Measuring economic water scarcity in agriculture: a cross-country empirical investigation

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What is economic water scarcity and why does it matter?

Food production is keeping pace of population growth globally and **food prices** have declined

However **poverty and malnutrition** persist in many regions (Asia, Sub-Saharan Africa, and parts of Latin America (Barrett 2010, FAO 2019).

=> benefits of increased agricultural production have been **unequally** distributed

=> possibly also due to inequality in **access to water resources**, in particular in agricultural production (Carr et al. 2015).

Water abundance is among the main factors that enhance land productivity, agricultural performance, and consequently food security.

=> It is crucial to **understand where (and why) water is lacking** for human consumption and agricultural production (Molden 2007).

Economic Water Scarcity = many countries have a high level of water availability according to the main hydrological indicators, but still face severe difficulties in the use of water resources for human activities (Molden 2007, FAO 2012)

=> Wide spectrum of **complex reasons**, from the lack of infrastructures to institutional inefficiencies (Marson and Savin 2015).

Water insecurity = when individuals lack secure access to safe and affordable water to consistently satisfy their needs for drinking, washing, food production, and livelihoods (Molden, 2007).

About 1.2 billion people live in areas of physical water scarcity;

1.6 billion people live in basins that face economic water scarcity.

Poor people suffer the most from symptoms of scarcity (UNDP 2006).

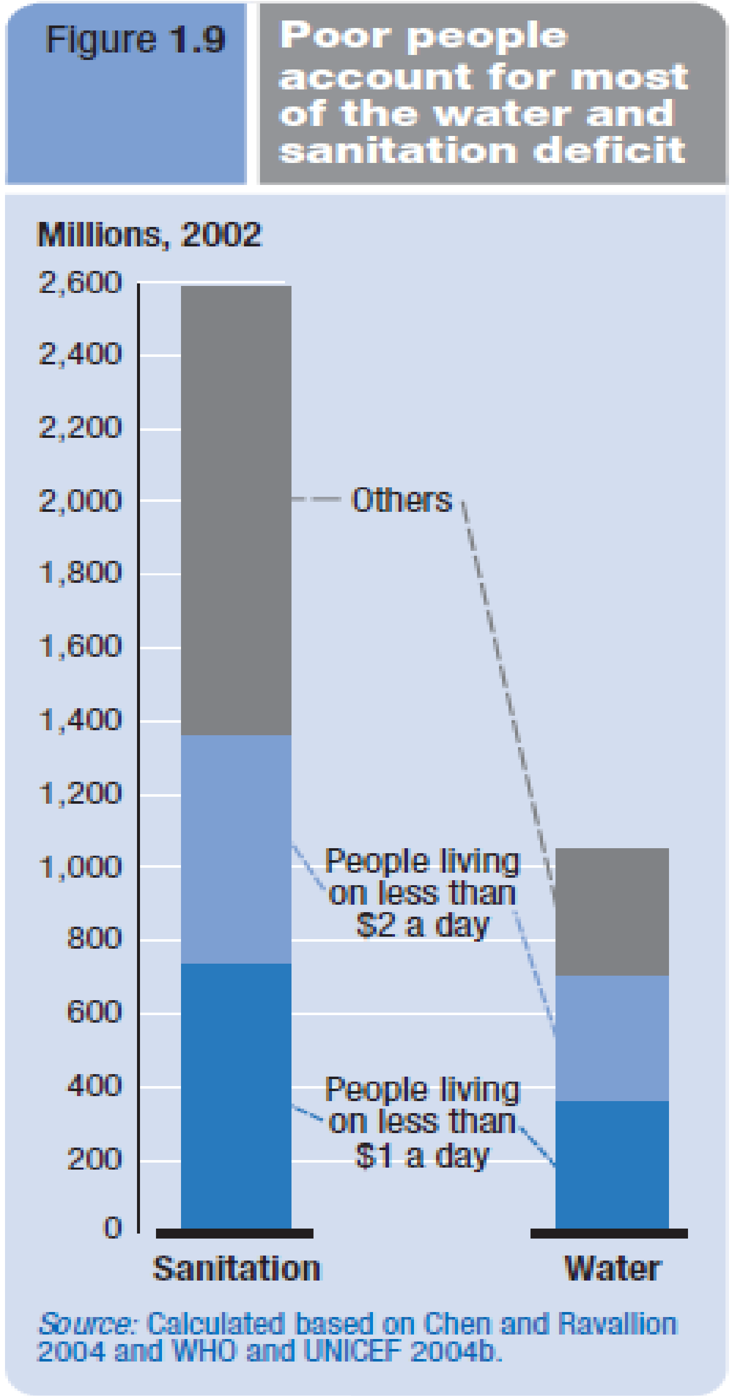
Large structural inequalities

About a third of people without access to an improved water live on less than $1 a day. Twice this share live on less than $2 a day = **660 million people lacking access to water have a limited capacity to pay for a connection to water service.**

More than half the 1.1 billion people without access are in the poorest 40% of the income distribution.

The association between poverty and lack of sanitation is stronger

Poverty ⬄lack of water



(UNDP 2006, p.48)

----The issue is relevant for many regions of the world. ----

Examples

Central African region (Congo)

water stress is inexistent according to current hydrological definitions

indicators on water use and agricultural performance have low values.

Central Asian countries

water abundant in hydrological terms

figures on water use in irrigation per hectare are comparatively higher

but disinvestment in the irrigation infrastructure => waste of water resources + economic damages in agriculture (UNDP 2006).

Low level of water management =>

-physical water scarcity for immediate **consumption**

-negative impact on **agricultural** yields

-**inefficiencies in water** use in agriculture => disproportionally high water footprint.

Improving water governance => **address simultaneously resource sustainability and food security.**

Nevertheless, such improvements require institutional innovation in **multiple domains (**Molden 2007).

Data driven studies are necessary to quantify the impact of water availability and access on livelihood and agriculture

Several indicators of physical water availability (water scarcity, water stress, % of renewable water resources, transboundary figures, water inflows and outflows, surface and groundwater , ….. => Schyns et al. 2015)

BUT

Measuring economic water scarcity is challenging!

Sustainable Development Goal Indicator 6.5.1: degree of implementation of Integrated Water Resource Management (IWRM)

⇒information at a national level on legislative, managerial and financial environment for water management, agreements for the management of transboundary watersheds and rivers and on stakeholders participation processes

⇒90% of the countries

⇒**Could it be a good indicator for economic water scarcity?**

---Contribution to different literature streams---:

- Water footprint and virtual water trade studies: only physical water scarcity.

- Rural development studies: no global data-driven studies.

Attempts of economic water scarcity measurement

Sullivan (2002): water poverty index

+: physical estimates of water + socio-economic variables on poverty

-: no info on weights of the different kind of variables; no water fluctuations; no global scale

De Fraiture (2005): actual-potential irrigation gap (Sub-Saharan Africa)

+: focus on gap between water availability and capacity to use

-: lack of water access is more than lack of infrastructure

Noemdoe et al (2006); Anand (2994): water scarcity subjective perception

+: focus on political and social inequality

-: no effort to quantify

World Bank (2007); FAO (2012): improvement of water scarcity concept

+: organization+political accountablity+infrastructure+institutions

-: no index

Gain et al. (2016): multidimensional global water security index

+: w availability, accessibility, safety, management; quantitative index, global coverage, grid scale

- : water management focus only on transboundary issues; water access is only on drinking and sanitation, no agriculture

Rosa et al. (2020): global measurement of economic water scarcity in irrigated areas

+: good quantification, high level data

-focus only on infrastructures for irrigation; only description, no impact

Integrated Water Resource Management (IWRM)

Developed by UN-Water (2018) in the framework of the Sustainable Development Goals definition

it measures the **SDG 6.5.1.**

Country level

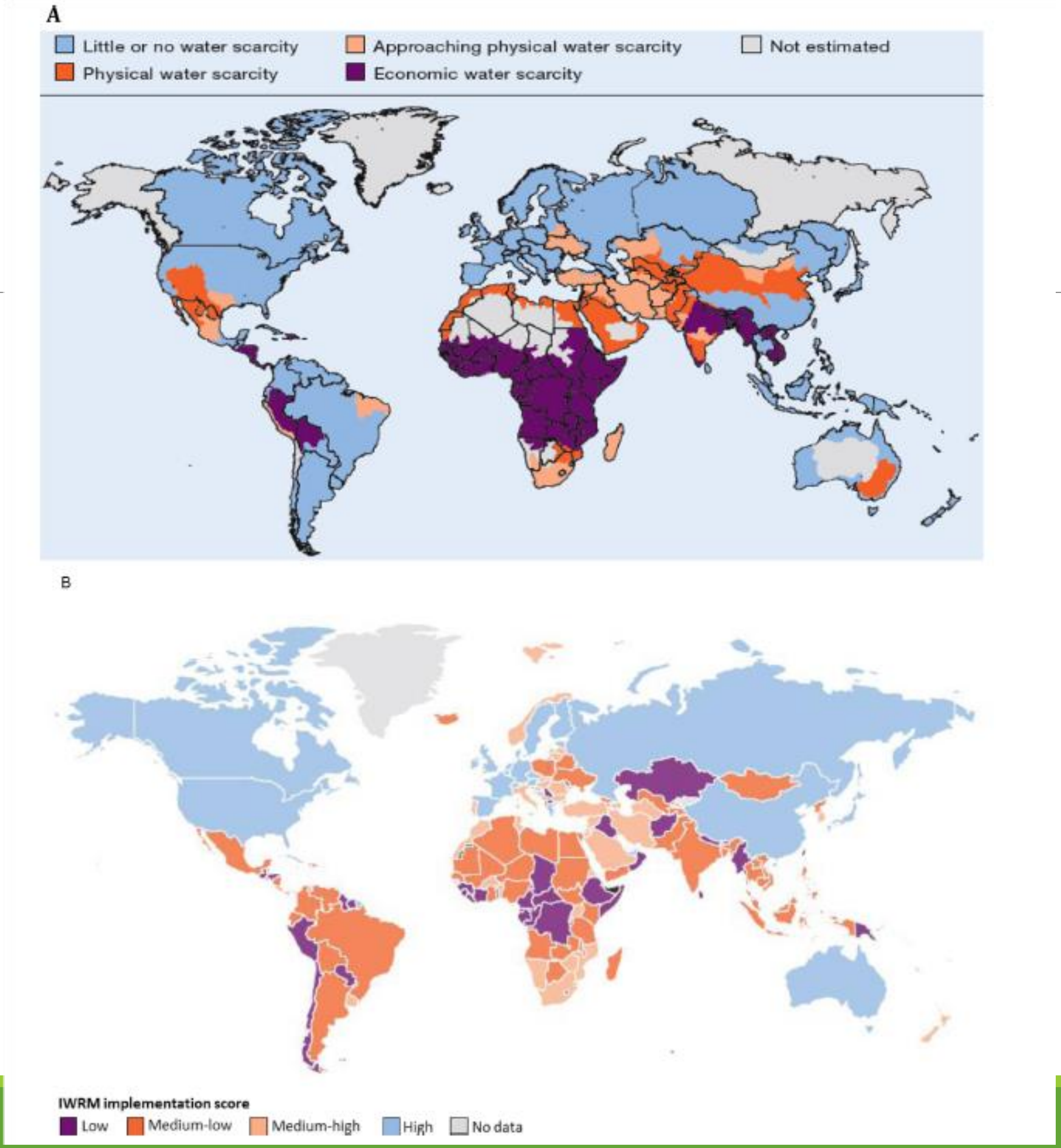
framework to assess whether water resources are developed, managed and used in an equitable, sustainable, and efficient manner, reflecting the diverse dimensions of water governance

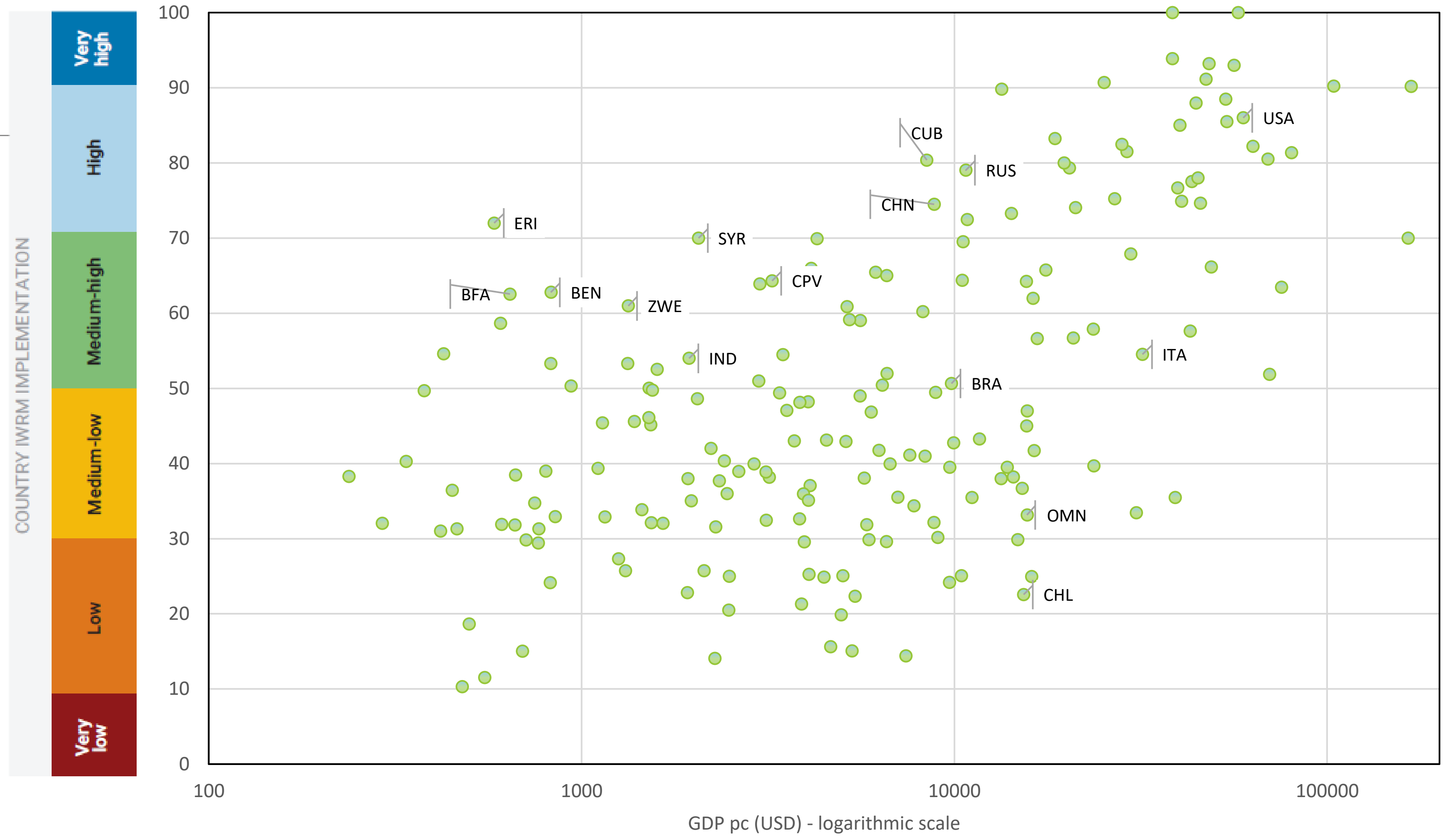
scale of zero to 100 (degree of IWRM implementation)

based on the responses to 33 questions in a country self-assessment questionnaire (**2017-2018)**

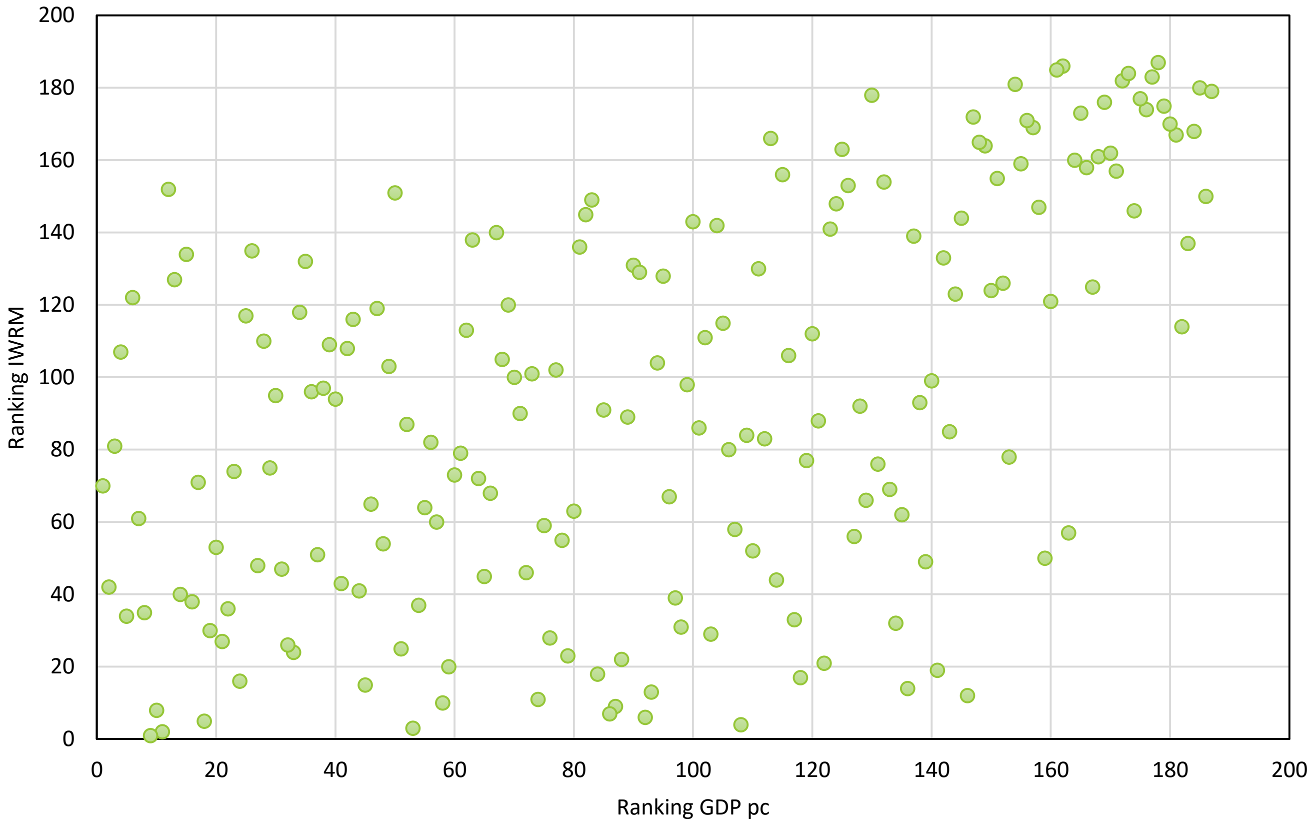
4 pillars of water governance: enabling environment, institutions and participation, management instruments and financing.

Missing scores for 2018 retrieved from similar surveys 2007 and 2011 worldwide (USA did not answer in 2018)


A
Little or no water scarcity
Approaching physical water scarcity
Not estimated
Physical water scarcity
Economic water scarcity
B
IWRM implementation score
Low
Medium-low
Medium-high
High
No data



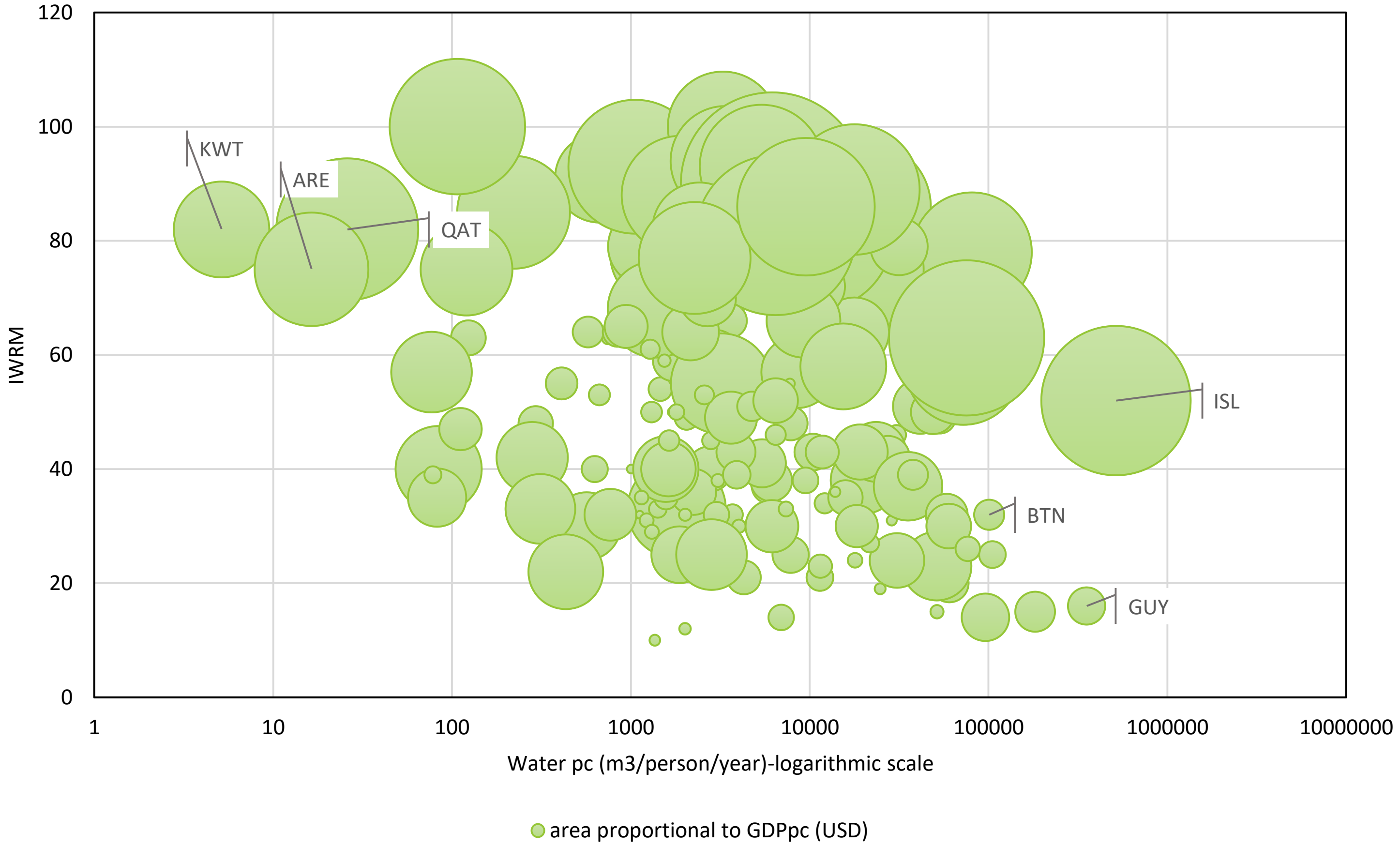
IWRM and GDP per capita in USD (2017, 187 countries). BEN: Benin, BFA: Burkina Faso, BRA: Brazil, CHL: Chile, CHN: China, CPV: Cape Verde, CUB: Cuba, ERI: Eritrea, IND: India, ITA: Italy, OMN: Oman, RUS: Russian Federation, SYR: Syrian Arab Republic, USA: United States of America, ZWE: Zimbabwe. Data from (2018) and from (2019).



Rankings of countries for GDP per capita and for IWRM indicator. The 187 countries are ranked in increasing order: small values on the axes indicate a low GDP per capita and a low IWRM indicator. Data from (2018) and (2019).

Figure 10 Degree of IWRM implementation by HDI score[23, 24]

UN Environment (2018)



IWRM (2017) and renewable water availability per capita (average 2013-2017) for 163 countries. The point area is proportional to the GDP per capita in USD (2017). ARE: United Arab Emirates, BTN: Bhutan, GUY: Guyana, ISL: Iceland, KWT: Kuwait, QAT: Qatar. Data are from UN Environment (2018), The World Bank (2019) and FAO (2019b).

Despite the clear association between high economic power and high IWRM index, the GDP is not the only crucial driver for investments in water governance => extreme **variability** in the IWRM index for similar ranges of economic wealth.

Water availability loosely influences the water governance level => more political and economic considerations

Assuming that economic water scarcity generates inefficiencies in agricultural production, we utilize the IWRM index as an explanatory variable to predict yields and water-use conditions, in order to understand whether the index can act as an indicator of the EWS.

10 crops crucial for nutrition both worldwide and in areas of economic water scarcity: wheat, maize, soya, rice, potatoes, cassava, sweet potatoes, millet, sorghum, and sugarcane (D’Odorico et al. 2014, de Fraiture 2005, FAO 2019a, Molden 2007).

Year 2016

Yield: FAOSTAT

Crop Water Footprint: CWASI (Tamea et al. 2019, PoliTo)

$$uWF = 10 \cdot ET/Y$$

ratio between the water consumed by the crop during the growing season and lost through evapotranspiration (*ET,* in mm), and the crop yield, *Y* (in ton/ha)

Sum of green water (rainfall) and blue (irrigation: surface or groundwater (Hoekstra et al., 2011)).

Yield and WF are crop and country specific.

Tamea et al.: time variability

For comparison

Normalized yield for each crop in each country

$NY_{z,i} = Y_{z,i}/WAY_z$

where $WAY_z = \sum_{i=1}^{n} t_{z,i}/\sum_{i=1}^{n} ha_{z,i}$ (weighted average yield, globally)

Normalized yield (*NY*) values around 1 = the yield of the given crop in the given country is close to the world weighted average yield for that crop.

Same for crop water footprint

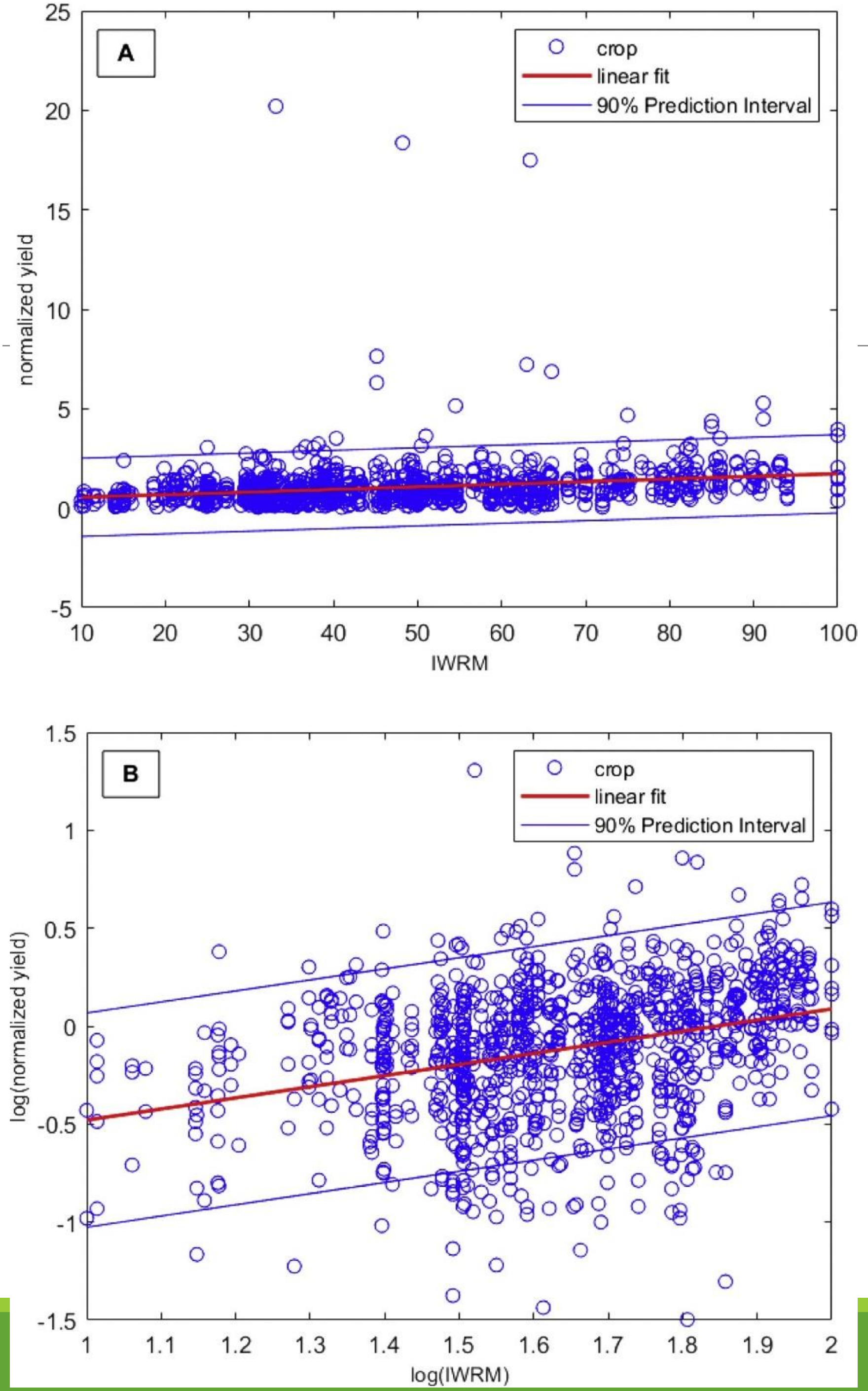


Fig. 5. IWRM indicator and normalized yield for ten selected products (2016). In panel 5.A the red line represents the trend of the linear model with actual values (Equation 4; Table 3-left upper panel-I), while in panel 5.B the red line shows the trend of the linear model with logarithmic values (Equation 5; Table 3-right upper panel-I), with IWRM as unique regressor in both cases. In both panels, the blue lines represent the upper and lower bounds of the prediction intervals at 90%. Data sources: (2018) and FAO (2019a).

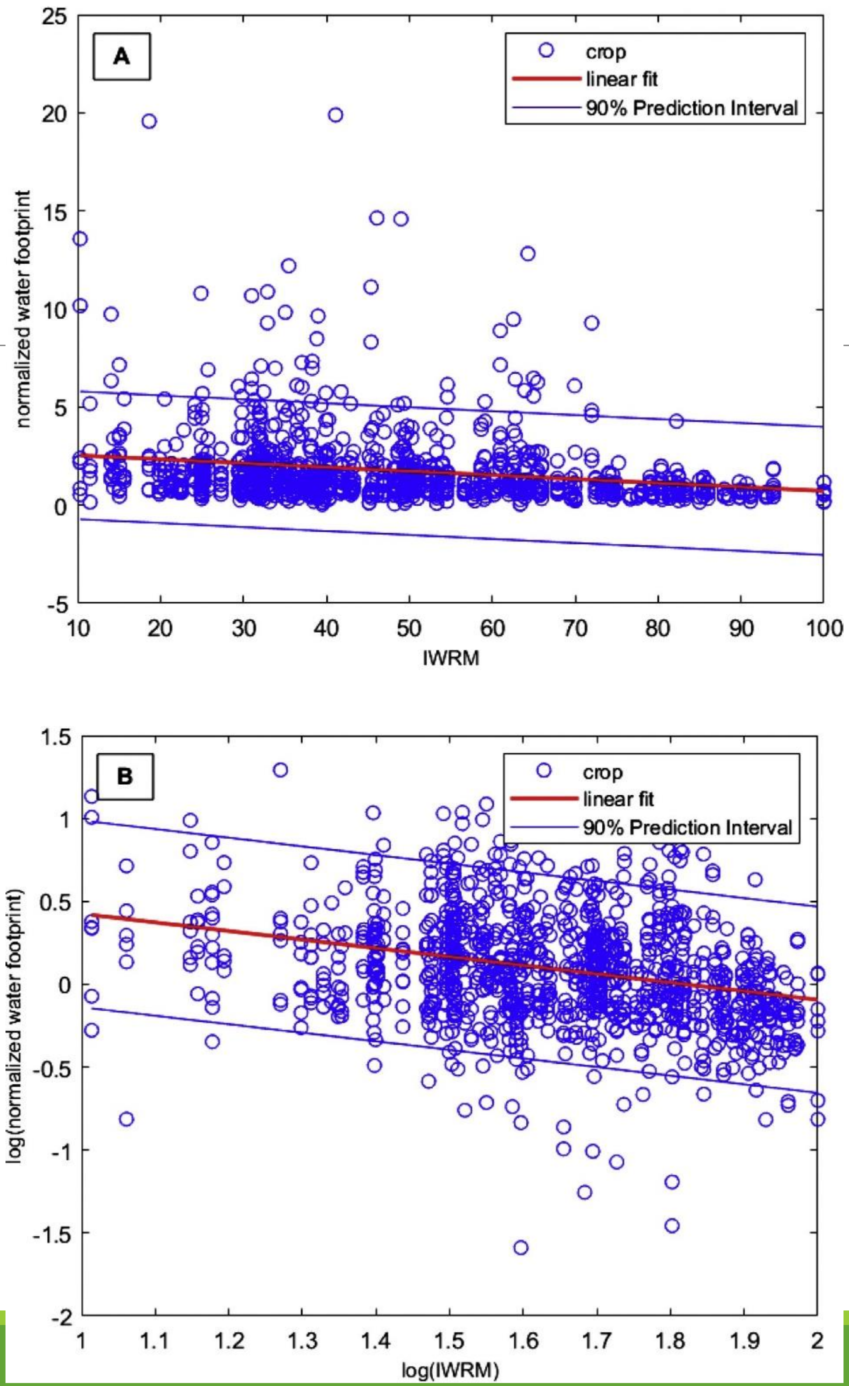


Fig. 6. IWRM and normalized water footprint of ten selected crops (2016). The red line in panel 6.A represents the trend of the linear model with actual values (Equation 6; Table 3-left bottom panel-I), while the red line in panel 6.B shows the trend of the linear model with logarithmic values (Equation 7; Table 3-right bottom panel-I), with IWRM as unique regressor in both cases. In both panels, the blue lines represent the upper and lower bounds of the prediction intervals at 90%. Data sources: UN Environment (2018) and Tamea et al. (1961-2016).

Including **GDP per capita** and **Falkenmark Indicator on water availability (W)**

Yield

$$NY_{z,i} = \beta_0 + \beta_1 IWRM_i + \beta_2 GDPpc_i + \beta_3 W_i + \varepsilon_{zt}$$

Log for regressors

$$NY_{z,i} = \beta_0 * IWRM_i^{\beta_1} * GDPpc_i^{\beta_2} * W_i^{\beta_3} * \varepsilon_{zt}$$

Crop Water Footprint

$$NWF_{z,i} = \beta_0 + \beta_1 IWRM_i + \beta_2 GDPpc_i + \beta_3 W_i + \varepsilon_{zt}$$

Log for regressors

$$NWF_{z,i} = \beta_0 * IWRM_i^{\beta_1} * GDPpc_i^{\beta_2} * W_i^{\beta_3} * \varepsilon_{zt}$$

Table 1. Coefficients estimated through the linear regression models (respectively standard and power law), considering normalized yield (NY) and normalized water footprint (NWF) for 10 crops. IWRM: Integrated Water Resource Management Index. GDPpc: gross domestic product per capita (USD). W: Total renewable water per capita (m^3). *p-value<0.10; **p-value<0.05; ***p-value<0.01

	Indep. Var.	Linear model (Eq. 4 and 6)				Power law model (Eq. 5 and 7)			
		I	II	III	IV	I	II	III	IV
Normalized Y	IWRM	0.013 ***		0.008 ***	0.008 ***	0.567 ***		0.272 ***	0.254 ***
	GDPpc		$1.816 \cdot 10^{-5}$ ***	$1.187 \cdot 10^{-5}$ ***	$1.238 \cdot 10^{-5}$ ***		0.246 ***	0.204 ***	0.206 ***
	W				$-8.592 \cdot 10^{-7}$				-0.005
Normalized WF	IWRM	-0.020 ***		-0.010 ***	-0.011 ***	-0.519 ***		-0.250 ***	-0.235 ***
	GDPpc		$-2.997 \cdot 10^{-5}$ ***	$-2.150 \cdot 10^{-5}$ ***	$-2.039 \cdot 10^{-5}$ ***		-0.225 ***	-0.187 ***	-0.190 ***
	W				$-1.245 \cdot 10^{-6}$				0.007
	Obs.	1094	1094	1094	1068	1094	1094	1094	1068

We performed the same regression models considering **each of the ten crop individually**

(i.e. the coefficients/exponents become crop specific).

Running the model specification that includes the IWRM index as the only regressor (case I), we observe that yield coefficient values range from 0.01 for millet to 0.1 for maize.

The regressions for the water footprint give coefficients from -0.01 to -0.05.

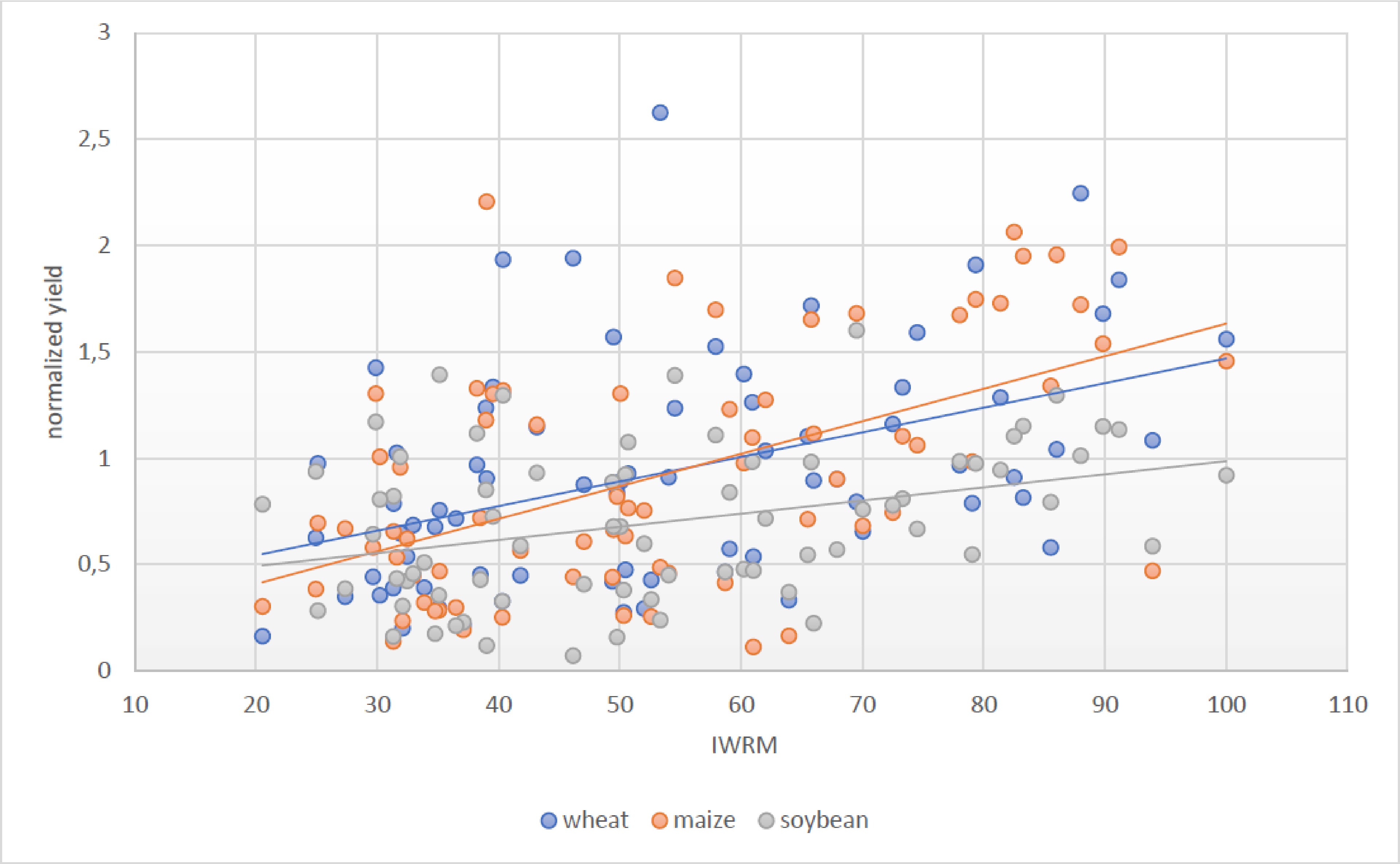


Figure S6. Relation between the IWRM index and the normalized yield of wheat, maize and soybean. Normalized yield values above 1 indicate a country specific yield above the world weighted average for that crop, and *vice versa*. Data sources: UN-Environment (2018) and FAO (2019a).

Summary of findings

The **water governance** dimension provides new information beyond the most traditional measures of water availability and it is not full explained by wealth of a country.

Having a more sophisticated level of water governance has a **positive effect** on water consumption for the **production** of the most important agricultural products, leading to more **efficient** solutions from the point of view of **water footprint**.

IWRM index maintains significance also when GDP per capita and physical water availability of the country are considered as explanatory variables.

Results holds across countries with different economic and climatic conditions, and **across products** (both aggregate and single)

More investigation for **blue** water isolated. Opposite trends