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The hidden health costs of irrigation: Evidence from rural Burkina Faso

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Abstract

While irrigation is key to boosting agricultural productivity in Burkina Faso, it may come with hidden health costs. Drawing on data from over 1 000 households in the Sourou Valley and using propensity score matching, this study uncovers the unintended consequences of irrigation for public health. Households practising irrigation experience 3.5 to 3.8 more cases of illness annually and spend up to CFA 27 915 more on healthcare compared to rain-fed farmers. These impacts are linked to stagnant water and unsafe chemical use. The findings highlight the urgent need for integrated policies that combine agricultural gains with improved sanitation, safe input practices, and environmental safeguards. Balancing productivity and health is essential for sustainable rural development.

Key words: irrigation adoption, health impacts, socio-environmental externalities, propensity score matching

1. Introduction

For centuries, various development strategies have been implemented worldwide. Industry, often regarded as the cornerstone of economic growth, remains underdeveloped in Africa. Despite recent efforts, the continent still contributes less than 3% to global manufacturing output, reflecting persistent structural challenges (Newman *et al*. 2016). In response to this reality, countries have devised tailored strategies aligned with their specific contexts. In many developing nations, agriculture continues to play a central role in economic recovery, with irrigation remaining a key instrument to enhance yields and resilience (Glatzel *et al*. 2018).

Beyond food security, agricultural policies in many developing countries are also designed to raise the contribution of agriculture to the gross domestic product (GDP) and to stimulate overall economic growth. Recent evidence highlights that agriculture remains central not only as a source of income, but also as a driver of rural transformation and employment creation (World Bank 2020). At the same time, development today is understood as a multidimensional process that goes beyond economic wealth and integrates social, cultural and environmental dimensions to ensure sustainability (Rockström *et al*. 2017; Fiori Maccioni 2018). Nevertheless, agricultural production and consumption activities generate important externalities, particularly environmental and health related, that must be considered in policy design (FAO 2017).

The concept of environmental externality sheds light on the social costs arising from nuisances generated by production and consumption (Dasgupta *et al*. 2016; Read 2023). In this context, agriculture is identified as a significant contributor to pollution, primarily through greenhouse gas emissions and the extensive use of chemicals (Kazimierczuk *et al*. 2023)). While irrigation plays a pivotal role in agricultural intensification, it is also linked to health risks, being associated with over 20 diseases (Giordano *et al*. 2019).

In Burkina Faso, where limited industrialisation constrains economic opportunities, agriculture occupies a central place in development strategies. With 80% of the workforce employed in this sector (INSD 2018), the country has adopted an agro-sylvo-pastoral intensification strategy for the period from 2018 to 2027 period. Key priorities of this strategy include the sustainable management of natural resources and the expansion of irrigated production. However, the intensification of agriculture – characterised by the clearing of 5.94 million hectares and the widespread use of chemical inputs, such as 181.51 kg/ha of fertilisers, as well as large quantities of herbicides, fungicides and pesticides (DGESS/MARAH 2022) – presents significant environmental and health challenges, generating considerable social costs (Bélair-Hamel 2017).

Against this backdrop, the rural commune of Di cultivates 9 385 hectares of developed irrigated perimeters (AMVS 2022a). However, irrigation practices in this area raise significant health concerns, with certain diseases directly linked to these activities (Salomon 2006). This study examines whether irrigation systems exacerbate health risks and financial burdens for local populations.

While the existing literature extensively highlights the multifaceted health impacts of irrigation, including waterborne and vector-borne diseases, and chemical contamination (Domenech & Ringler 2013; Senanayake & Mukherji 2014; Giordano *et al*. 2019), our study contributes a localised and empirical perspective by focusing on the environmental externalities of irrigation systems in the rural commune of Di, Burkina Faso. Our research employs a robust propensity score matching (PSM) methodology to assess the causal health effects specific to irrigated perimeters. By quantifying the frequency of illnesses and healthcare expenditures directly attributable to irrigation activities, we bridge a critical gap in understanding the socio-environmental costs faced by local populations.

To address this, the manuscript is structured as follows: Section 2 provides a literature review on the socio-environmental effects of irrigation. Section 3 describes the study areas and their characteristics. Sections 4 and 5 outline the methodology, focusing on the propensity score matching (PSM) approach. Section 6 presents the results, discussing the health and economic impacts of irrigation. Finally, Section 7 concludes.

2. Literature review

Irrigation plays a critical role in enhancing agricultural productivity and ensuring food security. However, its health-related effects are multifaceted, affecting local populations both positively and negatively (Domenech & Ringler 2013). These impacts are particularly evident in the spread of waterborne and vector-borne diseases, chemical contamination, and the dynamics of malaria prevalence. Nevertheless, irrigation also offers significant health benefits, particularly through improved hygiene and nutrition.

Irrigation that relies on untreated or minimally treated wastewater is a significant source of waterborne and vector-borne diseases. In semi-arid regions, these practices heighten the risk of illnesses such as schistosomiasis and diarrhoea, exacerbating existing health vulnerabilities (Amoah *et al*. 2009; Giordano *et al*. 2019). In addition, the construction of irrigation-related dams alters aquatic ecosystems by slowing river flows, creating stagnant water zones. These zones provide ideal habitats for disease vectors, including *Anopheles* mosquitoes and tsetse flies, thereby fostering the spread of malaria, dengue and sleeping sickness. However, these impacts vary depending on the quality of irrigation system management (Jobin 1999).

The water used for irrigation can be contaminated by naturally occurring substances such as arsenic, or by human-introduced chemicals, including pesticides, fertilisers and heavy metals like cadmium. These contaminants pose significant health risks, causing neurological, respiratory, endocrine and dermatological disorders (Simmons *et al*. 2005; Senanayake & Mukherji 2014; Koley 2022). Furthermore, irrigation increases agricultural productivity, which often leads to higher usage of chemical inputs, thereby raising exposure risks for both farmers and consumers. Studies demonstrate that the intensification of agriculture facilitated by irrigation is closely linked to these health challenges (Audibert *et al*. 1990; Adugna *et al*. 2024).

The relationship between irrigation and increased malaria incidence is well documented. Surface irrigation systems, especially those used for rice cultivation, create shallow water bodies that serve as breeding grounds for mosquito vectors. Research has shown that villages near dams or irrigation systems experience significantly higher numbers of malaria cases. For instance, in Ethiopia, small-scale dams led to a sevenfold increase in malaria prevalence (Ghebreyesus *et al*. 1999; Guthmann *et al*. 2002). However, these impacts are influenced by several factors, including prior exposure to malaria, the quality of health infrastructure, and migration levels into irrigated areas (Coluzzi 1984; Giordano *et al*. 2019).

Despite its risks, irrigation also yields notable health benefits. It improves water availability, facilitating better hygiene and sanitation practices, which reduce the prevalence of diarrhoea, schistosomiasis and other waterborne diseases (Meinzen-Dick & Van der Hoek 2001; Konradsen *et al*. 2004; Frake *et al*. 2024). In addition, the wealth generated by irrigation allows households to invest in health solutions such as mosquito nets and water filters (Klinkenberg *et al*. 2004). Increased income also enhances dietary diversity, addressing nutritional deficiencies like anaemia and night blindness (Robert *et al*. 1985; Ijumba & Lindsay 2001).

The way irrigation systems are managed plays a pivotal role in mitigating its negative health effects. Poorly maintained canals or inadequate landscape levelling can lead to an increase in vector-borne diseases (Chimbari *et al*. 2004; Mwangangi *et al*. 2013). In contrast, well-coordinated practices, such as synchronising planting seasons, can reduce stagnant water and limit vector breeding sites, thereby minimising malaria cases (Jobin 1999; Konradsen *et al*. 2004).

3. Overview of the study area

This study focuses on two rural communes in the Sourou Valley: the commune of Di, characterised by its irrigated agricultural perimeters, and Kassoum, which relies exclusively on rain-fed agriculture and serves as the control area.

3.1 Socio-environmental characteristics of the commune of Di

The commune of Di has experienced significant hydro-agricultural expansion since the introduction of irrigated farming in the 1960s. In addition to agriculture, fishing remains a key livelihood activity. Spanning 9 385 hectares along the Sourou River, these developments have largely replaced the former rain-fed agricultural lands (AMVS 2022a). Farmers are organised into cooperatives and have received training in production, infrastructure maintenance, marketing and financial management. However, environmental management has been largely overlooked (Semde *et al*. 2023).

The irrigation system in Di includes gravity-fed and sprinkler systems, relying on open concrete channels to transport water from 29 pumping stations equipped with 10 six-cylinder diesel engines. Each pump operates 10 to 12 hours per day over eight to 10 months, consuming about 12 litres of fuel daily. Oil changes, conducted every 150 hours, require 25 litres of oil (AMVS 2022b). These operations contribute to water contamination through the release of used oil and fuel into the channels, and to air pollution from diesel exhaust.

The agricultural model relies heavily on synthetic fertilisers (N, P_2O_5, K_2O, NPK), pesticides and herbicides – some considered hazardous, leading to potential environmental and health concerns (Semde *et al*. 2023). Poor handling and storage of these inputs expose farmers and vendors to respiratory hazards, while nearby residents also face health risks due to airborne chemicals.

Although the expansion of irrigation has led to the establishment of social infrastructure, such as a health centre, schools and potable water points (AMVS 2022b), sanitation remains severely inadequate. In the absence of proper waste management, open defecation is widespread, exacerbating environmental degradation and public health risks (Semde *et al*. 2023).

These socio-environmental conditions create a paradox: while irrigation provides reliable water access and supports local livelihoods, it also generates adverse externalities that facilitate the transmission of disease. Stagnant water from irrigation promotes the spread of waterborne diseases like schistosomiasis and malaria. Furthermore, extensive exposure to agrochemicals contributes to chronic respiratory illnesses such as asthma, bronchitis and rhinitis.

3.2 Socio-environmental characteristics of the commune of Kassoum

The commune of Kassoum lacks hydro-agricultural infrastructure. Agriculture in the area is extensive and family based, with producers relying on chemical fertilisers and organic manure, while the use of pesticides and herbicides remains minimal. Although rain-fed farming poses fewer environmental risks compared to irrigated agriculture, farmers still handle chemical products as part of their production activities.

From an environmental perspective, the commune is characterised by an almost complete lack of sanitation infrastructure. During the rainy season, which lasts from May to September, local water bodies (marigots) are frequently used by children for bathing, raising additional concerns about hygiene and public health.

4. Methodology and data

4.1 Description of the propensity score matching (PSM) procedure

A household typically chooses to engage in irrigated farming if the expected benefits outweigh those of not adopting it. However, this decision may overlook potential adverse effects that irrigation could have on overall well-being. The choice to adopt irrigation depends on several socioeconomic characteristics of households and the specific attributes of their farming practices. A vector X, comprising these characteristics, represents the explanatory variables that determine utility, influencing both the decision to adopt irrigation and the environmental externalities experienced by households.

In this context, we consider U_{i1} as the expected utility from irrigated farming and, U_{i0} as the utility expected from non-irrigated farming. A household engaged in irrigation will have $U_{i1} > U_{i0}$. However, utilities are not directly observable and depend on the variables included in the vector X.

Endogeneity presents a significant methodological challenge in evaluating irrigation adoption, often arising from self-selection. Households adopting irrigation may systematically differ from non-adopters due to factors such as better resource access, farming experience, proximity to infrastructure, cooperative membership, or training in agricultural techniques. These differences can influence both irrigation decisions and measured outcomes, such as health expenditures and environmental externalities, leading to biased results if not addressed.

To mitigate this issue, the study employs propensity score matching (PSM), an econometric method effective in controlling for observable characteristics (Rosenbaum & Rubin 1985). PSM assumes that, once observable factors are accounted for, the decision to adopt irrigation is independent of health outcomes. This is supported by a comprehensive set of control variables, including socio-demographic factors (e.g. gender, marital status), agricultural variables (e.g. farming experience, storage facilities), and health-related practices (e.g. latrine use, mosquito net usage). These controls ensure robust estimates of the influence of irrigation on illness frequency and related health expenditures.

4.1.1 Estimation of propensity scores

Propensity scores ($e(X_i)$) represent the probability that a household i adopts irrigation ($T = 1$), given its observable characteristics (X_i). These scores are estimated using a logistic regression model:

$$e(X_i) = P(T_i = 1|X_i) = \frac{exp(\beta_0+\beta_1 X_{i1}+\beta_2 X_{i2}+\cdots+\beta_k X_{ik})}{1+xp(\beta_0+\beta_1 X_{i1}+\beta_2 X_{i2}+\cdots+\beta_k X_{ik})}, \quad (1)$$

where:

$T_i = 1$ for households adopting irrigation and $T_i = 0$ for non-adopting households;
X_i represents the vector of explanatory variables (socio-demographic, agricultural, health and hygiene characteristics); and
$\beta_0, \beta_1, \ldots \beta_k$ are the parameters to be estimated.

4.1.2 Establishing common support

Before matching, it is essential to verify the existence of common support, ensuring that irrigating and non-irrigating households share overlapping ranges of propensity scores (Rosenbaum & Rubin 1983, 1985). This ensures that each treated household has a comparable control household. To verify the existence of common support, the first step involves visually inspecting the distributions of propensity scores for the treated and control groups. By plotting these distributions, overlapping regions can be identified, which indicate the presence of common support. This overlap ensures that treated households have comparable control households within the same range of propensity scores.

The common support region is formally defined as the range where the propensity score lies strictly between 0 and 1 ($0 < P(T = 1|X) < 1$). This definition ensures that no treated household is left unmatched due to the absence of similar control households within the propensity score range.

Finally, households that fall outside the common support region, such as treated households without comparable controls, are excluded from the analysis. By restricting the analysis to households within the common support region, the estimated treatment effects are based solely on comparable treated and control groups.

4.1.3 Matching procedure

To ensure a comprehensive and reliable evaluation of the effect of irrigation, we employed multiple propensity score matching (PSM) techniques, each designed to balance the treated (irrigating) and control (non-irrigating) groups, following the practical guidance of Caliendo and Kopeinig (2008). By varying these methods, we rigorously tested result consistency, thereby enhancing reliability and validity. Nearest neighbour matching paired each treated household with its closest control counterpart based on propensity scores. We implemented three variations: matching with one, two and three nearest neighbours to assess the effects of sample size on balance and robustness. Radius matching matched treated households within defined propensity score thresholds, testing radii of 0.01, 0.05 and 0.1. These thresholds balanced precision with sample inclusivity, revealing trade-offs between accuracy and match numbers. Kernel matching utilised a weighted average of all control households within the common support region, with weights based on proximity in propensity scores. This ensured robust estimates with minimal variability, while maximising sample use. Stratification matching divided the sample into propensity score blocks, ensuring comparability within blocks and structured analysis. Finally, linear regression adjustment matching refined estimates by addressing residual covariate imbalances post-matching, thus improving precision. This diverse suite of methods reduced biases, strengthened robustness, and provided reliable causal estimates of the effect of irrigation on illness frequency and healthcare expenses.

4.1.4 Verification of covariate balance

To confirm the quality of the matching process, the balance of covariates was evaluated between the treated (irrigating) and control (non-irrigating) groups. Balance tests, such as t-tests for means or standardised mean differences, were used to ensure that observable characteristics were statistically similar across the matched samples. This step verifies that the matched groups are appropriately comparable.

4.1.5 Estimation of treatment effects

After confirming covariate balance, the average treatment effect on the treated (ATT) was estimated. This represents the impact of irrigation on health outcomes, such as the frequency of illnesses, and the underlying expenses for households that adopted irrigation. Differences in outcomes between the matched groups are attributed solely to irrigation, as the matching process eliminates confounding effects from observable characteristics:

$$ATT = \frac{1}{N_T} \sum_{i \epsilon T} (Y_{i1} - Y_{i0}), \quad (2)$$

where:

N_T is the number of treated households;
Y_{i1} is the observed outcome (e.g. frequency of illnesses) for the treated households; and
Y_{i0} is the counterfactual outcome for the same households had they not adopted irrigation; for matched control households, Y_{i0} was estimated using the matched sample.

4.2 Data and variables used in the model

4.2.1 Data

The evaluation of the effects of irrigation on household well-being was based on a comparative design between two communes of the Sourou Valley: Di, which benefits from hydro-agricultural schemes, and Kassoum, which relies exclusively on rain-fed agriculture and serves as the control area. The proximity of these two communes, as well as their broadly similar agroecological and socio-cultural conditions, makes them particularly suitable for identifying the different impacts attributable to irrigation.

In Di, three villages (Di, Niassan and Débé) were selected because of their long-standing exposure to irrigation schemes and their socio-territorial diversity, including both long-established communities and resettlement areas created during the expansion of irrigation. Irrigation in this commune originates from large-scale schemes developed since the 1960s under government policies implemented by the *Autorité de Mise en Valeur de la Vallée du Sourou (AMVS)*, with initial support from international partners. These schemes are now operated through cooperatives, with farmers benefiting from shared infrastructure, while covering their own input costs such as seeds, fertilisers and pesticides.

As a counterfactual, three villages were chosen in Kassoum (Kassoum, Moara and Tiao), where agriculture is entirely rain-fed. Their selection was guided by their similarity to the villages of Di, while ensuring a minimum distance of 17 km from irrigated schemes in order to limit diffusion effects.

Data collection was conducted through a household survey between November 2022 and July 2023 using a structured questionnaire. In Di, purposive sampling was conducted, targeting 465 households actively cultivating at least one irrigated plot. In Kassoum, a random sampling procedure was applied to census lists provided by the local authorities, leading to the selection of 615 households. This strategy ensured both the representativeness of farming households and comparability between irrigating and non-irrigating groups.

For the purpose of this study, irrigation adopters are defined as households cultivating irrigated plots within the schemes of Di, while non-adopters are households practising only rain-fed agriculture in Kassoum. This operational definition provides a clear separation between the treated and control groups and guarantees consistency with the requirements of the propensity score matching (PSM) methodology.

4.2.2 Variables

The analysis focuses on two dependent variables: frequency of illnesses, reflecting the health impact of environmental externalities, and healthcare expenditures, capturing the financial burden of illnesses. These indicators were chosen because irrigation-related environmental externalities, such as stagnant water and chemical exposure, often lead to health risks, increased medical costs and reduced well-being. The treatment variable distinguishes between households practising irrigated farming (coded as 1) and those practising rain-fed farming (coded as 0). To account for confounding factors, a comprehensive set of explanatory variables was included:

- Gender of household head: male-headed households often access larger landholdings, enabling modern farming practices (Rieu 2004).
- Marital status: married heads benefit from labour sharing and resource allocation, boosting productivity (Yessoufou *et al*. 2021).
- Farming experience: experienced farmers manage risks better and are more likely to adopt irrigation (Ndiaye 2017).
- Sanitation infrastructure: access to latrines and proper waste management reduces disease prevalence (UNEP 2010).
- Distance to field: proximity enhances productivity, but may increase exposure to environmental risks.
- Storage facilities: mitigate contamination and improve agricultural output.
- Food and chemical safety: disinfection practices and the use of protective gear reduce health risks.

By incorporating these variables, the study controls for socio-demographic, agricultural and health-related factors, ensuring robust estimates of the causal effects of irrigation on environmental and health outcomes.

5. Findings and discussion

5.1 Descriptive statistics

Table 1 compares households practising irrigation (n = 465) and those relying on rain-fed agriculture (n = 615), highlighting significant disparities. Male-headed households are more likely to adopt irrigation, while irrigators report significantly more farming experience (29.57 years vs. 27.09 years). Irrigation fields tend to be located farther away (1.93 km vs. 1.69 km), reflecting the need for strategic access to water sources. Infrastructure differences are notable: 60.4% of irrigators have access to storage facilities, compared to only 10.2% of non-irrigators.

Health-related behaviours show mixed outcomes. Irrigators are more likely to have access to latrines (98.7% vs. 93.2%) and to disinfect food (24.1% vs. 6.8%), which may mitigate some health risks. However, they use mosquito nets less frequently (89.7% vs. 93.3%), raising concerns about vector-borne disease protection.

Health outcomes reveal significant challenges for irrigators, who report more cases of illness annually (6.32 vs. 2.73) and significantly higher healthcare expenses (CFA[1] 37 493 vs. CFA 8 658). This dual burden of health risks and economic costs underscores the complexities of irrigation adoption.

Environmental sanitation infrastructure remains similar between groups, with no significant differences in waste or wastewater management. However, stagnant water and unsafe chemical use in irrigation likely contribute to the observed health disparities.

Table 1: Descriptive statistics and mean differences between irrigation and non-irrigation households

	Treated (n = 465)		Untreated (n = 615)		Mean difference
	Mean	Std. dev	Mean	Std. dev	
Gender (1 = male)	0.963	0.009)	0.904	0.012	0.059***
Marital status (1 = married)	0.776	0.019	0.748	0.018	0.028
Education (1= yes)	0.389	0.023	0.343	0.019	0.046
Years of farming experience	29.568	0.760	27.088	0.741	2.480**
Distance to field (km)	1.928	0.048	1.687	0.045	0.241***
Latrine (1 = yes)	0.987	0.005	0.932	0.010	0.055***
Waste management infrastructure (1 = yes)	0.933	0.012	0.946	0.009	-0.013
Wastewater management (1 = yes)	0.030	0.008	0.033	0.007	-0.002
Storage facilities (1 = yes)	0.604	0.023	0.102	0.012	0.502***
Use of protective gear (1 = yes)	0.028	0.008	0.015	0.005	0.013
Food disinfection (1 = yes)	0.241	0.020	0.068	0.010	0.173***
Use of mosquito nets (1 = yes)	0.897	0.014	0.933	0.010	-0.037**
Frequency of illnesses	6.323	0.160	2.728	0.064	3.594***
Healthcare expenses (CFA francs)	37 493	1 682	8 658	398	28 835***

Note: ** and *** indicate significance at the 5% and 1% levels, respectively
Source: Survey data

5.2 Tests of validation of PSM

Before presenting the results of the impact of irrigation adoption on household health outcomes and healthcare expenses, it is essential to establish the robustness of the analytical approach. The validity of PSM relies on two critical assumptions (Rosenbaum & Rubin 1983, 1985): the existence of a common support region and the achievement of a covariate balance between treated (irrigating) and control (non-irrigating) households. This section outlines the validation process used to confirm these assumptions. First, the common support region was examined to verify that treated and control households share overlapping propensity score distributions, ensuring the feasibility of matching. Next, the balance of covariates before and after matching was assessed to demonstrate that observable characteristics influencing both treatment and outcomes are well matched across the groups.

5.2.1 Results of the common support

Figure 1 illustrates the distribution of propensity scores for treated households (in red) and untreated households (in blue), highlighting the extent of overlap necessary for effective propensity score matching. The common support results indicate that the majority of observations fall within the interval [0.2 to 0.8]. According to Caliendo and Kopeinig (2008), restricting the analysis to this region is a standard practice in propensity score matching, as it ensures sufficient overlap between the treated and control groups and reduces bias from poor matches. This approach is consistent with the recommendations of Heckman *et al*. (1997), and with empirical applications such as those of Dehejia and Wahba (2002) in program evaluation and Kassie and Alemu (2021) in agricultural technology

[1] CFA = CFA franc (Communauté Financière Africaine)

adoption. Therefore, the feasibility of PSM in our context is well supported by both methodological and empirical literature.

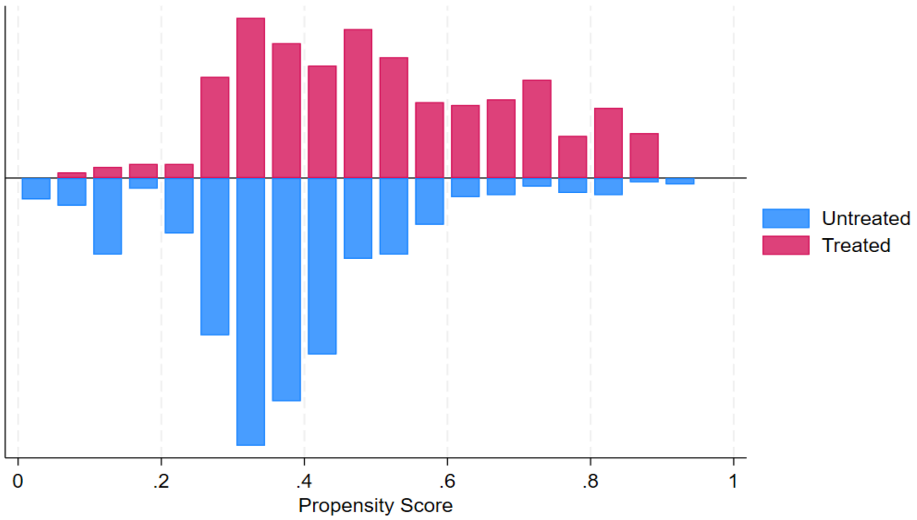

Figure 1: Distribution of propensity scores for treated and untreated households

5.2.2 Covariate balance before and after matching

Table 2 highlights significant improvements in covariate balance between irrigating and rain-fed farming households, enhancing the robustness of the irrigation impact evaluation. Propensity scores initially showed a substantial imbalance (bias: 150.8%, $p = 0.00$), but matching reduced this bias to 1.4% ($p = 0.86$), achieving a 99.1% reduction and ensuring comparability between the treated and control groups. Socio-demographic covariates improved notably. Gender bias decreased from 24% to 7.7%, while marital status achieved near-perfect balance, with bias reduced from 6.7% to -1.2% ($p = 0.85$). Sanitation and health infrastructure also saw improvements, with latrine access bias reduced from 28.3% to 7.9%, and waste management balanced even before matching ($p = 0.99$). Agricultural and environmental factors showed mixed results. Farming experience bias decreased from 14.2% to 10.1% ($p = 0.14$), while distance to fields improved from 22.6% to -14.3%, although a small imbalance remained ($p = 0.07$). Storage facilities achieved excellent balance post-matching, with bias reduced from 123.2% to -1.4% ($p = 0.86$). Health-related variables also improved. Mosquito net use bias declined from -13.1% to -8.1%, protective gear usage achieved near-perfect balance (bias: -31.6% to 0.2%, $p = 0.98$), and food disinfection bias fell from 49.1% to -3.6% ($p = 0.66$). Overall, the enhanced covariate balance validates the PSM approach, enabling reliable attribution of outcome differences to irrigation adoption.

Table 2: Balance of covariates before and after propensity score matching

	Status	Mean (treated)	Mean (control)	% Bias	% Bias reduction	t-stat	p-value
P-scores	Unmatched	0.64	0.27	150.80	-	25.15	0.00
	Matched	0.64	0.63	1.40	99.10	0.18	0.86
Gender	Unmatched	0.96	0.90	24.00	-	3.80	0.00
	Matched	0.96	0.94	7.70	68.00	1.38	0.17
Marital status	Unmatched	0.78	0.75	6.70	-	1.08	0.28
	Matched	0.78	0.78	-1.20	82.20	-0.19	0.85
Access to latrines	Unmatched	0.99	0.93	28.30	-	4.41	0.00
	Matched	0.99	0.97	7.90	72.10	1.66	0.10
Waste management infrastructure	Unmatched	0.93	0.95	-5.50	-	-0.90	0.37
	Matched	0.93	0.93	0.10	98.60	0.01	0.99
Wastewater management	Unmatched	0.03	0.03	-1.40	-	-0.22	0.82
	Matched	0.03	0.03	-1.50	-6.60	-0.22	0.82
Use of mosquito nets	Unmatched	0.90	0.93	-13.10	-	-2.17	0.03
	Matched	0.90	0.92	-8.10	38.30	-1.19	0.23
Years of farming experience	Unmatched	29.57	27.09	14.20	-	2.30	0.02
	Matched	29.57	27.82	10.10	29.40	1.47	0.14
Distance to field	Unmatched	1.93	1.69	22.60	-	3.66	0.00
	Matched	1.93	2.08	-14.30	36.90	-1.83	0.07
Storage facilities	Unmatched	0.60	0.10	123.20	-	20.70	0.00
	Matched	0.60	0.61	-1.40	98.80	-0.18	0.86
Food disinfection	Unmatched	0.24	0.07	49.10	-	8.27	0.00
	Matched	0.24	0.25	-3.60	92.70	-0.44	0.66
Use of protective gear	Unmatched	1.31	1.59	-31.60	-	-5.19	0.00
	Matched	1.31	1.31	0.20	99.50	0.02	0.98

Source: Authors' estimations

5.3 The determinants of irrigation adoption

The logistic regression analysis highlights key determinants of irrigation adoption among households (Table 3). The model demonstrates strong explanatory power, with a significant likelihood ratio chi-square ($\chi^2 = 431.01$, $p < 0.001$) and a pseudo-R^2 of 0.2920, indicating that the predictors explain a substantial share of the variance in adoption decisions. Significant predictors include gender, with male-headed households more likely to adopt irrigation, reflecting disparities in resource access. Access to latrines and proximity to fields also positively influence adoption by reducing logistical and health challenges. Storage facilities emerge as a critical driver, emphasising the importance of infrastructure for agricultural productivity. In addition, food disinfection practices suggest a link between health-conscious behaviours and irrigation adoption. Surprisingly, the use of protective gear shows a negative association, warranting further investigation into potential constraints or trade-offs. In contrast, variables such as marital status, waste management, mosquito net use and farming experience do not significantly affect irrigation adoption.

Table 3: Logistic regression results for determinants of irrigation adoption

Number of observations = 1 080				
LR $chi^2(11)$ = 431.01				
Prob > chi^2 = 0.0000				
Pseudo R^2 = 0.2920				
Log likelihood = -522.64554				
	Coefficient	**Std. err.**	**z**	**P > z**
Gender	0.851***	0.247	3.440	0.001
Marital status	-0.007	0.132	-0.050	0.957
Latrine	1.022***	0.254	4.010	0.000
Waste management infrastructure	-0.246	0.184	-1.330	0.183
Wastewater management	-0.379	0.264	-1.440	0.151
Use of mosquito nets	-0.010	0.167	-0.060	0.954
Years of farming experience	0.005	0.003	1.500	0.132
Distance to field	0.109***	0.041	2.640	0.008
Storage facilities	1.559	0.100	15.590	0.000
Food disinfection	0.905***	0.133	6.790	0.000
Use of protective gear	-0.145***	0.053	-2.720	0.006
Constant	-2.434***	0.403	-6.040	0.000

Note: *** indicates significance at the 1% level
Source: Authors' estimations

5.4 Impacts of irrigation on frequency of illnesses and healthcare expenses

Table 4 presents the average treatment effects on the treated (ATT) for two outcomes – frequency of illnesses and healthcare expenses – derived using various PSM methods. The results, supported by robust t-statistics from bootstrapped standard errors, provide critical insights into the health and economic impacts of irrigation adoption.

For frequency of illnesses, ATT estimates consistently indicate an average increase of 3.5 to 3.8 cases annually among irrigated households compared to non-irrigated ones. This association is statistically significant at the 1% level across all methods, underscoring its reliability. Techniques such as nearest-neighbour matching, radius matching, stratification matching, kernel matching and linear regression adjustment exhibit minimal variability. Nearest-neighbour matching shows a slight decline in ATT values as the number of neighbours increases (from 3.76 for one neighbour to 3.60 for three neighbours), while radius matching maintains stable results across thresholds.

For healthcare expenses, ATT estimates demonstrate a significant increase, ranging from CFA 25 932 to CFA 27 915, depending on the method. All estimates are highly significant at the 1% level, confirming the strong correlation between irrigation adoption and increased health expenditures. Variability is minor, with nearest-neighbour matching showing a slight reduction in ATT values as the number of neighbours increases (CFA 27 915 for one neighbour to CFA 24 263 for three neighbours). Radius matching also yields consistent results, except for a marginally lower ATT under the narrowest radius (r = 0.01). Other methods, including stratification, kernel and linear regression matching, validate these findings, offering robust estimates within a consistent range.

Sample composition shows 465 treated households, except under radius matching (r = 0.01), where stricter criteria reduced this to 416. Untreated households vary slightly, with kernel matching including 589 observations, compared to 615 in other methods. Total observations range between 1 031 and 1 080 due to adjustments for unmatched households.

The minimal variability across methods demonstrates the robustness of the results. Bootstrapped t-statistics with 500 replications further validate these findings, reducing random variability.

The consistent increase in cases of illness and healthcare expenses highlights significant health risks and economic burdens linked to the adoption of irrigation. These findings emphasise the need for targeted interventions, such as improved sanitation and protective measures, to mitigate these challenges.

These findings align with existing research. Studies by Amoah *et al*. (2009) and Giordano *et al*. (2019) emphasise the heightened health risks posed by waterborne and vector-borne diseases in irrigation settings. Factors such as stagnant water, which provides breeding grounds for vectors like mosquitoes, further exacerbate these risks, as highlighted in malaria and schistosomiasis research by Ghebreyesus et al. (1999) and Ijumba and Lindsay (2001). Similarly, the significant rise in healthcare expenses, estimated to be between CFA 25 932 and CFA 27 915, reflects findings by Audibert *et al*. (1990) and Adugna *et al*. (2024), where irrigation systems increased exposure to health hazards, including pesticide contamination, leading to higher medical costs.

These findings highlight the dual nature of irrigation. On one hand, it enhances agricultural productivity and economic growth, as noted by Parent *et al*. (2002), Ahmed and Mesfin (2017) and Zidouemba and Gerard (2018). On the other, it introduces substantial social costs through environmental health risks, particularly in the Sourou Valley, where poor water management and the use of chemical inputs intensify these externalities (Semde *et al*. 2023). Addressing these challenges requires targeted infrastructure improvements, such as enhanced drainage systems, as proposed by Meinzen-Dick and Van der Hoek (2001), and investments in sanitation facilities, which remain inadequate in areas like the commune of Di (AMVS 2022a).

Table 4: Estimated average treatment effects on the treated (ATT) for frequency of illnesses and healthcare expenses

	Nearest-neighbour matching			Radius matching			Stratification matching	Kernel matching	Linear regression matching
	n = 1	n = 2	n = 3	r = 0.01	r = 0.05	r = 0.1			
Frequency of illnesses									
ATT	3.76***	3.69***	3.60***	3.56***	3.51***	3.56***	3.54***	3.52***	3.52***
Robust t-stats	(13.96)	(15.00)	(15.18)	(15.42)	(15.63)	(16.45)	(12.73)	(15.60)	(11.48)
Obs. treated	465	465	465	416	465	465	465	465	465
Obs. untreated	615	615	615	615	615	615	589	615	615
Total obs.	1 080	1 080	1 080	1 031	1 080	1 080	1 054	1 080	1 080
Healthcare expenses (CFA francs)									
ATT	27 915***	27 474***	24 263***	25 932***	26 066***	25 964***	26 491***	25 808***	27 043***
Robust t-stats	(14.19)	(12.81)	(11.85)	(12.52)	(13.39)	(13.60)	(6.33)	(13.25)	(24.53)
Obs. treated	465	465	465	416	465	465	465	465	465
Obs. untreated	615	615	615	615	615	615	589	615	615
Total obs.	1 080	1 080	1 080	1 031	1 080	1 080	1 054	1 080	1 080

Notes: t-stats from bootstrapped standard errors (via 500 replications) in brackets; obs. = observations; *** indicates significance at the 1% level; for stratification matching, the number of strata is seven and the level of significance is 0.01.
Source: Authors' estimations

6. Conclusion and policy implications

This study assessed the socio-environmental impacts of irrigation adoption in Burkina Faso, with a particular focus on health outcomes and related costs. The results show that irrigation is associated with an average annual increase of 3.5 to 3.8 illness cases per household and additional healthcare expenditures ranging from CFA 25 932 to CFA 27 915. These findings highlight the paradox of irrigation: while it contributes to agricultural productivity and food security, it also generates health risks linked to stagnant water and unsafe use of agricultural chemicals, thereby exacerbating the prevalence of waterborne and vector-borne diseases.

From a policy perspective, balancing the agricultural benefits of irrigation with its environmental and health costs is essential for sustainable development. Interventions such as improved drainage systems, better sanitation infrastructure and educational programmes on safe chemical use and water management are critical to reduce risks. In addition, environmental audits – as recommended by Semde *et al*. (2023) – should be institutionalised to systematically monitor and mitigate negative externalities. Practical measures, such as the synchronised planting schedules advocated by Jobin (1999), can further limit water stagnation and reduce vector breeding in areas like the Sourou Valley. The study also reveals important structural and social challenges. Gender disparities in irrigation adoption, with male-headed households more likely to engage in irrigated farming (Rieu 2004), call for policies that specifically address barriers faced by women, including access to land, credit and training. Moreover, the reliance on cross-sectional data limits the capacity to capture temporal variations in health impacts, underscoring the need for future longitudinal studies.

Data availability

The data that support the findings of this study are available from the authors upon reasonable request.

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