

## The Paradox of Irrigation Efficiency in Semi-Arid Agriculture: New Evidence from the Souss-Massa River Basin of Morocco

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### Abstract

Irrigation modernisation is heavily promoted as a main strategy to improve water efficiency and climate resilience in semi-arid agriculture. Yet, empirical evidence increasingly questions whether improvements in production efficiency lead to overall lower water abstractions. The paradox of irrigation efficiency in souss-Massa region (Morocco): A case study This paper analyses the “paradoxes” of irrigation efficiency as observed in the Moroccan Souss-Massa region where large scale adoption of drip-irrigation is concomitant with declining groundwater. Based on survey of 80 stakeholders, semi-structured interviews and fieldwork observations, this study employs a mixed-methods embedded case study to examine irrigation practice, monitoring technologies and governance frameworks. Results show extensive use of drip but ongoing groundwater reliance, low formal water accounting and fragmented institutional collaboration. We show that efficiency increases without abstraction regulation and governance integration may trigger rebound effects leading to enhanced water extraction. The paper concludes that sustainable agricultural water management in semi-arid areas depends on changing the current modernisation-oriented technology based approaches to management-based control efforts for water. The Moroccan example offers a wider perspective for water scarce regions subjected to structural drought in Climate Change.

**Keywords:** Irrigation efficiency, Groundwater depletion, Rebound effect, Water governance, Semi-arid agriculture, Water accounting

## 1. Introduction

Water shortage is among the major environmental and economic issues in semi-arid areas throughout the world. In regions like those of Mediterranean and North Africa, other factors to consider are the pattern of global environmental change that has increased hydrological variability, decreased groundwater recharge and evapotranspiration (IPCC 2023). Agriculture, which is responsible for ~70% of all freshwater withdrawals in the world — and over 80% in areas with low availability — stands at the heart of sustainability dilemma (FAO, 2022).

In turn, governments have focused on investing in improved irrigation systems – especially enlarged use of localised (drip) irrigation – as a means to improve water productivity and to build climate resilience. Drip irrigation lowers losses during conveyance and increases the precision of application and is central to climate adaptation strategies (FAO, 2010).

Morocco is an important case in point. On national scale, since two decades (e.g. Programme National d'Économie d'Eau d'Irrigation – PNEEI), subsidies for drip irrigation equipments and the homogenisation of modern equipments has developed. Notwithstanding this, the water levels in main agricultural basins (like Souss-Massa) are still falling (MAPMDREF, 2023). The yearly drawdown rate of the aquifer in some areas is greater than 1.5–2 m/year.

An important research question arises:

Why should modernised irrigation not necessarily mean sustainable water use?

In this article we investigate what might be called the irrigation efficiency paradox (IEP)—the concurrent prevalence of improved technologies with ongoing or increasing resource depletion. It suggests that increases in technological efficiency without a framework of water accounting and governance integration do not provide for systemic sustainability and may lead to a further expansion of resource exploitation due to rebound effects.

## 2. Literature Review

### 2.1 The Irrigation Efficiency Paradigm

General efficiency of irrigation is often understood as the proportion of water delivered to crops against that abstracted from a source. Drip irrigation allows high application efficiency and low evaporation and conveyance losses. As a consequence, it was widely endorsed as a climate-smart technology (FAO, 2010).

Yet, irrigation at field-level efficiency does not equal reduced basin withdrawal. It is important to make a distinction between application efficiency and consumptive use. More efficient use of water may imply less loss at the field level but it does not ensure reduction in overall abstraction (Hassani & Chafik, 2021).

### 2.2 The rebound effect on agricultural water consumption

The mathematics of the rebound effect, that someone would be tired and want to take a nap.<sup>24</sup> The rebound effect, introduced by the energy economist I tackled below in this report through measures which contribute. We have yet to decide how buildings can achieve their full potential for reductions, including changes in behaviour as part of any exploration into dwell commitments rather than acts. In the agricultural industry, efficiencies could also prompt:

- Expansion of irrigated area
- Increased cropping intensity
- Decades-long changes to higher-value, water-consuming crops

Unconstrained abstractions (no caps, no mechanisms for allocation) can indeed lead to irrigation modernisation increase explicitly in total water use EFFECTS WITHOUT ABSTRACTION CAPS OR ALLOCATION MECHANISMS.

### 2.3 Governance and IWRM Limitations

IWRM is based on holistic basin-based good governance (GWP 2000). But, some of the critics stress that IWRM, in many cases does not support farmers with operational tools for farm level use (UNDP, 2020).

Sustainable water management requires:

- Measurement
- Monitoring
- Allocation control
- Institutional coordination

Accounting for water, the systematic measurement and reporting of water use is increasingly understood to be critical (World Bank, 2023). Disappointingly, however, its use has not been widespread in many semi-arid agro-practice.

## 2.4 Architectonic Drought and Global Warming

The latest assessments of IPCC (2023) begin to describe water scarcity problems in semi-arid regions as more structural than cyclical. Chronic supply-demand imbalances exacerbate the vulnerability. Under such a situation, even if efficiency is improved, it is impossible to offset the total over-extraction of the system.

## 3. Methodology

This research uses a mixed method case study approach at the Souss-Massa region of Morocco .

### 3.1 Data Collection

- 80 respondents (farmers, advisors and institutional actors)
- Structured questionnaires
- Semi-structured interviews
- Field observations

The combination of quantitative irrigation data with qualitative governance analysis through mixed methods enables triangulation and hence the deepening understanding.

### 3.2 Analytical Framework

The analysis focuses on:

- Irrigation technology adoption
- Water source dependence
- Water measurement practices
- Institutional coordination

## 4. Results

### 4.1 Large-Scale Introduction of Drip Irrigation

The use of drip irrigation systems on surveyed farms is around 75%. Modernisation on irrigation is technically widespread.

### 4.2 Persistent Groundwater Dependence

More than 80% of the farms draw water from ground source as major supply. Aquifer drops persist, and pumping depths have risen markedly.

### 4.3 Weak Water Accounting Practices

Structured accounting for water is practised by only a small number of farms. Most of them use indirect indicators such as energy bill or pump working time instead of volumetric readings.

### 4.4 Rising Irrigation Costs

The high cost of more deep pumping for energy. However, the impact of costs on abstraction behaviour have not consistently resulted in lower water take as farmers may favour production certainty over short-term.

## 5. Discussion

### 5.1 Efficiency Without Abstraction Control

The results verify the paradox of irrigation efficiency. These systems increase the efficiency of water application, however, they do not translate necessarily into a basin-scale reduction in withdrawals. In the absence of:

- Abstraction caps
- Metering requirements
- Performance monitoring

expansion rather than retraction may be driven by efficiency gains.

## 5.2 The Governance Vacuum

Policy durability is reduced by institutional fragmentation and weak enforcement. Farmers frequently see water laws as remote or applied irregularly. Basin-level data integration remains limited.

This is consistent with governance literature's focus on coordination, transparency and participatory accountability (UNDP, 2020).

## 5.3 From Infrastructure to Management

The real challenge is managerially rather than technically. Sustainable water use requires:

- Farm-level volumetric accounting
- Basin-level aggregation of data
- Performance-based subsidy systems
- Digital monitoring integration

Without them, irrigation modernisation is partial reform.

## 6. Conclusion

The Moroccan situation shows that only an increase in irrigation efficiency will not be able to solve the agricultural water crisis in semi-arid areas.

Technology modernization, without institution of integrated water accounting

and governance reform, threatens to lead to deepening groundwater overdraft through the phenomenon known as rebound.

Amid structural drought and climate risk, the sustainable path calls for a shift away from infrastructure-led reform towards better water governance. The paradox of irrigation efficiency in Souss-Massa contains more general teaching-points for water-scarce areas globally.

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