Collegiate Research Journals

OPEN ACCESS

Global Research Journal of Social Sciences
Vol 6(10) pp. 011-018 October, 2026.
https://collegiatejournals.us/assd
Copyright © 2026 Collegiate Research Journals

Full Length Manuscript

Irrigation and Agricultural Water Management in Egypt: Efficiency, Drainage, Water Reuse and Climate-Resilient Pathways

Ahmed Nour* and Mahmoud Ashraf

Accepted 4th September 2026

Abstract

Egyptian agriculture depends overwhelmingly on irrigation because rainfall is insufficient to sustain most crop production. The Nile Valley and Delta therefore form a highly engineered irrigation landscape in which conveyance, field application, drainage, groundwater interactions and reuse are tightly connected. This review synthesizes evidence on irrigation management in Egypt, with emphasis on irrigation efficiency, surface versus modern irrigation systems, subsurface drainage, salinity, agricultural drainage-water reuse, and the emerging need for integrated water management under increasing demand and climate uncertainty. Published studies indicate that improving field and conveyance performance can reduce avoidable losses, but apparent water savings at farm scale do not automatically translate into equivalent basin-scale savings because return flows and drainage-water reuse are integral components of the Egyptian water system. Research from the Nile Delta also shows that drainage design affects irrigation efficiency, water use efficiency, crop performance and salinity control. Recent work on modern irrigation systems highlights an additional trade-off: localized irrigation may reduce crop water consumption while altering groundwater recharge and salinity dynamics, particularly in coastal parts of the Delta [9]. The review proposes an integrated framework linking irrigation scheduling, land leveling, appropriate modernization, drainage management, water-quality monitoring, treated drainage-water reuse and farmer participation. The evidence suggests that Egypt's most useful irrigation strategy is not a single technology but coordinated management of water quantity, quality, soil salinity and return flows at farm, canal and basin scales.

Keywords: Egypt; irrigation; agriculture; Nile Delta; agricultural water management; irrigation efficiency; drainage; salinity; water reuse

1. Introduction

Egypt is one of the world's most irrigation-dependent agricultural systems. In the Nile Valley and Delta, crop production is sustained by a dense network of canals, field channels, pumping stations and drainage infrastructure. The Delta alone contains more than two million hectares of irrigated land and a highly interconnected irrigation and drainage network [1]. The resulting system should be understood as a circulation of water rather than a one-way delivery chain: water diverted to fields can be consumed by crops, evaporated, infiltrated, returned through drains, reused elsewhere, or ultimately discharged to the Mediterranean [1,3,4].

Water scarcity, agricultural expansion, urban growth, groundwater pressures and climate uncertainty increase the importance of irrigation management. Egypt has consequently pursued irrigation improvement, drainage programs and reuse of agricultural drainage water. FAO documentation describes drainage-water reuse as an important component of Egypt's irrigation supply, while also emphasizing that drainage water may have higher salinity and pollution loads than fresh irrigation water and therefore requires quality management [10,11].

Modernization is not synonymous with simply replacing surface irrigation with drip or sprinkler systems. Basin-scale water accounting matters. Studies of the Delta indicate that only a fraction of water apparently saved through irrigation improvement may become available for new consumptive uses because return flows and downstream reuse are part of the existing balance [2,3]. Thus, irrigation policy should distinguish field-scale efficiency from basin-scale water saving and evaluate salinity, groundwater and drainage consequences alongside crop yield.

2. Objectives

- Synthesize the principal irrigation and agricultural water-management challenges in Egypt.
- Examine relationships among irrigation efficiency, drainage, salinity and drainage-water reuse.
- Compare the management logic of surface and modern irrigation systems in Egyptian conditions.
- Identify research and management priorities for water productivity and climate resilience.

3. Method

This manuscript was prepared as a narrative evidence review focused on irrigation and agricultural water management in Egypt. Literature was identified through targeted searches of peer-reviewed journal articles and institutional sources, prioritizing studies on the Nile Valley, Nile Delta, irrigation improvement, drainage, salinity, water reuse and modern irrigation systems. Recent peer-reviewed evidence was emphasized, while foundational studies were retained where they establish hydrological or management context. Sources were screened for relevance to Egyptian agricultural irrigation, and findings were synthesized thematically rather than statistically. Because the review does not constitute a systematic review or meta-analysis, no pooled effect estimate is reported. Quantitative values in the tables are reported findings from cited studies and are not new field measurements. The two figures are original conceptual diagrams prepared for this manuscript.

4. Results

4.1 Structure of Egypt's Irrigation System

The evidence portrays Egyptian irrigation as a hierarchical network extending from Nile storage and major conveyance canals to branch canals, mesqas, farm fields and drainage systems. In the relatively flat Delta,

pumping is often required to move water from mesqas to fields. Irrigation scheduling and reliability therefore influence both crop production and farmer behavior [3].

4.2 Irrigation Efficiency and Water Productivity

Traditional irrigation-efficiency calculations can be misleading when applied to Egypt because drainage and return flows are frequently reused. FAO's assessment distinguished classical irrigation efficiency from broader system-level efficiency and reported that conventional overall irrigation efficiency could be approximately 40–50%, while sector-level efficiency was much higher when reuse was included [11]. This distinction is central: water leaving a field is not necessarily lost from the agricultural economy if it becomes a usable return flow.

Accordingly, practical irrigation improvement should target water productivity—the crop or economic output generated per unit of water consumed—rather than maximizing a single field-level efficiency ratio. Scheduling, land leveling, maintenance of conveyance structures, reliable deliveries and reduction of excessive applications can improve productivity without assuming that every reduction in drainage represents a net basin saving.

4.3 Surface Irrigation and Modern Irrigation Systems

Surface irrigation remains important in the Nile Delta because of land fragmentation, established infrastructure and farmer practices [3,7]. Modern irrigation systems, including drip and sprinkler technologies, can improve application control and reduce crop water consumption under suitable conditions. However, technology performance depends on crop type, soil texture, field geometry, filtration, pressure management, maintenance and farmer skill.

A 2024 study of the coastal Nile Delta compared several modern irrigation configurations and found that changing irrigation methods affected both water efficiency and groundwater salinity. The authors concluded that modern systems can reduce crop water consumption but may also influence saltwater intrusion and therefore should be integrated with groundwater and land-use management [9].

4.4 Drainage, Waterlogging and Salinity

Drainage is a core component of sustainable irrigation in Egypt. Intensive irrigation under an arid climate can raise groundwater levels and promote secondary salinization when salts are not adequately removed [5]. The Nile Delta has extensive subsurface drainage infrastructure that helps maintain soil productivity, but the depth and operation of drains affect both water losses and crop performance.

In a 2021 Nile Delta study, shallower drain placement reduced drain outflow and water input while increasing irrigation efficiency and water-use efficiency for sunflower; the reported optimum within that experiment was a 40-cm drain depth [7]. Another modeling study found that a 28.5% reduction in drainage depth was associated with approximately 15% irrigation-water conservation, while crop-yield reductions varied by crop and salinity conditions [8]. These results demonstrate that drainage design should be evaluated as part of the irrigation system rather than as an independent infrastructure component.

4.5 Agricultural Drainage-Water Reuse

Reuse of agricultural drainage water is an established element of Egyptian water management. Drainage water can supplement irrigation supplies, but its quality is influenced by salts, nutrients, pesticides, pathogens and other pollutants accumulated as water moves through agricultural land and drainage networks [10,12]. FAO assessments emphasize the importance of controlling the location and quality of reuse because poorly managed mixing can transfer contaminants downstream [10].

Recent scholarship describes a further development: drainage water from established agricultural areas is increasingly treated and conveyed toward newly reclaimed desert agricultural areas [12]. This creates an opportunity to expand agricultural production while also increasing the importance of treatment performance, salinity control, energy requirements, monitoring and equitable allocation.

4.6 Water Balance and Return Flows

The Nile Delta is a particularly important case for whole-system water accounting. A detailed water-balance study concluded that the Delta's outflow to the Mediterranean had remained relatively stable over several decades despite major changes in irrigation and water use, and emphasized uncertainty in many balance components [1]. A later analysis of irrigation improvement projects concluded that only about 5–10% of water could be saved at Delta scale for other uses or expansion under the conditions analyzed [3]. These findings caution against interpreting field-level reductions in irrigation as equal volumes of new water available to the basin.

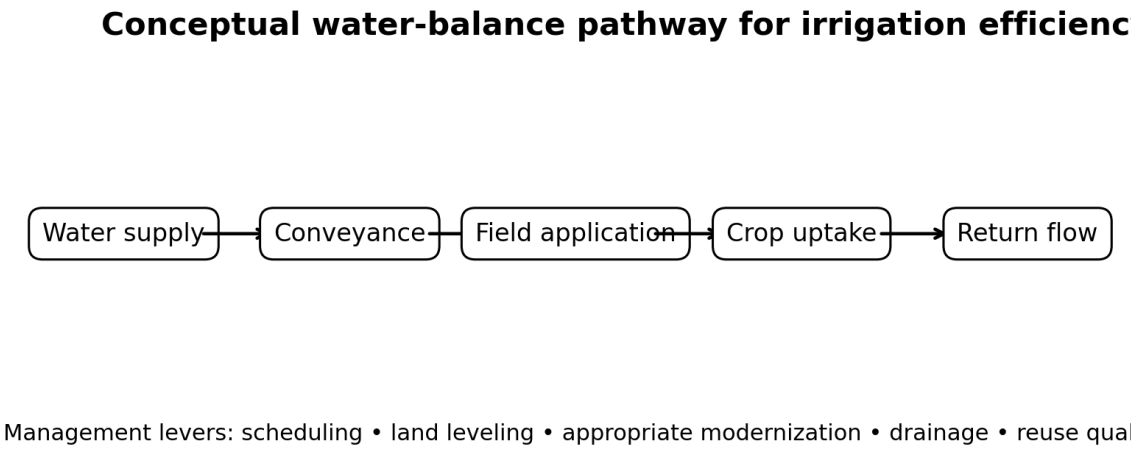


Figure 2. Conceptual water-balance pathway linking irrigation supply, crop uptake and return flow. Original figure.

4.7 Climate Resilience

Climate-resilient irrigation in Egypt requires management that can respond to variability in crop water demand, high evaporative losses, heat stress, salinity and changing groundwater conditions. The most transferable measures are combinations of improved scheduling, soil-moisture monitoring, maintenance, drainage, appropriate irrigation technology and crop choices rather than a universal prescription for one irrigation method.

Table 1. Principal irrigation-management components in Egypt

Component	Primary function	Potential benefit	Key constraint
Surface irrigation	Field water delivery	Compatible with existing systems	Uneven application; over-irrigation risk
Drip irrigation	Localized application	High application control; reduced crop water use in suitable settings	Capital, filtration, maintenance and salinity-management requirements
Sprinkler irrigation	Pressurized application	Uniformity on suitable soils/crops	Energy demand; wind and evaporation losses
Subsurface drainage	Control water table and salts	Reduces waterlogging and salinity risk	Installation and maintenance cost
Drainage-water reuse	Supplement irrigation supply	Adds usable water to agricultural system	Salinity and pollutant risks; treatment needs
Scheduling/monitoring	Match supply to crop demand	Reduces avoidable applications	Requires information and reliable delivery

Table 2. Selected quantitative findings from Egyptian irrigation studies

Study	**Reported finding**	**Interpretation**
FAO irrigation assessment [11]	Classical overall irrigation efficiency about 40–50%; sector-level efficiency approached 80% when drainage reuse was considered	Field efficiency and basin/system efficiency can differ
Nile Delta drainage-depth experiment [7]	Shallower drains reduced drain outflow and water input and improved irrigation efficiency; 40 cm gave maximum productivity/WUE in that experiment	Drain design affects water balance and crop response
Drainage-depth modeling [8]	28.5% reduction in drainage depth associated with about 15% irrigation-water conservation; yield response varied 1.2–5.8%	Drain optimization requires crop- and salinity-specific analysis
Nile Delta irrigation improvement analysis [3]	Estimated only 5–10% of water could be saved at Delta scale for other uses under analyzed conditions	Not all farm-level savings become basin-scale new water
Coastal Nile Delta study [9]	Modern irrigation reduced crop water consumption in analyzed scenarios but could alter groundwater salinity	Modernization should be linked to groundwater management

Table 3. Major challenges and research priorities

Challenge	**Management question**	**Research priority**
Water scarcity	How much water can be saved without harming downstream users?	Basin-scale water accounting
Salinity	How should irrigation and drainage be jointly optimized?	Coupled soil-water-salt models
Fragmented farms	Which technologies are practical for smallholders?	Low-cost collective modernization
Drainage reuse	Where is reuse safe and economically efficient?	Continuous water-quality monitoring and treatment
Groundwater	How does modernization change recharge and salinity?	Integrated groundwater–surface-water models
Climate variability	How should schedules adapt?	Weather and soil-moisture decision support

5. Discussion

The Egyptian case demonstrates why irrigation efficiency should be treated as a systems problem. At farm scale, reducing deep percolation or runoff may appear beneficial. At basin scale, however, those flows may support drainage, downstream irrigation or groundwater recharge. The value of an intervention therefore depends on where the water goes after the intervention and whether that destination has productive or environmental value [1–3,11].

Drainage illustrates the same principle. Removing excess water protects soil productivity and controls salinity, yet excessive drainage can reduce irrigation efficiency and transport salts and contaminants. Evidence from the Delta suggests that drain depth can be optimized rather than simply maximized [7,8]. This supports a management paradigm in which irrigation and drainage are designed together.

Modern irrigation technologies have a role but should be selected according to local conditions. Drip irrigation can provide precise delivery and fertigation opportunities, while sprinkler systems can be effective for particular crops and soils. In coastal Delta environments, groundwater and saltwater intrusion must be considered because changing irrigation and recharge patterns may have unintended consequences [9].

Drainage-water reuse can increase effective water supply, but it also concentrates the importance of water quality. Treatment, blending rules, monitoring and location of reuse points should therefore be considered alongside hydraulic capacity. Recent redistribution of treated drainage water toward reclaimed desert agriculture reinforces the need to evaluate energy, salinity and long-term soil impacts rather than measuring success only by the area newly irrigated [12].

6. Practical Management Framework for Egypt

Measure water at canal, farm and drainage levels so apparent savings can be distinguished from basin-scale savings.

Prioritize irrigation scheduling and field leveling before large-scale technology replacement where cost-effective.

Use drip or sprinkler systems selectively where crop value, soil, field geometry, pressure availability and maintenance capacity justify them.

Treat drainage as part of irrigation design, with drain depth and spacing optimized for crop yield, water-table control and salinity.

Expand drainage-water reuse only with water-quality monitoring, appropriate blending/treatment and safeguards for downstream users.

Integrate groundwater monitoring into modernization programs, especially in coastal Nile Delta zones.

Strengthen farmer participation, extension services and collective management for fragmented holdings.

Use climate and soil-moisture information to adapt irrigation timing rather than relying only on fixed calendars.

7. Limitations

This is a narrative review and not a systematic review or meta-analysis. Studies differ in crop, soil, drainage configuration, climate, experimental scale and definition of efficiency; therefore their numerical findings are not directly comparable. The manuscript does not present original field measurements or a new hydrological model. The conceptual figures are intended to clarify system relationships rather than represent measured Egyptian water balances.

8. Future Research Directions

Future Egyptian irrigation research should move toward integrated models that simultaneously represent crop demand, canal delivery, field application, drainage, groundwater, salinity and reuse. High-frequency sensors and remote sensing could support spatially explicit irrigation scheduling, while digital water accounting could help distinguish recoverable return flows from true basin-scale savings. More field trials are also needed to compare irrigation technologies under different soil textures, crop rotations and salinity conditions. Economic research should quantify total life-cycle costs, including energy, filtration, maintenance and replacement, rather than comparing installation costs alone.

9. Conclusion

Irrigation is the foundation of Egyptian agriculture, but sustainable irrigation cannot be reduced to a single efficiency percentage or technology choice. The evidence reviewed here shows that Egypt's irrigation future depends on managing water quantity and quality as one connected system. Surface-irrigation improvement, appropriate modernization, drainage optimization, salinity control and safe reuse of agricultural drainage water should be implemented together. The strongest research and management pathway is integrated, basin-aware and farmer-centered: improve productivity per unit of water while preserving the return flows, soils, groundwater and downstream functions on which the broader Nile agricultural system depends.

References

1. Darré E, Kuper M, et al. The Nile delta's water and salt balances and implications for management. Agricultural Water Management. 2018;197:110–121. doi:10.1016/j.agwat.2017.11.016.

2. Kuper M, et al. Irrigation improvement projects in the Nile Delta: Promises, challenges, surprises. Agricultural Water Management. 2019;216:425–435. doi:10.1016/j.agwat.2019.02.013.

3. Kuper M, et al. Irrigation improvement projects in the Nile Delta: Promises, challenges, surprises. Agricultural Water Management. 2019;216:425–435. doi:10.1016/j.agwat.2019.02.013.

4. El-Kady M, El-Shibini F. Desalination in Egypt and the future application in supplementary irrigation. Desalination. 2001;136(1–3):63–72. doi:10.1016/S0011-9167(01)00166-7.

5. Smedema L, Abdel-Dayem S, Ochs WJ. Soil salinization in the Nile Delta and related policy issues in Egypt. Agricultural Water Management. 2000;43(2):239–261. doi:10.1016/S0378-3774(99)00052-9.

6. FAO. Rapid assessment study: Towards integrated planning of irrigation and drainage in Egypt, in support of the Integrated Irrigation Improvement and Management Project. Food and Agriculture Organization of the United Nations.

7. El-Ghannam A, et al. Irrigation efficiency, drain outflow and yield responses to drain depth in the Nile delta clay soil, Egypt. Agricultural Water Management. 2021;246:106674. doi:10.1016/j.agwat.2020.106674.

8. Sheha M, et al. Effects of drain depth on crop yields and salinity in subsurface drainage in Nile Delta of Egypt. Ain Shams Engineering Journal. 2021;12(2):1595–1606. doi:10.1016/j.asej.2021.01.008.

9. Optimizing irrigation systems for water efficiency and groundwater sustainability in the coastal Nile Delta. Agricultural Water Management. 2024;304:109064. doi:10.1016/j.agwat.2024.109064.

10. Barnes J. Mixing waters: The reuse of agricultural drainage water in Egypt. Geoforum. 2013;46:138–147. doi:10.1016/j.geoforum.2012.11.019.

11. FAO. Rapid assessment study: Towards integrated planning of irrigation and drainage in Egypt, in support of the Integrated Irrigation Improvement and Management Project. FAO/International Programme for Technology and Research in Irrigation and Drainage.

12. Tawfik M, Hoogesteger J, Moussa M, Hellegers P. 'Squeezing Out' the Nile Delta's drainage water to irrigate Egypt's desert land. 2024. FAO AGRIS record.