Assessing the impacts of proposed lake restoration measures on the water-energy-food nexus in Urmia Lake, Iran

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INTRODUCTION

Water scarcity exacerbated by growing demand in different sectors has created environmental and socio-economic challenges in the Urmia Lake Basin, Iran (Fig. 1). Tackling this problem requires an integrated approach considering the basin as an interconnected system.

OBJECTIVE

This work provides insight on Water-Energy-Food (WEF) nexus impacts emanating from a number of proposed restoration measures for the basin using a holistic modelling approach.

MATERIALS AND METHODS

Study area

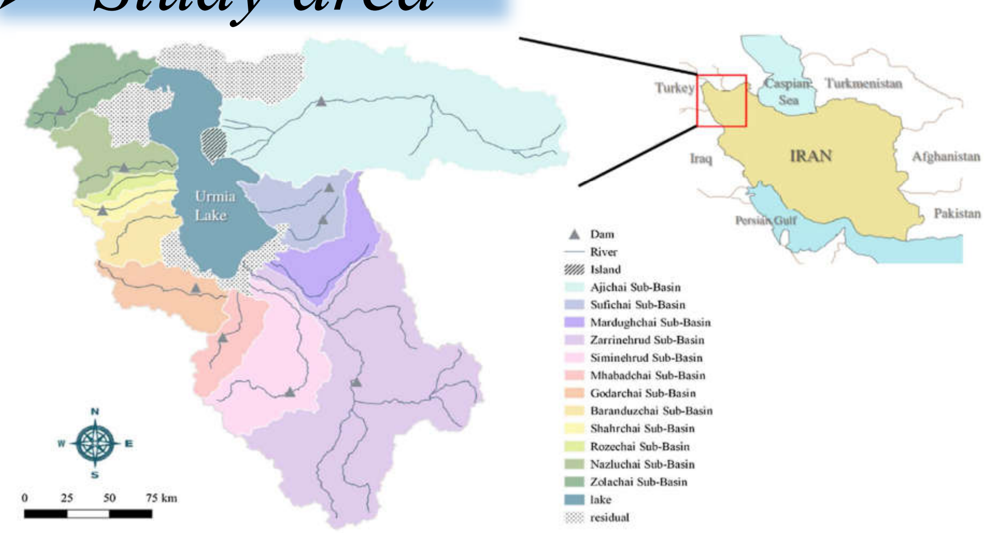

Fig.1 Urmia lake basin.

- Hypersaline endorheic Lake
- Basin area: 52000 km^2
- Lake area (in 2017): 5362 km^2
- Mean lake depth (in 2017): 6 m
- Lake water supply: 6900 million m^3
- Mean annual precipitation: 378 mm
- Mean annual evaporation: 800 mm
- Irrigated land: 500 *10^3 ha
- Agri water use: 4300 million m^3 yr^1
- Domestic water use: 460 million m^3
- Industry water use: 70 million m^3

Methodology

A qualitative causal loop diagram (CLD, Fig. 2) of the Urmia WEF nexus was developed and used to build a quantitative system dynamics model (SDM. Fig. 3) which was used to assess future development scenarios (Tab. 1).

Tab. 1: Outline of the scenarios simulated using the SDM.

Scenario	Measure	2020–2025	2025–2030	2030–2035	2035–2040
Climate change	RCP	2.6, 4.5, 8.5			
*ULRP-1	Irrigation efficiency	0.7	0.7	0.7	0.7
	Farmer collaboration	10–20%	20–40%	40–60%	60–80%
	Waste water return flow recharge (million m^3 yr^1)	50	80	130	150
	Increasing crop yield	10% and 20% increases			
	Percentage of electric pumps	10–20%	20–40%	40–60%	60–80%
*ULRP-2	*ULRP-1 plus interbasin water transfers (million m^3 yr^1)	700	700	700	700
*ULRP-3	*ULRP-2 plus interbasin water transfer (million m^3 yr^1)	700	700	0	0
Plausible-1 (*ULRP-1 plus cropland retirement and interbasin transfers)	Cropland retirement	10%	15%	20%	20%
	Interbasin transfers (million m^3 yr1)	700	700	0	0
Plausible-2 (Plausible-1 plus reviving a portion of the lake area)	Area of lake to be revived (% of total)	60	70	80	80
Plausible-3 (*ULRP-1 plus reviving a portion of the lake area)	Revived lake area	60	70	80	80

(**ULRP: Urmia Lake Restoration Programme*)

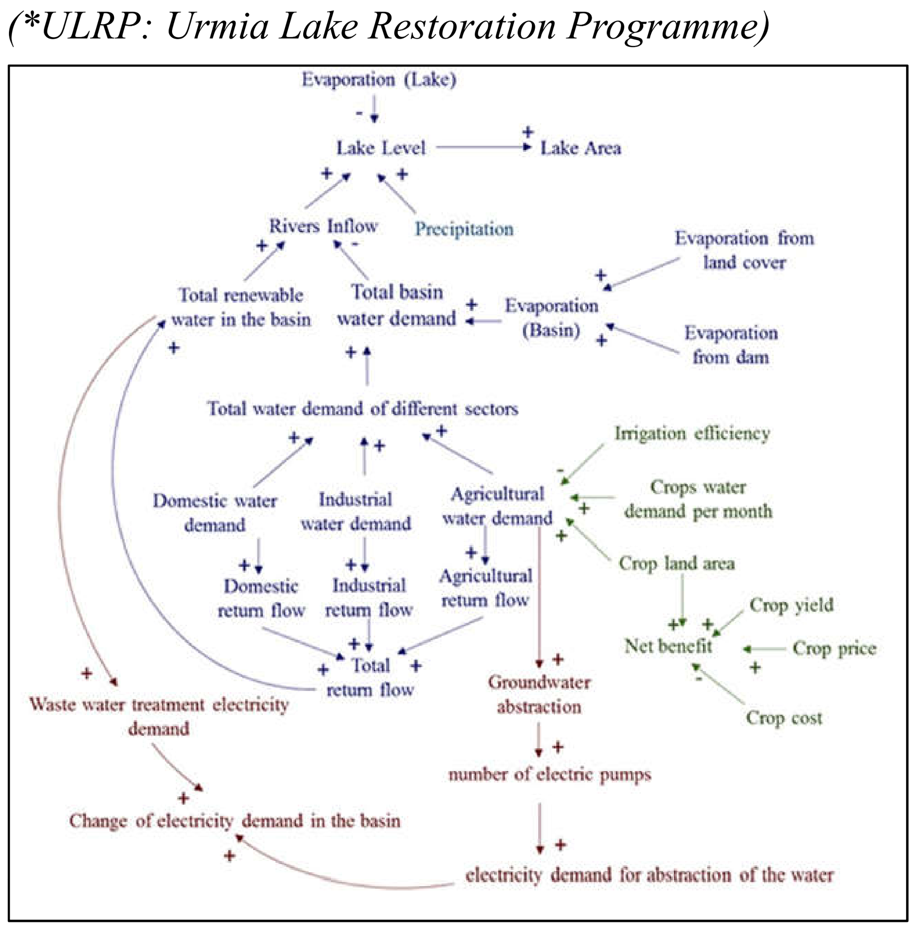

Fig.2 The causal loop diagram of the Urmia Lake Basin.

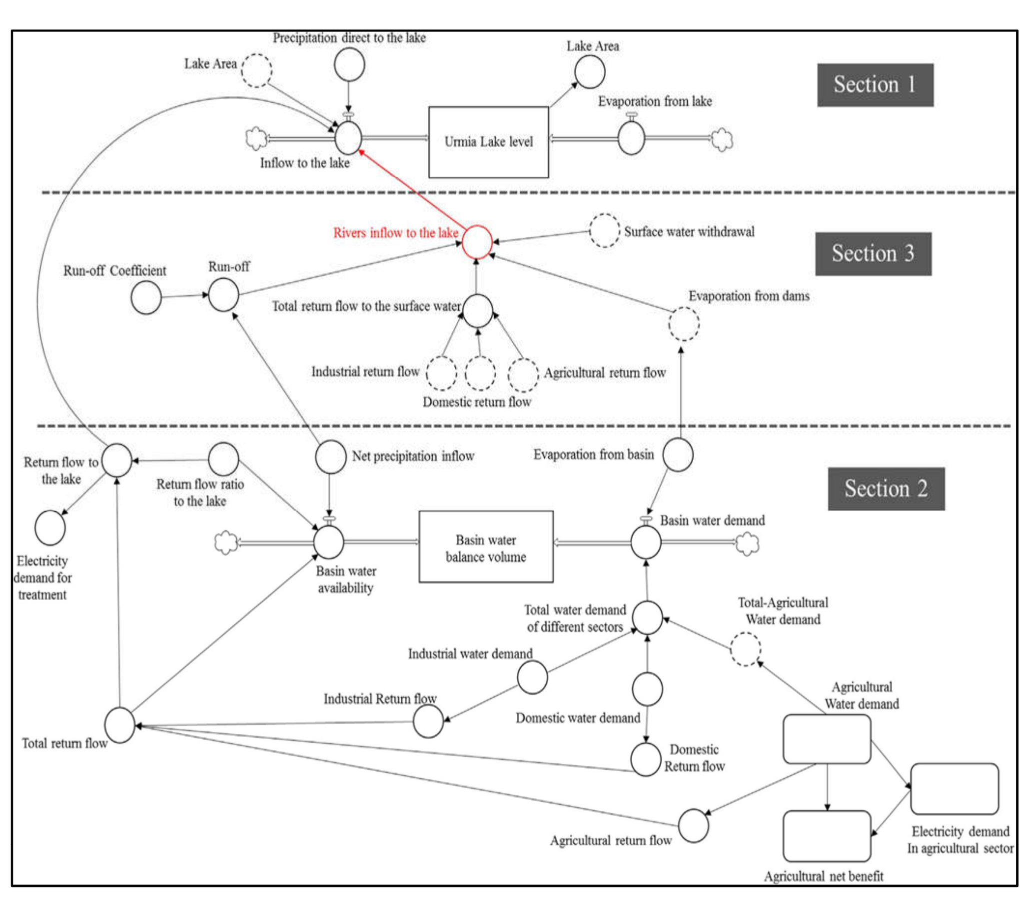

Fig.3 The developed SDM model of Urmia Lake Basin.

RESULTS

Model calibration

The model is calibrated for the period 1984–2014 (Tab.2).

Tab. 2: Calibration results; observed vs simulated data

	R2	RMSE	NSE
River inflow to the Lake	0.83	174.88 (Mm3)	0.865
Urmia Lake level	0.97	0.352 (m)	0.98

Where:
RMSE: Root Mean Square Error
R^2: R-squared
NSE: Nash–Sutcliffe efficiency

Sensitivity analysis

Lake level is most sensitive to changes in lake area, and least sensitive to change in precipitation. It is more sensitive to evaporation changes compared with river inflow variation.

River inflow is most sensitive to changes in runoff within the basin and to changes in demand from within the basin.

Scenario analysis

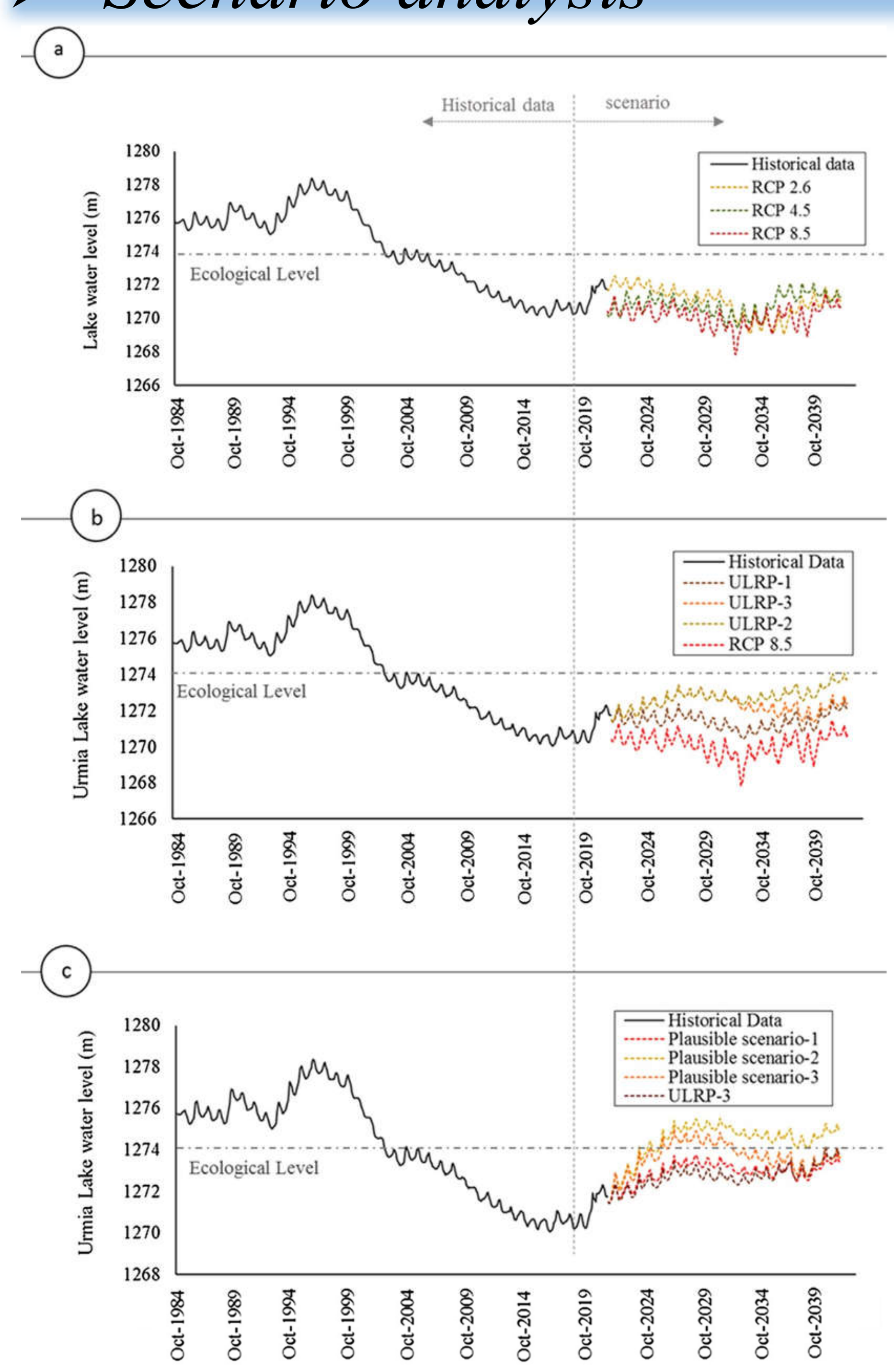

Fig 4. Trend of Urmia Lake level under different scenarios (Tab.1).

Based on a key objective, reaching a defined *sustainable* ecological lake level of 1274 m a.s.l. provides a suitable indicator against which to determine whether measures can achieve ecological restoration of the lake.

Plausible scenario-2 is the most effective in terms of lake level increase by 2040 (Fig. 4c).

Scenarios 1 and 3 both have similar results by 2040, but have very different trajectories (Fig. 4c).

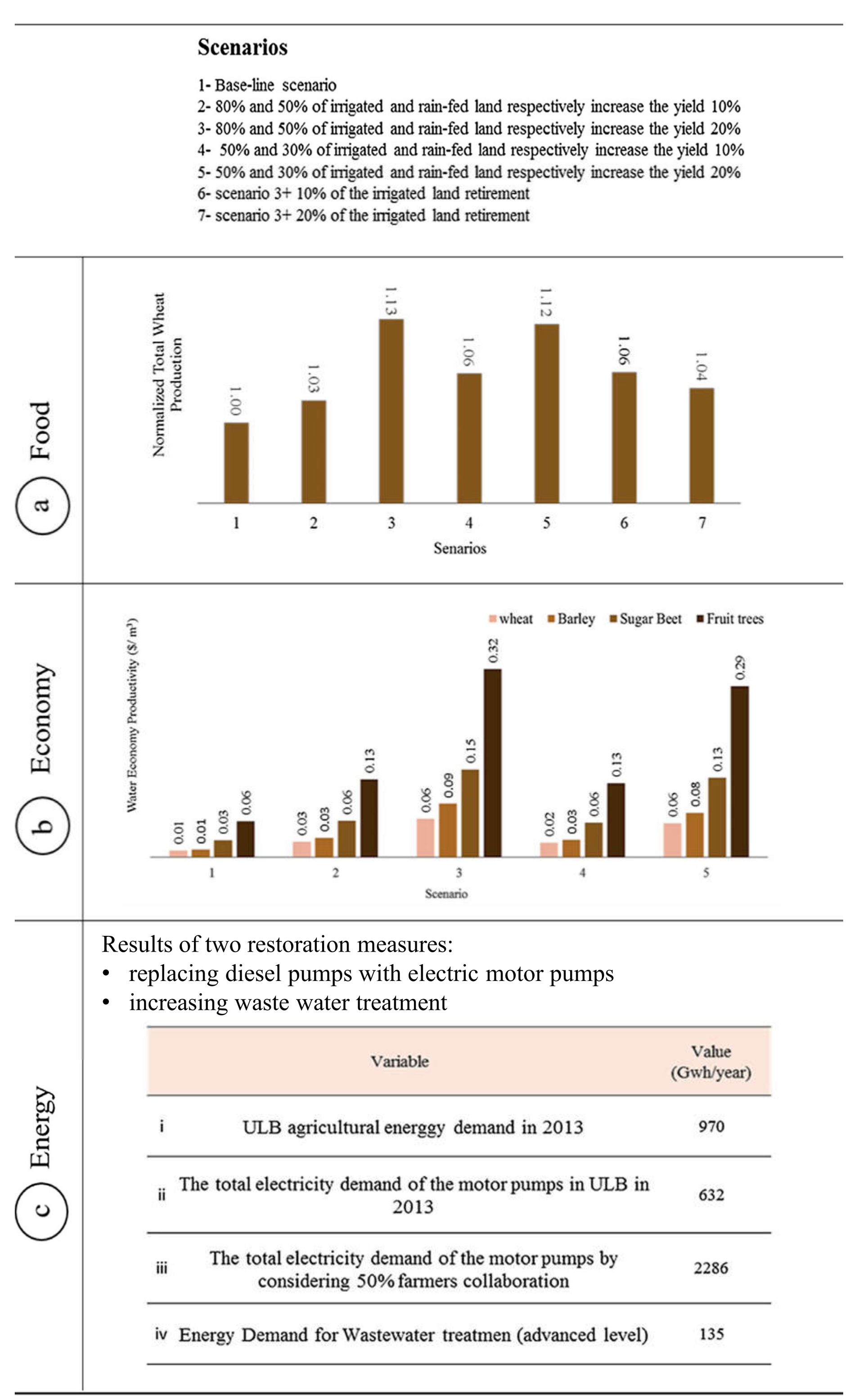

Fig. 5. The effects of the different scenarios on the: a) food; b) economy; and c) energy sectors.

Wheat production will increase compared to the baseline; Scenario 3 shows the greatest increase (Fig. 5a).

Scenario 3 is the most effective scenario for improvement of the agricultural economy (Fig. 5b).

If 50% of diesel pumps are replaced with electric pumps, grid-based energy demand for ground water abstraction will increase more than 3x (Fig. 5c).

Bakhshianlamouki et al. 2020. System dynamics model to quantify the impacts of restoration measures on the water-energy-food nexus in the Urmia lake Basin, Iran. Sci. Tot. Env., https://doi.org/10.1016/j.scitotenv.2019.134874.