offices.

7.3 *Mainstream Performance Assessment*

Routine benchmarking—adequacy, reliability, equity, timeliness, and maintenance responsiveness—must become a normal part of irrigation management reporting and review. This step transforms information from passive data storage into active management intelligence, making the investment in NIMIS and NIIMS operationally meaningful.

7.4 *Use Remote Sensing and Water Accounting Strategically*

Remote sensing should be mainstreamed as a scalable complement to ground monitoring. In Nepal, where field measurement coverage is uneven, remote sensing-based ET estimation and water accounting can identify underperforming areas, assess irrigation intensity patterns, support seasonal planning, and guide field verification priorities. Its greatest value lies in helping agencies ask better operational questions and prioritize scarce field resources.

7.5 *Strengthen Participatory Monitoring and Local Accountability*

Especially in FMIS and mixed-management systems, participatory monitoring should be linked to transparent service indicators. DWRI's implementation experience confirms that farmer participation from design to operation is essential for sustainable outcomes. Data systems should support accountability downward to water users, not only upward to administrative reporting.

7.6 *Adopt Selective, Readiness-Based Automation*

The planned installation of soil moisture sensors for basic decision support in irrigation scheduling is a well-calibrated next step. More broadly, automation and telemetry should be introduced only where hydraulic conditions, staffing, budget reliability, and institutional readiness justify them. In much of Nepal, the higher-return strategy will be basic measurement plus disciplined operations rather than complex automation.

7.7 *Reform Procurement and Maintenance Logic*

Modernization must be procured as a system, not as a set of disconnected items. Procurement packages should include training, calibration plans, maintenance arrangements, data protocols, documentation, and replacement strategies. This is especially important given the experience of telemetry systems that were installed but not yet handed over to operating projects, underscoring the need for transition management and operations capacity as integral components of procurement.

7.8 *Develop a New Skill Base for Irrigation Institutions*

DWRI's planned capacity-building training for field staff at telemetry-equipped projects is an important first step. Irrigation modernization requires a broader professional profile: combined strengths in hydraulics, instrumentation, GIS, data systems, agronomy linkages, and operational analytics. Capacity development should move beyond one-time training toward sustained institutional learning pathways, aligned with the mandate of the new MIS Division.

Discussion

Water-use efficiency in Nepal should not be interpreted narrowly as reducing water application per hectare. In practice, it is a broader management challenge involving source reliability, conveyance control, delivery timing, crop alignment, maintenance, and institutional responsiveness.

DWRI's recognition that 'a smart irrigation management system is needed to close operational, data, and coordination gaps' correctly frames the challenge. The current gaps—manual operations, fragmented records, limited real-time data—are not primarily technical deficits. They are institutional and organizational ones. Digital tools can only close these gaps if they are embedded in operational routines, maintained with dedicated resources, and linked to accountability for service performance.

DWRI's two-system architecture (NIMIS + NIIMS) represents a structurally sound approach. The static-dynamic combination mirrors best practice in irrigation information systems: asset management requires longitudinal, stable records, while operational management requires timely, dynamic data. The challenge ahead is not architectural design but institutional embedding—ensuring that data generated by these systems actually inform daily canal operations, maintenance decisions, and service delivery reviews.

Two major implications follow for Nepal's modernization path. First, efficiency gains cannot be achieved by hardware alone. Better structures without measurement leave operators partially blind. Sensors without protocols generate unused data. The lesson from DWRI's own experience is clear: digital irrigation must be treated as a service transformation, not only a technology rollout. Second, the modernization debate must remain grounded in Nepal's institutional and geographical reality. FMIS areas require low-cost, socially compatible, robust solutions that reinforce local institutions. Larger Terai AMIS require stronger institutional control, better service accountability, and systematic benchmarking. These are genuinely different modernization pathways.

Conclusion

Nepal's irrigation sector has reached a point where further progress depends less on infrastructure expansion alone and more on the quality of management, measurement, and institutional learning. Over 100 years of irrigation development has created an extensive infrastructure base, but coverage and service quality gaps remain large. The Department of Water Resources and Irrigation is responding with concrete digital initiatives—NIMIS and NIIMS—that provide the information backbone for technology-enabled management.

The sector's core weaknesses are clear: supply-driven operations without demand intelligence, inconsistent flow measurement, fragmented data systems, limited performance benchmarking, inadequate O&M support, skill gaps, and insufficient incentives for service-based management. These weaknesses collectively prevent Nepal from converting available technologies into sustained gains in water-use efficiency.

The way forward is staged, context-sensitive modernization: institutionalizing minimum monitoring packages built on the NIIMS telemetry foundation, strengthening NIMIS as an interoperable asset and service information system, mainstreaming performance assessment, using remote sensing strategically, reinforcing participatory accountability, and applying automation selectively. The establishment of a dedicated MIS Division within DWRI, the extension of provincial access to digital systems, and the planned soil moisture monitoring program all reflect this direction.

Ultimately, irrigation modernization in Nepal is not only a technical agenda—it is a governance, management, and service delivery agenda. Closing the data-to-decision gap is the central condition for making irrigation investments work better under the growing pressures of climate variability, fiscal constraints, and rising expectations from agriculture. Digital transformation succeeds only when technology is paired with farmer participation, institutional ownership, and long-term delivery capacity.

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