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ORIGINAL ARTICLE

Sustainable reuse of hemodialysis reject water for potato farming: a large-scale feasibility study in Morocco

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Abstract

Background Hemodialysis consumes huge volumes of water and produces large quantities of wastewater.

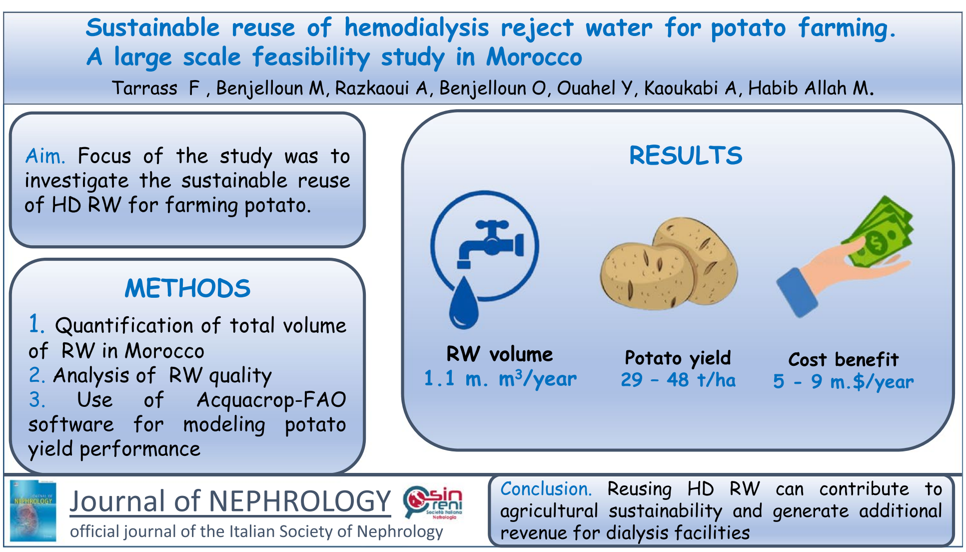
Aim This study explored how to sustainably reuse hemodialysis reject water for large-scale potato farming in Morocco. With the increasing demand for water resources in agriculture and the challenges posed by water scarcity, this project explored the potential benefits of using this wastewater, its impact on potato yields, and the possible economic aspects.

Methods The AquaCrop-FAO model was used to simulate potato growth in a hot, semi-arid area with drip irrigation. The model was calibrated using data concerning five potato varieties. Validation included information from experimental studies in similar climates and soil conditions.

Results Morocco produces about 1.1 million cubic meters of hemodialysis reject water each year. The simulated potato yield is estimated at 29.37–47.67 t/ha depending on the potato variety ($-8.8 < \text{Dev} < -2.5$). The model revealed a good fit for potato yield with $0.941 \leq R2 \leq 0.998$, $1.345 \leq \text{RMSE} \leq 3.324$, $0.05 \leq \text{NRMSE} \leq 0.092$, $0.443 \leq \text{EF} \leq 0.887$ and $0.855 \leq d \leq 0.974$. Cost evaluation showed that using reject water in agriculture could save about $638,000 USD each year in water costs. The financial benefit from potato farming with this type of water could reach $7000 to $10,000 USD per hectare, depending on the farm size, with an overall gross benefit from this water of $5–9 million USD per year.

Conclusion Reusing hemodialysis wastewater could save water and create extra income for dialysis facilities.

Graphical Abstract



Extended author information available on the last page of the article

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Keywords Hemodialysis · Sustainability · Water scarcity · Water conservation · Reject water reuse · Irrigation · Potato farming

Abbreviations

t/ha Tonne per hectare
Dev Deviation
RW Reject water
USD United State dollar
ha Hectare

Introduction

Water plays an essential role for the well-being of individuals and communities, and is crucial for economic survival. However, the availability of freshwater is becoming increasingly limited, particularly in arid regions. Factors such as global warming, climate change, uneven distribution of water resources, and rapid population growth have contributed to this scarcity [1]. Today, around 2.4 billion people live in water-stressed areas, and estimates suggest that the problem will worsen as water scarcity is highly sensitive to changing climate patterns [1].

The agriculture sector is expected to be the most affected due to its heavy reliance on water resources. Water scarcity is recognized as the main barrier to sustainable agricultural production. With the global population anticipated to reach about 9 billion by 2050, agricultural production will need to increase by over 60% [2]. This rising demand for food will lead to greater water needs for agriculture, particularly for irrigating food crops [2]. Relying solely on rainfed agriculture or traditional water sources like rivers, streams, lakes, and groundwater may not be a sustainable solution. Therefore, finding alternative nonconventional water sources for crop irrigation is crucial for sustaining agricultural production, especially in countries facing water stress.

In the current worldwide hemodialysis practice, considerable water is lost to drain. A typical reverse osmosis system commonly rejects 30 to 40% of water. According to a recent paper, water use in hemodialysis is estimated at 265 million m^3 per year globally [3], (equivalent to the total renewable water resources for the United Arab Emirates, Qatar, and Kuwait combined), and accordingly, reject water production approaches 80 to 100 million m^3 per year.

Many strategies have been suggested to reuse this type of water for watering, cleaning or even simply for toilet flushing [3]. One innovative approach to the dual challenges of water scarcity and dialysis wastewater management, is exploring the use of reject water for agricultural purposes, specifically for irrigating potato crops in water-scarce regions such as Morocco. The emphasis on potatoes is particularly important as they are a major crop worldwide and a dietary staple for over 1.3 billion people. Potatoes are versatile and can be grown in a variety of climatic conditions across more than 150 countries [2]. This study aims to establish a recycling loop between the medical and agricultural sectors, fostering a mutually beneficial relationship that improves resource efficiency.

Estimation of reject water production in Morocco

Data on the distribution of reverse osmosis systems, including their capacity, annual operating hours, and the percentage and volume of water rejected have been analyzed to estimate the yearly output of reject reverse osmosis water from dialysis units in Morocco. This information comes from a technical survey carried out by a specialized team, as detailed in Table 1 [unpublished work].

Evaluation of the overall quality for irrigation

To evaluate the quality of reject water, samples were collected from dialysis units across eight cities in northern, southern, central, eastern, and western Morocco. A standard multi-parameter pH and EC meter (HQ14 d, HACH) was utilized to measure pH and electrical conductivity. The concentrations of calcium, magnesium, sodium, and potassium ions were analyzed using inductively coupled plasma mass spectrometry (ICP/MS—NF EN ISO 17294-2). Additionally, chlorides, nitrates, nitrites, and sulfates were assessed through ion chromatography (NF EN ISO 10304-1).

The suitability of reject water for irrigation depends on the mineral elements it contains and their effects on soil and crops. The quality of reject water is compared to irrigation water standards [4], and to the quality of surface irrigation water from key Moroccan rivers, including the Oum Rabii, Sebou, Moulouya, and Loukkous. These four rivers are recognized as vital resources for water consumption and irrigation throughout Morocco [5–8].

AquaCrop model input parameters

AquaCrop (http://www.fao.org/nr/water/aquacrop.html) is a software system developed by the Land and Water Division of the Food and Agriculture Organization (FAO) of the United Nations in order to simulate the yield response to water by increasing water efficiency practices in agricultural production. The input data for the model includes climate, crop, irrigation management, field management, and soil properties [9].

Table 1 Estimation of HD reject water production in Morocco based on a technical survey

RO system Permeate capacity at 15 °C (l/h)	RO system Inlet water at 15 °C (l/h)	RO system recovery rate (%)	RO system rejection rate (%)	RO system rejection volume (l/h)	Operating hours of RO system/ week (h)	Volume of rejected water by one RO system/ week (m^3)	Volume of water rejected by one RO system/year (m^3)	RO system number in Morocco (n)	Volume of water rejected by all RO systems with same capacity/year (m^3)
700	1167	60	40	467	60	28.5	1482	2	2964
	933	75	25	233	60	14	728	3	2148
1050	1750	60	40	700	60	42	2184	5	10,920
	1750	60	40	700	72	51	2652	2	5304
	1400	75	25	350	60	21	1092	3	3276
	1400	75	25	350	72	25.5	1326	26	34,476
	1400	75	25	350	84	30	1560	2	3120
1400	2333	60	40	933	60	56	2912	48	139.776
	2333	60	40	933	72	67.5	3510	4	14,040
	1867	75	25	467	60	28.5	1482	10	14,820
	1867	75	25	467	72	34	1768	23	40,664
	1867	75	25	467	84	39.5	2054	109	223,886
	1647	85	15	247	60	15	780	7	5460
	1556	90	10	156	84	13.5	702	2	1404
1750	2917	60	40	1167	60	70.5	3666	5	18,330
	2917	60	40	1167	72	81	4212	27	113,724
	2917	60	40	1167	84	98.5	5122	3	15,366
	2333	75	25	583	60	35	1820	5	9100
	2333	75	25	583	72	42	2184	3	6552
	2333	75	25	583	84	49	2548	60	152,880
	2059	85	15	309	72	22.5	1170	2	2340
2100	3500	60	40	1400	60	84	4368	20	87,360
	3500	60	40	1400	72	101	5252	7	36,764
	2800	75	25	700	60	42	2184	4	8736
	2800	75	25	700	72	51	2652	54	143,208
	2800	75	25	700	120	84	4368	1	4368
Total								437	1.100.986

HD, hemodialysis; RO -reverse osmosis

For this study, soil data along with daily precipitation and temperature records from the Sidi El Adi region (33.10°N, 7.66°W) for the crop season 2022–2023 were input into the model. Crop data for potato farming were extracted from experimental studies conducted under similar weather variations, soil conditions and salinity gradient [10–12].

AquaCrop model calibration, validation and evaluation statistics

The calibration of the model was conducted through an iterative process that introduced the data values that best simulate observed crop yield. The values used were obtained from several sources: experimental data from the 2022–2023 cropping season [13], and data obtained from field experiments conducted on drip-irrigated potato crops in an arid Mediterranean environment [12]. In this study, model calibration and validation were undertaken for five local potato varieties (Desiree, Nicola, Mondial, Hermes, Charlotte) which are currently widely grown in Morocco. The AquaCrop model simulates observed crop yield within full drip irrigation with reject hemodialysis reverse osmosis water.

To assess the performance of AquaCrop in evaluating the correlation between observed and simulated potato yields, the following five metrics were used: the coefficient of determination (R^2), the Willmott index of agreement (*d*-index), the root mean square error (RMSE), the normalized root mean square error (NRMSE), and the Nash–Sutcliffe model efficiency coefficient (EF). The evaluations of simulation results were recorded in statistics output files.

According to the FAO [14], R^2 values > 0.90 were considered to be very good, while values between 0.70 and 0.90 were considered to be good. Values between 0.50 and 0.70 were considered to be moderately good, while values below 0.50 were considered to be poor. The *d*-index ranges from 0 to 1, where 0 indicates no agreement and 1 indicates perfect agreement between simulated and observed data; the *d*-index was acceptable when it was above 0.64. RMSE varies from 0 to positive infinity and is expressed in units of the studied variable. An RMSE close to 0 indicates good model performance. The NRMSE, on the other hand, gives an indication of the relative difference between the simulated and observed values. NRMSE < 5% is considered very good; 6–15% is good; 16–25% is moderately good, 16–25% is moderately poor, and NRMSE > 26% is poor. The Nash–Sutcliffe model efficiency coefficient model determines the relative magnitude of the residual variance, compared to the variance of the observations. A Nash–Sutcliffe model efficiency coefficient indicates how good the fit of the plot of observed vs. simulated data is on the 1:1 line; it ranges from minus infinity to one. One means a perfect fit, and zero indicates that the model predictions are as accurate as the average of the observed data and negative when the mean of the observations is less than the model predictions. A Nash–Sutcliffe model efficiency coefficient < 0.4 is considered deficient. The simulation results were considered good when at least three of the five statistical fit indicators of the model evaluation were classified as good to very good.

Results

Volume and quality of reject water

In Morocco, there are 437 hemodialysis facilities, comprising 135 public and 302 private units, which were providing treatment to around 39,000 patients as of March 2024. The findings indicate that the volume of reject water produced from the first stage reverse osmosis is nearly 1.1 million m^3 annually. Reject water is shown to meet both water quality standards for irrigation water, as well as the standards for surface water from the key Moroccan rivers that are used as a source in agricultural activity, as reported in Table 2.

Performance of the AquaCrop model for potato yield estimation

Comparison of observed and simulated yields for different potato varieties suggests that the simulation model is very good. The simulated outputs of 29.37–47.67 t/ha, match the range and distribution of observed yields (27–46 t/ha), indicating that the simulation accurately generates realistic levels of productivity. Table 3 presents the statistical analysis of the model's performance.

AquaCrop performed well in the calibration of potato on yield, as shown in Table 3. Simulations of potato yield correlated strongly with observed values, with $0.941 \leq R^2 \leq 0.998$, $1.345 \leq \text{RMSE} \leq 3.324$, $0.05 \leq \text{NRMSE} \leq 0.092$, $0.443 \leq \text{EF} \leq 0.887$ and $0.855 \leq d \leq 0.974$.

Table 2 Quality of HD reject water compared with surface water from main Moroccan rivers and water standards for irrigation

Parameter	Reject water (results from 8 Moroccan cities)	Surface irrigation water				Moroccan standards for surface water for irrigation [4]
		Oum Rabii river [5]	Sebou river [6]	Melouya river [7]	Loukous river [8]	
PH	7.8–8.4	–	7.1–8.9	6.12–8.11	7.2–8.4	< 9
Hardness (mg/l)	0–1	26.4–32.4	70–182.5	–	–	–
TDS (mg/l)	8.21–446	–	–	–	–	< 500
Conductivity (µS/cm)	1157–1800	898–2260	420–2850	413–2070	500–1400	< 2700
Calcium (mg/l)	0–1.12	–	32.5–87	–	–	< 120
Magnesium (mg/l)	0–0.44	–	2.4–116.8	–	–	< 24
Potassium (mg/l)	0.1–4	–	–	–	–	< 10
Chlorides (mg/l)	115.37–324	163.3–724.9	95.5–556.9	–	–	< 350
Nitrates (mg/l)	0.48–24	4.22–11.5	0.15–7.75	1.12–102.9	0.3–12.8	< 50
Nitrites (mg/l)	0.002–0.27	0.004–2.09	–	0.008–4.07	–	–
Sulfates (mg/l)	25–180	45–86.7	–	45–279	–	< 250
Aluminum (mg/l)	0.038–0.099	–	–	–	–	< 5

HD; hemodialysis

Table 3 Comparison of the observed and simulated potato crop yield using the AquaCrop-FAO model

Potato variety	Cumulative yield			R^2	RMSE (t/ha)	NRMSE (%)	EF	*d*
	Observed (t/ha)	Simulated (t/ha)	DEV (%)					
Desiree	42	43.05	− 2.5	0.998	2.12	0.05	0.859	0.974
Nicola	41	43.40	− 5.9	0.941	2.587	0.063	0.443	0.855
Mondial	46	47.67	− 3.6	0.965	3.324	0.072	0.655	0.943
Hermes	35	36.17	− 3.3	0.992	1.345	0.038	0.887	0.968
Charlotte	27	29.37	− 8.8	0.958	2.494	0.092	0.481	0.889

Table 4 Cost benefit evaluation of reject water use by farm size in Morocco

	Small farm (< 5 ha)	Medium-sized farm (5–15 ha)	Large farm (> 15 ha)
Cost value of reject water from dialysis units			
Volume of reject water per year (m^3)	1,100,000	1,100,000	1,100,000
Price of water per m^3 (USD), [15]	0.58	0.58	0.58
Estimated cost value of reject water in Morocco (USD)	638,000	638,000	638,000
Irrigation water need per hectare (m^3), [16]	1800	1600	1200
Saving on water cost per hectare (USD)	1044	928	696
Potato production charges			
Energy requirement for irrigation per year (kwh), [17]	3148	1667	1472
Cost of energy per kwh (USD), [18]	0.108	0.108	0.108
Cost of energy per hectare (USD)	341	181	159
Cost of labor per hour (USD), [19]	0.847	0.847	0.847
Recommended hours of labor per hectare, [20]	700	600	500
Cost of labor per hectare (USD)	590	510	425
Cost of seeds per kg (USD), [21]	1.1	1.1	1.1
Recommended seed quantity per hectare (kg), [22]	2500	2500	2500
Cost of seeds per hectare (USD)	2750	2750	2750
Cost of N fertilizers per kg (USD), [23]	2.4	2.4	2.4
Recommended N fertilization rate per hectare (kg), [24]	200	200	200
Cost of N fertilizers per hectare (USD)	48	48	48
Total charges per hectare (USD)	3729	3489	3382
Cost of Reject water harvesting and transport to farms			
Cost of RW harvesting per hectare (USD)	108	102	96
Cost of RW transport to farms (USD/m^3/km), [25]	0.04	0.04	0.04
Cost of RW transport to 20 km distance per hectare (USD)	1440	1280	960
Total charges per hectare	1548	1382	1056
Income and profit from potato farming with RW			
Potato production (T/ha)	40	40	40
Potato wholesale price per kg (USD), [26]	0.32	0.32	0.32
Potato wholesale price per hectare (USD)	12,800	12,800	12,800
Total charges per hectare (USD)	5277	4871	4438
Benefit from RW if sold to farms per hectare (USD)	1044	928	696
Subsidy for potato seeds per hectare (USD), [27]	800	800	1500
Gross benefit per hectare (USD)	7279	7891	9166
Estimated surface to be irrigated by 1.1 m.m^3 RW (ha)	611	687	916
Total income from RW reuse for farming potato (USD)	4,447,469	5,421,117	8,396,056

Cost, return, and profitability analysis

To reflect Moroccan farming characteristics, the analysis of costs was based on the average farm size [14]. In Morocco, average farms tend to be small, often less than 5 hectares, which is typical of traditional farming methods focused on subsistence. Evaluation of the costs, returns, and profitability of large-scale potato farming using reject water is detailed in Table 4. The average cost of cultivation across all sample farms was $4438 to $5277 USD per hectare. The cost of cultivating agricultural land includes various expenses such as fertilizers, seeds, human labor, energy charges, and irrigation charges.

The cost for reject water harvesting and transport by tankers to farm site has been evaluated and has been determined to be from $1056 to $1548 USD per hectare depending on farm size, which accounts for 23.8–29.3% of the total cost.

The benefits from farming potatoes with reject water could vary between $7000 to $10,000 USD per hectare per year, based on farm size, with a total income, when farming at large scale with the 1.1 million m^3 of water of $5–$9 million USD per year, and a cost saving of $638,000 USD of irrigation water price per year.

Discussion

Freshwater availability is decreasing globally. Increasing instances of drought, minimal rainfall, and reduced snowfall have significantly impacted the supply of clean and fresh water on the planet. The rapidly growing population has made it challenging to meet the collective water needs for agriculture, industry, and human consumption [1]. As current water resources become depleted, the reuse or recycling of water is an essential strategy for sustainable water conservation. This article introduces a novel approach; utilizing reject reverse osmosis water from hemodialysis for large-scale potato crop irrigation within a circular economy framework.

Dialysis poses a significant challenge to environmental sustainability due to its high water and electricity consumption, hazardous waste incineration, and the resulting greenhouse gas emissions. The importance of water conservation for a sustainable environment cannot be overstated. Irrigating potato crops with reject water could lead to sustainable development, significantly reducing the environmental impact of hemodialysis, boosting income generation, and contributing to global food security. Based on our findings, the economic value of reject water from hemodialysis is estimated to be between $46.5 and $58 million USD per year globally, yielding a gross benefit from potato farming of $400–$650 million USD annually.

Reject water can be transported to farms using two major modes of transportation, truck and pipeline. Truck transportation is favored for low volumes and short distances. Truck costs rapidly increase for large scale transportation of wastewater. On the other hand, pipeline transportation is favored for large volumes and long travel distances [28].

Harvesting reject water can turn hemodialysis centers into water-efficient facilities, providing suitable water for irrigating farms and agricultural lands in rural areas, or for watering nearby parks, gardens, golf courses, and football stadiums. In Morocco, a country that will host the football world cup in 2030, there will be a high demand for water for stadium field irrigation. Therefore, the volume of reject water from the RO currently present in the country, accounting for 1.1 million m^3 per year is enough to maintain at least 110 football stadiums. A standard football pitch measuring 110×70 m typically requires between 2.3 and 2.5 m^3 of water daily [29].

Reject water from hemodialysis is remarkably good water that does not at any stage come into contact with the patient and therefore poses no infection risk [4]. Despite the suitability of using this type of water for crop irrigation, this topic remains controversial among government authorities and policymakers globally. Typically, reject water from hemodialysis (and RO reject water is assimilated to this type of reject water) is classified as wastewater and cannot be used unless treated, as per regulations. In Morocco, for example, Decree (No 2–97–875, dated February 4, 1998), acting as Water Law 10- 95 related to the use of wastewater, stipulates that no wastewater can be used if it has not been recognized as treated wastewater [30]. Therefore, great efforts need to be made to address this perception gap, and modify regulations accordingly.

Conclusion

To transition towards more sustainable hemodialysis, new concepts of wastewater management are needed. Reusing hemodialysis reject water can contribute to agricultural sustainability and innovation, paving the way for smarter and more resilient food and water systems, and it can generate additional revenue for dialysis facilities.

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Data availability The authors confirm that the data supporting the findings of this study are available within the article and its Supplementary material. Raw data that support the findings of this study are available from the corresponding author, upon reasonable request.

Declarations

Conflict of interest The authors confirm that they have no known financial interests or personal relationships that could have affected the research work presented in this paper.

Ethical approval Not applicable. This research does not involve Human Participants and/or Animals.

Informed consent Not needed.

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