Managed aquifer recharge and water harvesting from impermeable infrastructure surfaces

Urban water harvesting, roofs and solar panels

Oct 9, 2025

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Aquifer recharge

- **Unintentional Recharge:**
    - Clearing of deep-rooted vegetation (e.g. deforestation)
    - Deep seepage under irrigation areas
    - Leaks from water pipes and sewers
- **Unmanaged Recharge:**
    - Stormwater drainage wells and sumps
    - Septic tank leach fields
  - Typically used for disposing of unwanted water without considering reuse.
- **Managed Recharge:**
    - Spreading methods
    - Injection wells
    - Infiltration basins and galleries
  - Utilized for various water sources including rainwater, stormwater, reclaimed water, mains water, and water from other aquifers
  - These methods ensure water is recovered for all types of uses

Aquifer recharge categories

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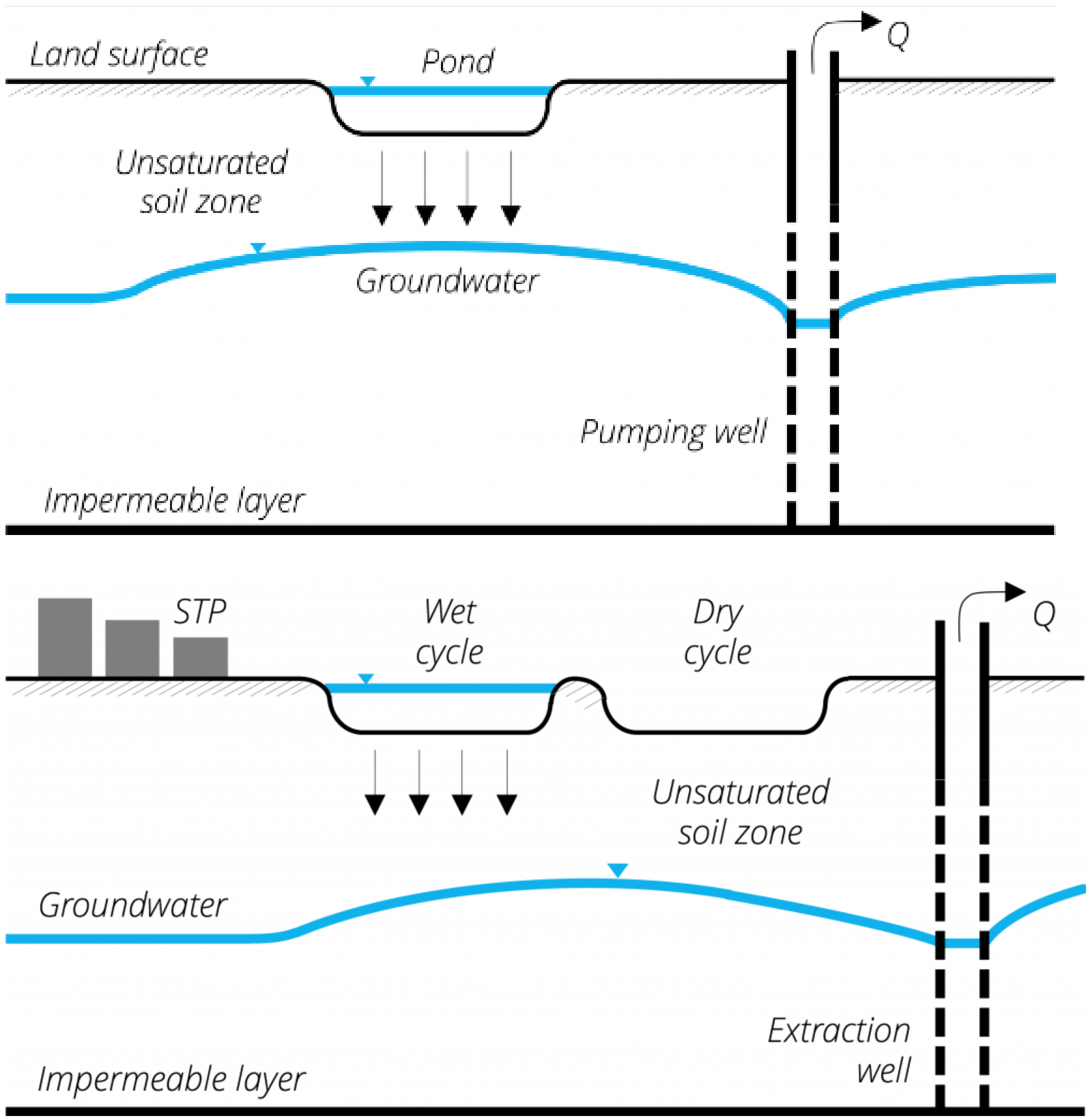
Spreading methods

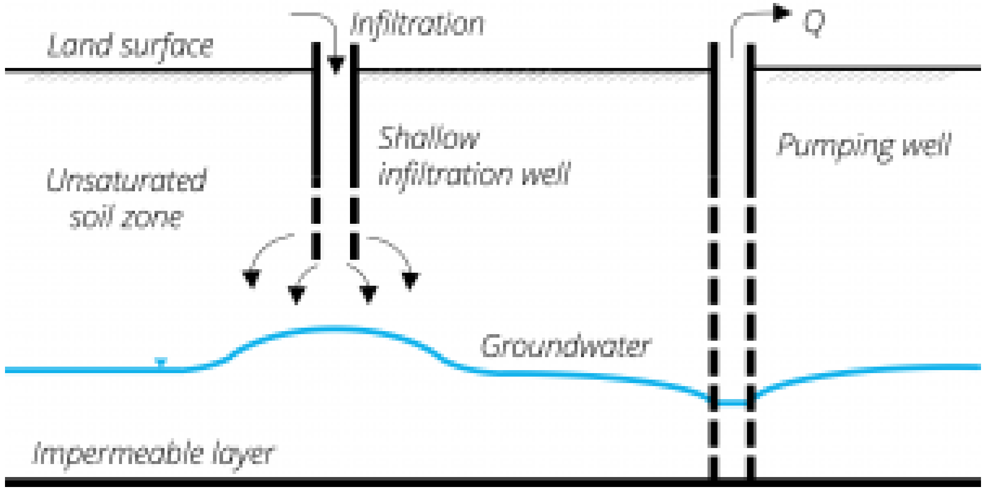
- Enhance gravitational infiltration and percolation of water to phreatic aquifers
- **Surface spreading** – most applied MAR method
  - Construction of infiltration ponds (hafir) is the common method for the retention and spreading of water
- **Soil aquifer treatment (SAT)** - quality of the feed water (stormwater or waste water treatment plant effluent) is further improved during soil passage (e.g. pathogen or nutrient removal)

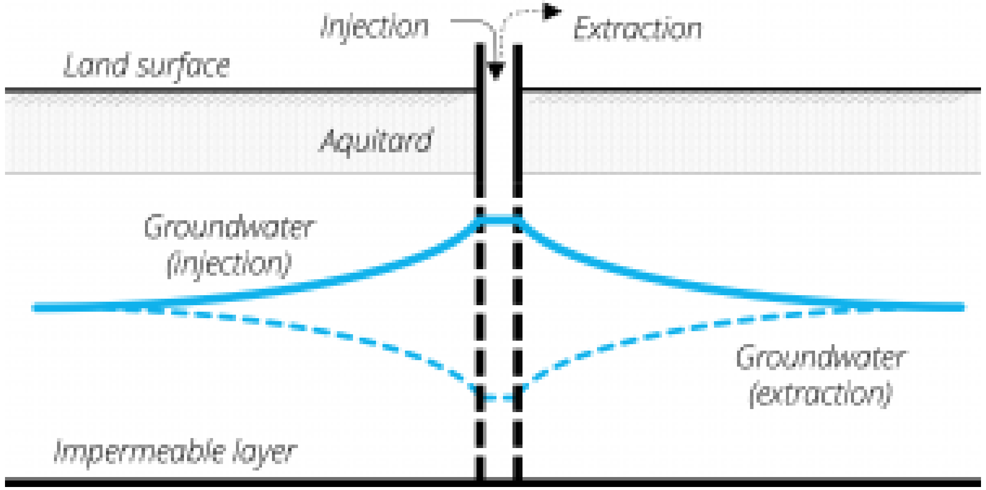


In-stream structures

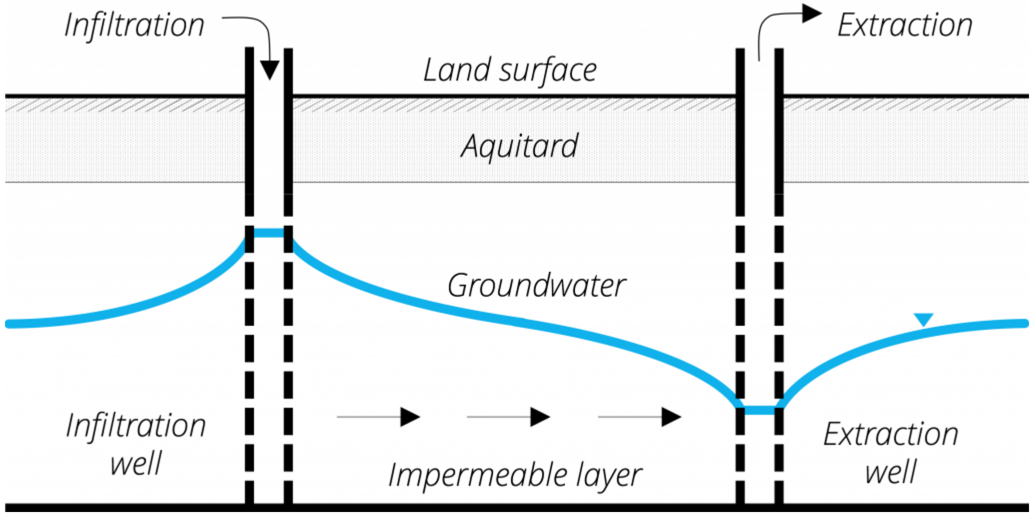
- Structures built in drainage channels that intercept or delay wadi / river run-off, thereby increasing riverbed infiltration time
  - Leaky and non-leaky dams
  - Subsurface dams
  - Sand dams
  - In-channel flow delay structures
- Mainly built in intermittent or ephemeral streams with distinct wet periods

Dry well or borehole recharge

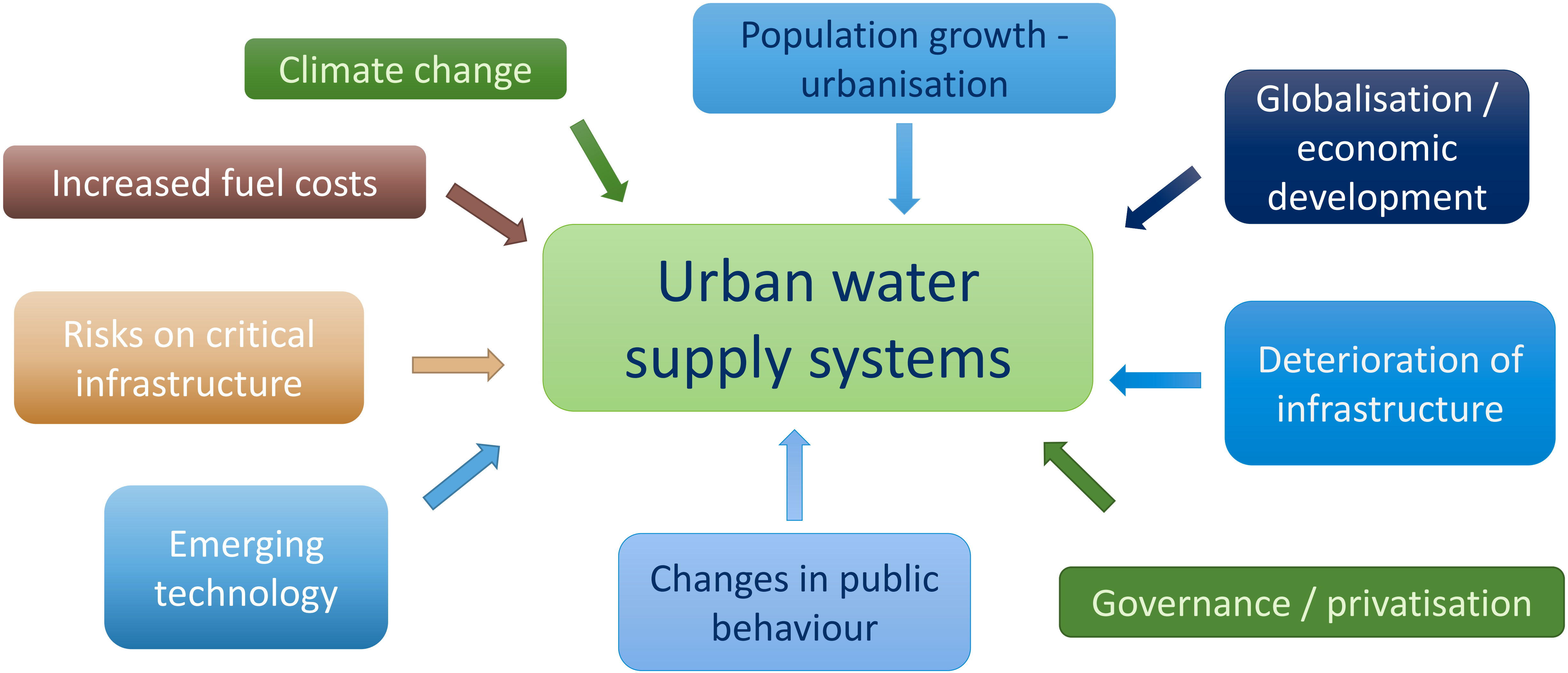




- Gravitational recharge through shallow or deep structures such as dry wells, shafts, boreholes or pits.
- **Deep well injection**:
  - Aquifer Storage & Recovery (ASR)
  - Aquifer Storage, Treatment & Recovery (ASTR)
- **Shallow infiltration**: wells/ shafts/ pits



Urban water supply challenges



Ecohydrological principle

- Precipitation falling on a surface is:
  - Temporarily stored on vegetation surface – storage capacity
  - Evaporates from surface during and after precipitation
  - Drips/percolates from surface when storage is filled – throughfall
- Rainfall interception = water lost to atmosphere by evaporation
  - Grassland: 1 - 5% of gross rainfall
  - Agricultural crops: 3 - 40% (but over short growing period)
  - Deciduous forest: 10 - 25% (includes orchards)
  - Coniferous forest: 15 - 40%
  - Roof surfaces: 5 - 30%
  - Solar panel surfaces: Few data, 13%?
- Percolating water can be captured and stored for later use

Important parameters for roof rainwater harvesting

- Climate: daily precipitation total P and evaporative demand
- Roof surface storage capacity S – related to roughness of surface
  - RWH = 0 mm d^{-1} for days with $P < S$
- Roof water runoff coefficient ($R = Q/P$)
  - If $P > S$, $RWH = (P - S) * R$
- Roof water can be collected and stored in tanks / basins or in geological storage options

Roof water harvesting – traditional way in Aruba

Roof water harvesting potential studies, Jordan

- Yarmouk University: 91,000 m^2 roof and 37,100 m^3 y^{-1} water (Awawdeh et al., 2011)
- Al Ajloun region: 0.39 Mm^3 in dry year (2017) and 0.96 Mm^3 in wet year (2018). Equal to 8-17% of domestic water supply (Al-Houri and Al-Omani, 2022)
- Jordan country-wide:
  - 15.5 Mm^3 y^{-1} of rainwater from roofs of all residential buildings, assuming that all precipitation is collected. Equal to 6% of domestic demand in 2005 (Abdulla and Al-Shareef, 2009)
  - 30.5 Mm^3 y^{-1} equal to 8% of domestic demand (Abdulla, 2019)
- Much interest by society in installation of roof water harvesting systems, with demand for subsidies to cover high initial installation costs

Advantages and disadvantages roof water harvesting

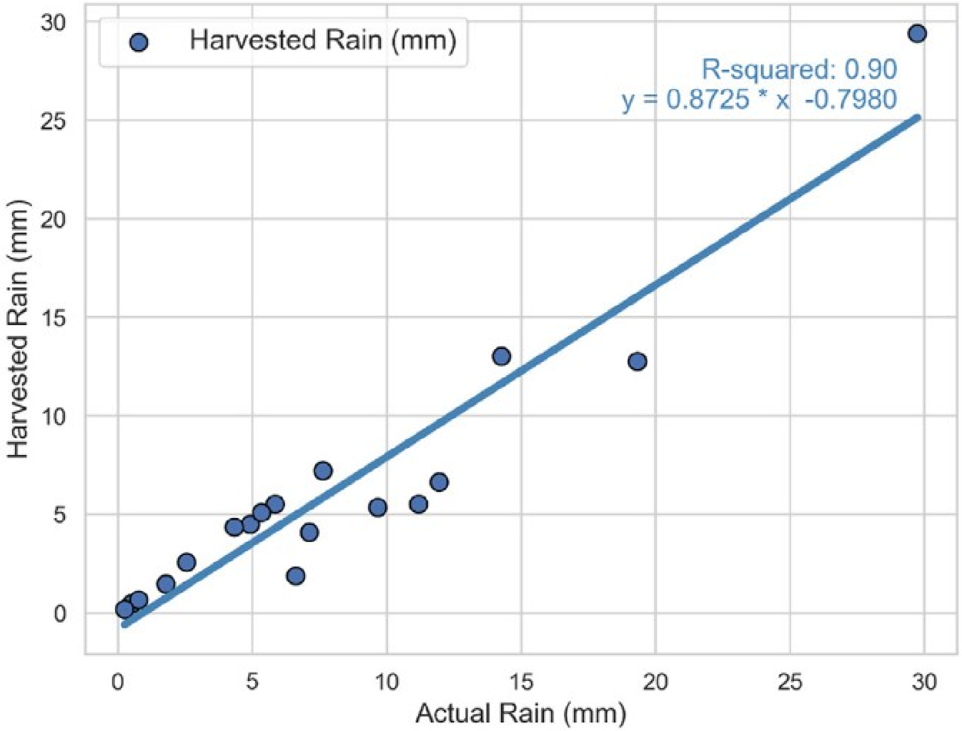
- Extra supply of water to households, saves money on water bill
- Buffering of runoff during high precipitation, slow release of collected water as wastewater. This means a lower burden on sewer and drainage systems
- Decentralized water supply system (non-revenue loss)
- High installation costs and perhaps maintenance costs
- Two separated water systems needed in household (drinking and cooking from regular water supply; shower, toilet and other uses from harvested water)
- Storage limits and uncertain amounts of water harvested (dry years)
- How to guarantee water quality - water treatment essential
- Who is responsible for proper operation and quality control

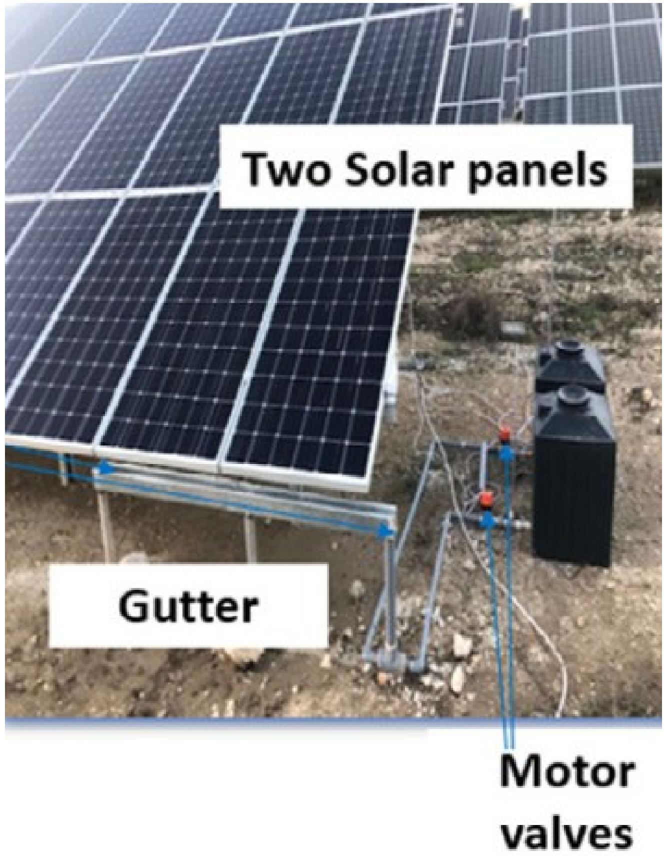
Solar panel water harvesting

- High demand for renewable energy and declining process for solar panels
- Transition to hydrogen economy needs abundant green energy
  - Production of 1 kg H_2 needs about 40-50 kWh of energy and 9 L of water
  - Household daily energy use < 5 kWh day^{-1}
- The Ministry of Energy and Mineral Resources of Jordan is working on a National Green Hydrogen Strategy for Jordan
- Not much data on solar panel runoff from precipitation

Only one study globally for solar, done in Jordan

- Location Hai Al Sahabah, Al Muqabalayn, Amman
- Good water quality (EC = < 300 µS cm^{-1})

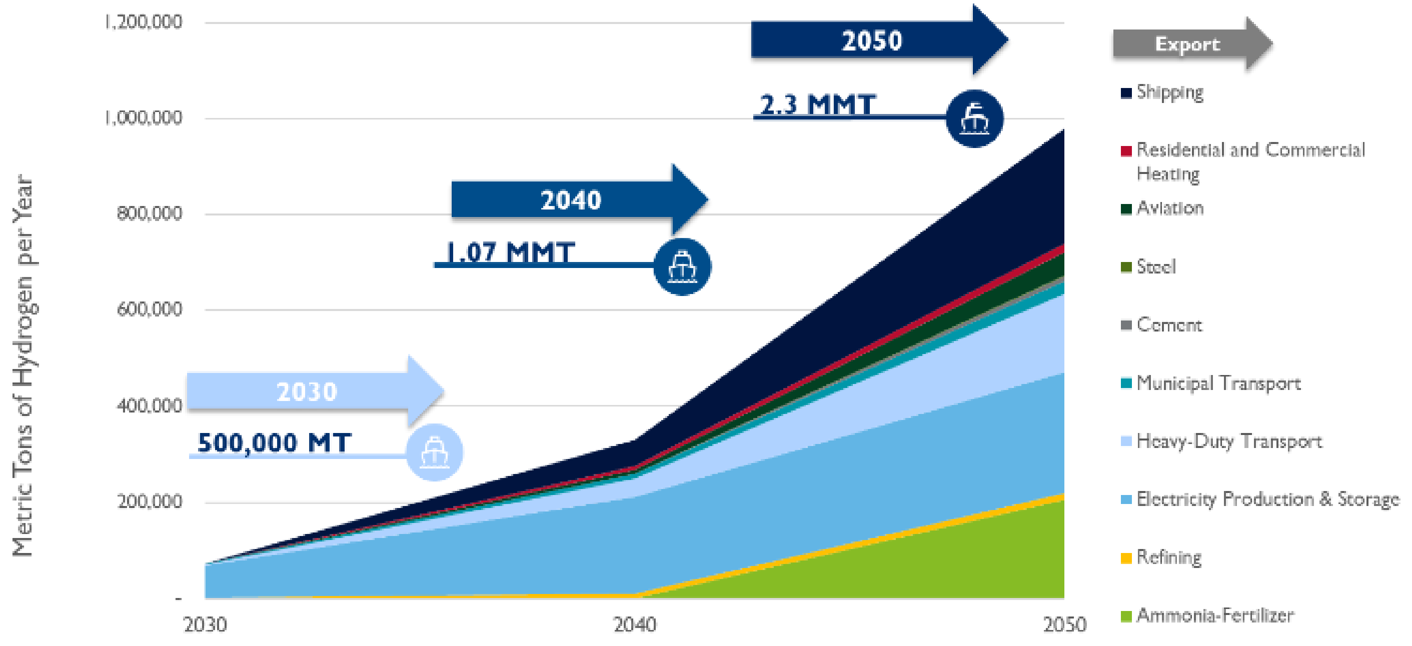




Alazzam et al., 2024. GJESM 10(3): 1-14

Geen hydrogen production potential in Jordan

- Green hydrogen depends on two key inputs:
  - Green electricity
  - Purified water
- Jordan has potential H_2 production of about 4,700 t H_2 km^2 a^{-1} at cost of $5 per kg for solar energy



- Potential of about 800 t H_2 km^2 y^{-1} at cost of $4 per kg for wind energy
- Water needs for 2030: 5.3 Mm^3 a^{-1}

Source: Ministry of Energy and Mineral Resources, 2023. National Green Hydrogen Strategy for Jordan, draft report

https://www.memr.gov.jo/EBV4.0/Root_Storage/AR/EB_Info_Page/GH2_Strategy.pdf

Base scenario values for H_2 production, Jordan

By 2030, **0.59 MMT of H_2** will create over **11,000 jobs** avoid **4.2 MMT CO2e emissions** and require:

0.5MMT	$28B	448km²	5GW	8GW	5.3M m^3
for export	*of investment*	*of land*	*of electrolyzer capacity*	*of wind and solar*	*of water*

By 2040, **1.5 MMT of H_2** will create over **30,000 jobs** avoid **6.1 MMT CO2e emissions** and require:

1MMT	$78B	1,204km²	13GW	22GW	14M m^3
for export	*of investment*	*of land*	*of electrolyzer capacity*	*of wind and solar*	*of water*

By 2050, **3.4 MMT of H_2** will create over **65,000 jobs** avoid **8.2 MMT CO2e emissions** and require:

2.3MMT	$175B	2,614km²	29GW	47GW	31M m^3
for export	*of investment*	*of land*	*of electrolyzer capacity*	*of wind and solar*	*of water*

Source: Ministry of Energy and Mineral Resources, 2023. National Green Hydrogen Strategy for Jordan, draft report
https://www.memr.gov.jo/EBV4.0/Root_Storage/AR/EB_Info_Page/GH2_Strategy.pdf

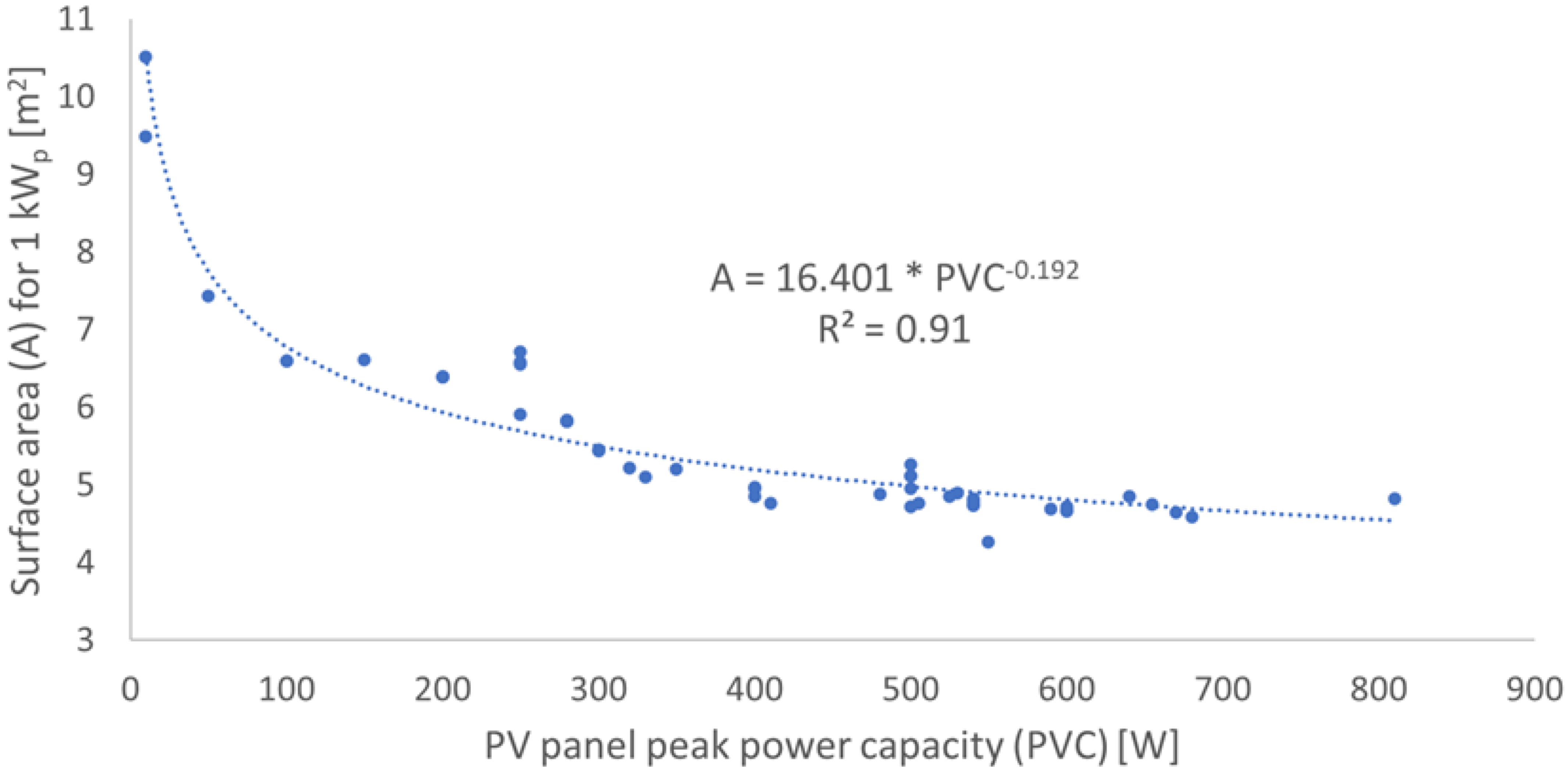
Criteria for power generation / energy harvesting

- Solar potential high
- Slope / aspect of terrain, not steep
- Area for establishment of solar farm close to, but outside of agricultural area
- Solar power plant close to urban / industrial area, good access
- Energy needs – non-functional grid, hydrogen production plans
- Stakeholder and community support
- Security and protection of installations
- Maintenance training
- Energy tariffing system

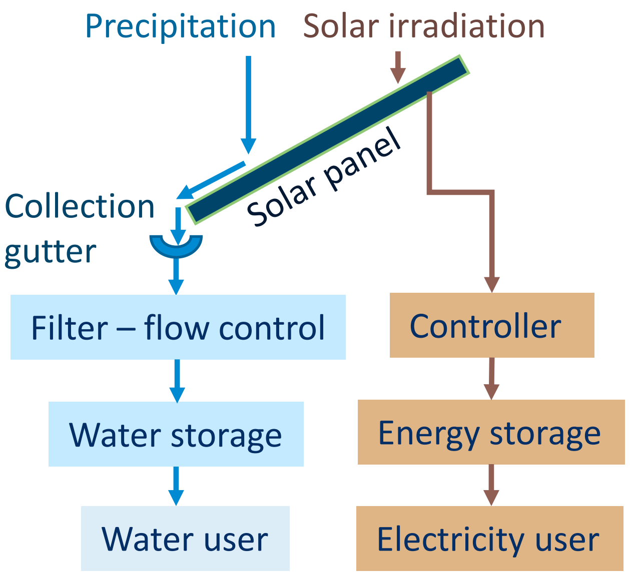
Criteria for water harvesting

- Precipitation amount and seasonality, dry season length;
- Distance to infiltration / storage opportunities (groundwater wells);
- Need for dry season irrigation water, emphasis on water efficient techniques (drip irrigation);
- Observed water shortages;
- Soil degradation and erosion, warranting soil conservation measures;
- Stakeholder / community support;
- Labour and material availability
- Water tariffing system

Solar panel peak power rating and surface area

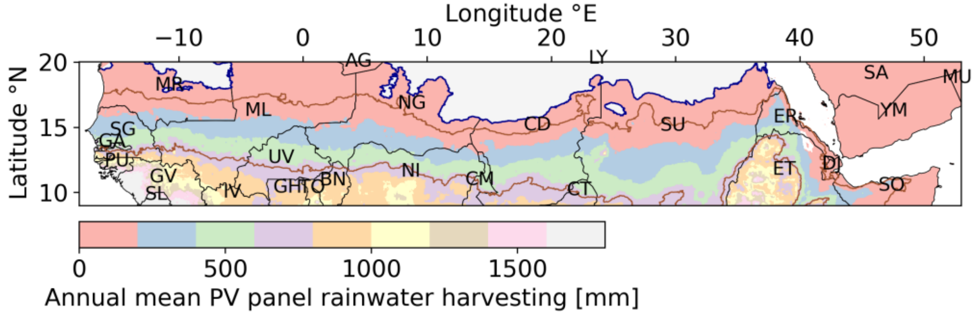


Rainwater harvesting potential from photovoltaic energy systems in the Sahel

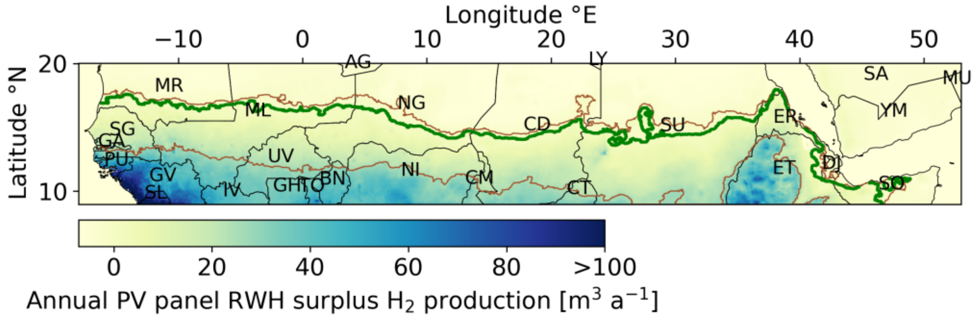


Household water needs: 50 m^3 a^{-1}
Household Tier 4 energy: 4.5 kWh d^{-1}
H_2 production water: 15 L kg^{-1} H_2
H_2 production energy: 40 kWh d^{-1} kg^{-1} H_2

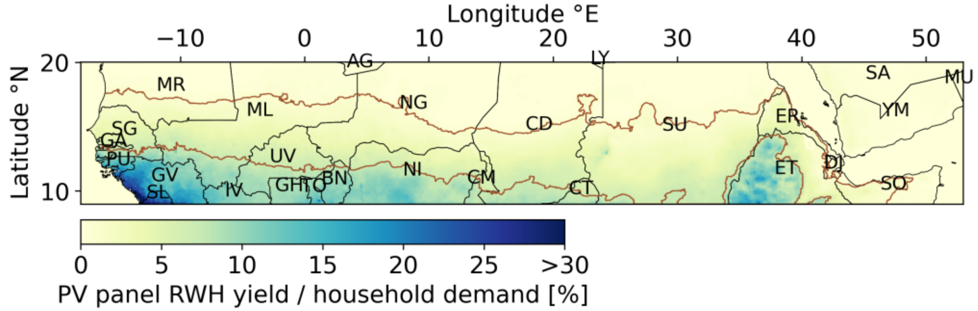
Solar panel rainwater harvesting yield



Surplus rainwater harvesting yield at 1 kg d^{-1} H_2 production



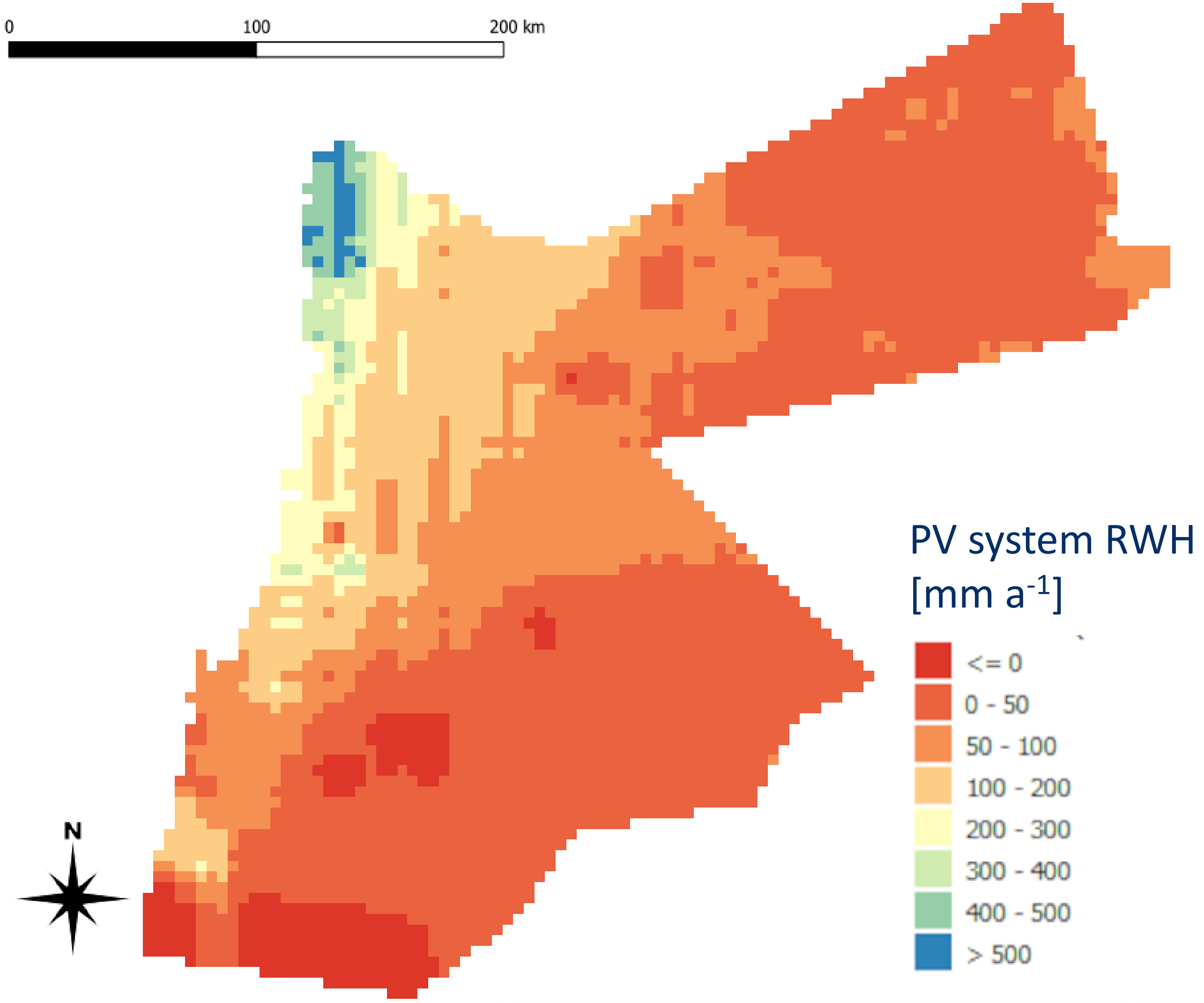
Percentage of household demand from Tier 4 solar system rainwater harvesting



Where precipitation exceeds 200 mm a^{-1} combined solar energy and rainwater harvesting has potential to increase available water resources in the Sahel Region. High water gains are obtained when energy is harvested for H_2 production

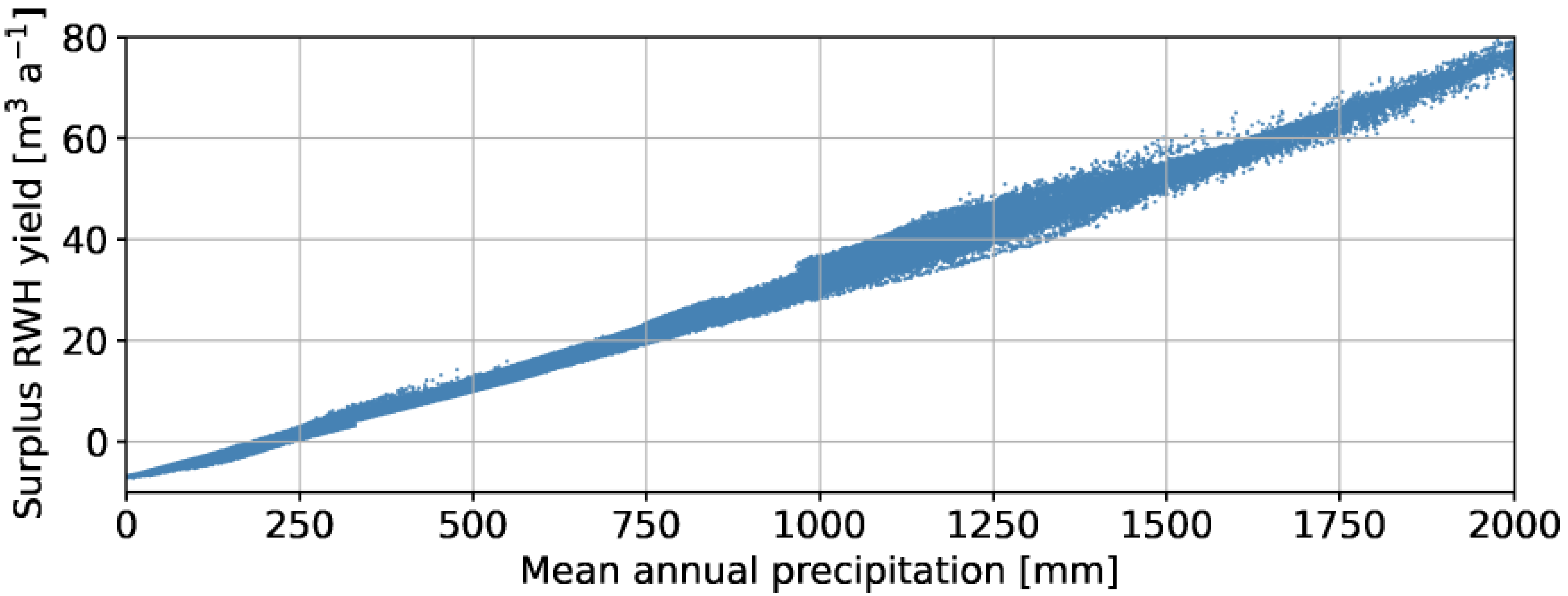
PV power system rainwater harvesting potential Jordan

- Solar panel (350 W_p) water harvesting potential with cleaning water needs subtracted
- For H_2 production up to 200 mm a^{-1} of precipitation on panel surfaces is required



Solar panel arrays water yield hydrogen production

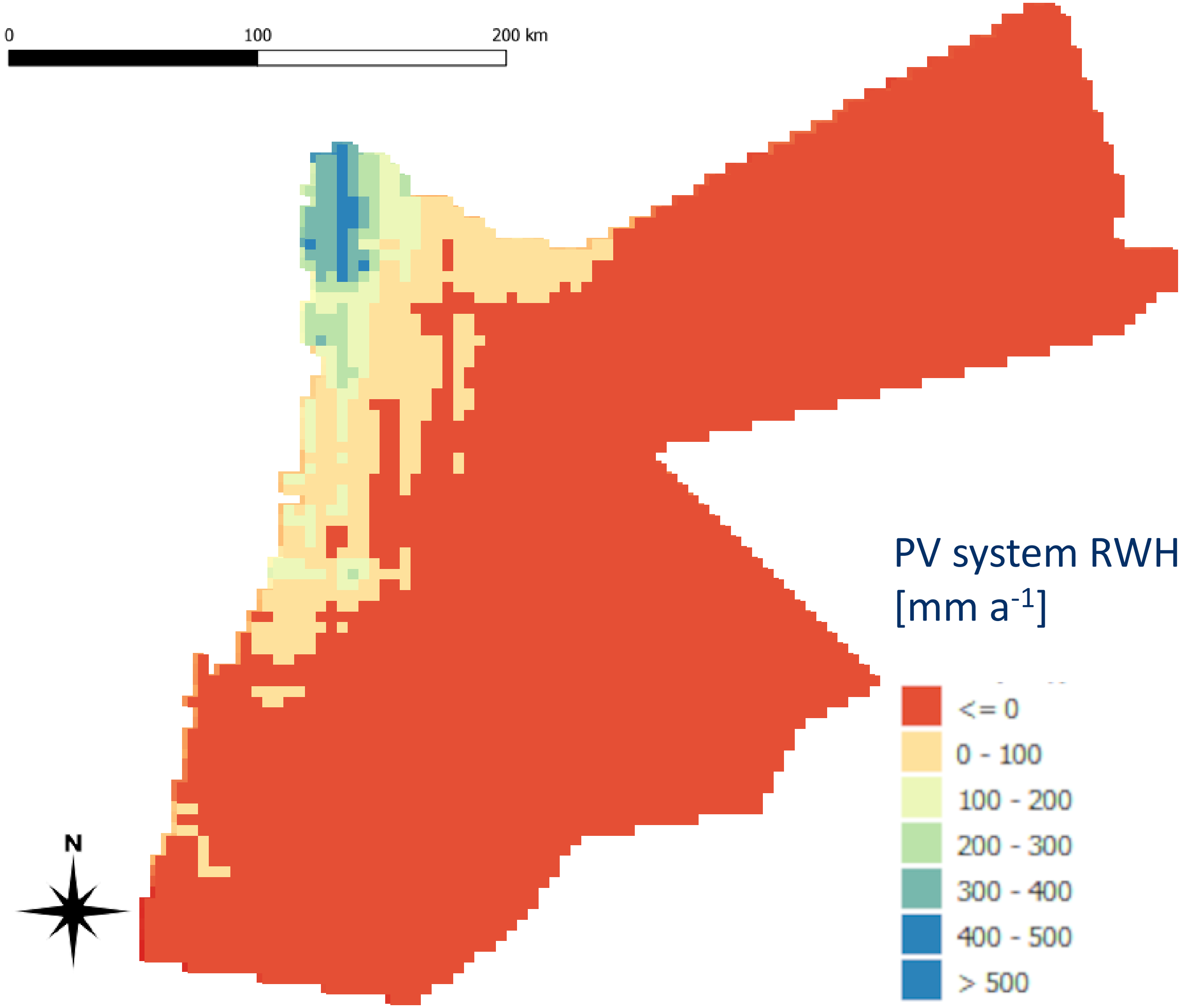
- Relation between mean annual precipitation and annual rainwater harvesting yield from PV panel arrays at daily production of 1 kg H_2 in the Sahel, includes PV panel cleaning and H_2 production water needs
- No surplus at P < 200 mm a^{-1}



Source: Waterloo et al., 2025. Water-Energy Nexus 8: 115-131

Excess water harvesting after H_2 production

- Areas where excess water can be harvested after extracting H_2 production water needs
- Extra water is needed for H_2 production in red areas
  - Groundwater
  - Desalinated water



Summary

- Roof and solar panel systems can be used to collect water in urban or industrial areas
- In Jordan, part of the water needed for H_2 production can be obtained by water harvesting from the solar panels providing the energy for H_2 production
- Highest water yields in areas with higher precipitation
- This technique has not implemented yet anywhere in the world, research is needed (pilot study)

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