Food and Agriculture Organization of the United Nations

The dimensions of water productivity

As the world population increases, so does the demand for water in all domains of human life: food production, domestic use and industry. Of these three sectors, agriculture is the largest user as **"irrigated agriculture accounts for more than 70 percent of global water withdrawals, and, globally, 41 percent of withdrawals are not compatible with sustaining ecosystem services"** according to FAO figures.
These figures call for increased attention to be brought upon the use of water in agriculture and its optimisation in a global context of water scarcity brought about by overexploitation, mismanagement and a changing climate. In this case, a concept like water productivity can be helpful since, as we will see throughout this document, it is **multidimensional** and can help us account for different aspects of water use that a local context might call for: it can be geared towards local priorities.

Productivity can be broadly defined as the ratio between a unit of output and a unit of input; therefore, water productivity is:

$$WP = \frac{\text{output of water use}}{\text{water used}}$$

What we choose to measure as **output** will dictate what kind of water productivity we are looking at: whether it is biophysical, economic, social or nutritional water productivity. **In this sense, improving water productivity means taking measures to boost output, respectively biomass production (yield), income, jobs and nutrition, reduce water used, or both.** How to go about that will depend on the area at hand and the priorities of the stakeholders.

THE DENOMINATOR

It is worthy to note that, in the water productivity equation, the denominator can also differ depending on the interests of the stakeholders: whether they be agronomists, farmers, water managers, hydrologists, etc, as they see and qualify water flows differently. A farmer or an agronomist might consider drainage water as lost, whereas a hydrologist working at the basin level may quantify it as a flux of water within the same system, with a negligible impact on the basin water balance (Molden et al., 2003).

While some stakeholders might consider ***water used*** as ***water consumed by the plant***, as is the case with the WaPOR WP protocol, others might consider ***the irrigation water that is applied*** or even ***water diverted*** from the source for irrigation. It is therefore important to pay attention to which denominators are used when considering water productivity, especially when comparing values from different sources.

The water used by the plant, ie. its **evapotranspiration** can be obtained in near real time with **WaPOR data** derived from remote sensing.

THE NUMERATOR

(**BWP**)
Biophysical water productivity :

kg/ m³

This dimension of water productivity is the most broadly used; it describes agricultural output (biomass production or yield) per unit of water used in a given area.

$$BWP = \frac{\text{biomass production or yield}}{\text{water used}}$$

biomass production or yield: kg, tons
water used: mm, m³

WaPOR data, derived from **remote sensing**, can be used to estimate both elements of this equation: **biomass production** (from which **yield** can be estimated) and **evapotranspiration** (water used) in near real time, allowing for close monitoring of BWP.

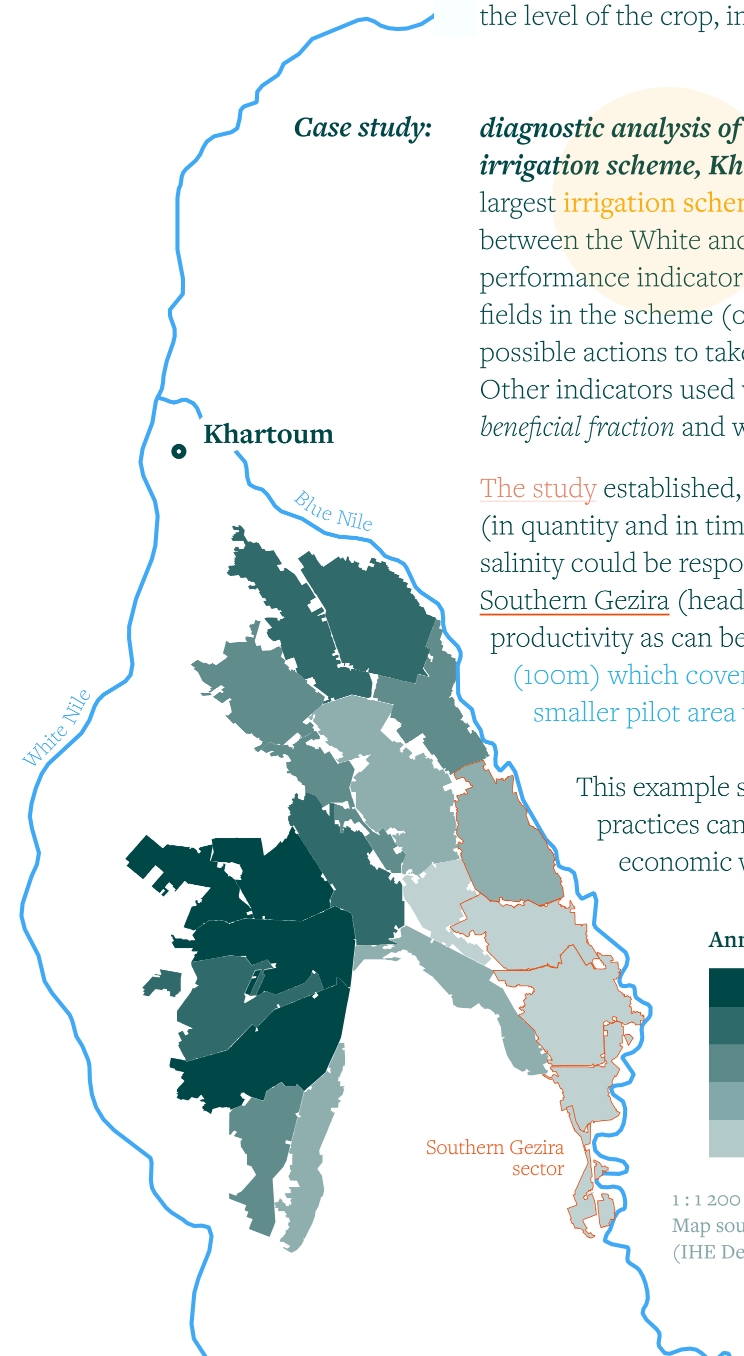
Optimizing this dimension of water productivity means producing **more crop for every drop of water** either by taking management measures to increase yield at the same water use level (such as with improved application of fertilizers, better choice of crop varieties and cropping calendars, or by mitigating on-field factors that reduce production such as salinity), decreasing water use at the same production level (with deficit irrigation practices in some instances, or by reducing non-productive water consumption such as evaporation, etc.) or doing both at the same time.

Management measures to improve BWP can be taken at different scales: at the level of the crop, in the field, or at the level of the irrigation scheme.

Case study: ***diagnostic analysis of irrigation performance of wheat in the Gezira irrigation scheme, Khartoum*** (***Sudan***): in Gezira, Sub-Saharan Africa's largest irrigation scheme under one management situated South of Khartoum between the White and the Blue Nile, BWP was used as one of the irrigation performance indicators to map the better and worse performing wheat fields in the scheme (over 3 seasons: 2019, 2020 and 2021) and identify the possible actions to take in order to improve the performance of irrigation. Other indicators used were *uniformity, adequacy, yield* (land productivity) and *beneficial fraction* and were calculated according to the WaPOR WP protocol.

The study established, amongst other conclusions, that inadequate irrigation (in quantity and in timing), low farmer awareness of proper irrigation and soil salinity could be responsible for the lower performance of parts of the Southern Gezira (head-end), an area that is characterized by low water productivity as can be seen in the map besides. WaPOR data at level 2 (100m) which covers the entire scheme, and level 3 (30m), which covers a smaller pilot area within it, were used for the analysis in this study.

This example shows that decision-making about on-farm irrigation practices can be improved through the use of biophysical and economic water productivity indicators.



Map source: Gezira sectors and water productivity data provided by Shaima Amir (IHE Delft) and hydrologic data from Natural Earth.

(EWP)
Economic water productivity :

This dimension of water productivity can be defined as the economic value of water used for production.

$$\text{EWP} = \frac{(\text{yield} \times \text{price received for crops}) - \text{production costs}}{\text{water used}}$$

in USD or local currency, as relevant

mm or m^3

usd/m^3

Just as for BWP, the water consumed (**evapotranspiration**) and the **yield** (derived from biomass production) are variables that can be obtained in near real time with **WaPOR data** derived from remote sensing. Other inputs are from national sources and local data.

Optimizing economic water productivity has to do with obtaining **more "dollars" per drop** by attempting to influence elements of the equation:

- **yield**: producing more
- **price**: selling at a time when prices are higher if the prices are fluctuating (though that requires access to markets and storage)
- **costs**: reducing when possible
- **water used**: taking measures to reduce the water use.

Alternatively, farmers may choose to switch to a crop or a different cropping system that will have a higher economic water productivity.
At the farm level, EWP can help farmers make decisions that will help them increase their income. At the policy-level, this indicator can assist decision-makers and water managers in allocating water in an economically optimal way.

Case studies:

One case study explores the ***improvement of economic water productivity of dates***, a crop that in Oman grows in more than 50% of the country's arable lands, by considering different strategies of adding value to the products post-harvest, to boost the economic value generated. The study found that the strategy that improved EWP most significantly is to package the dates with nuts.

Another study focuses on the Turkish market where the pricing of sugar-beets is dependent on sugar content, and states that in that context, practicing different levels of ***deficit irrigation could be a strategy for realizing significant water savings without much loss of income***, increasing therefore EWP with up to a 40% deficit in water application in the fields. While that does not need to be the default practice in the area of the study, that can be a solution to resort to in periods of severe shortage of irrigation water.

Both BWP and EWP were calculated for banana and sugarcane fields using remore sensing data, at the river basin scale.

In the South African part of the Incomati River, scholars have laid out ***a methodology for the use of remote-sensing data in water management*** that involves looking at biophysical and economic water productivity side by side to determine the best way to reallocate water away from agriculture, and into uses that are more in line with one of the social objectives of the country's Water Act: to redress past inequalities. With this methodology, if water is to be reallocated, it could be done in such a way that areas that have the lowest EWP and/or BWP are targeted, and, as much as possible, the areas that perform better can remain as agricultural areas.
The study shows that maximum BWP or EWP is not always the goal. There are contexts where social objectives may supercede the maximisation of these indicators. Yet, even in these situations, they remain helpful tools for decision-making, for understanding how to go about the resource reallocation.

Beyond acting in accordance to social objectives, it is also possible to quantify social gains per unit of water with social water productivity, the next dimension that we will delve into.

(SWP)
Social water productivity :

Although seeking to attain higher biophysical or economic water productivity can bring many societal benefits including poverty alleviation, or water savings that might free-up water for environmental flows, it is always important to remain critical of the tools we have and take into consideration the **societal objectives that they may help us further.**

$$SWP = \frac{\text{net social benefits}}{\text{water used}}$$

the numerator depends on the societal objectives in question

mm or m^3

in the case of pro-poor water productivity, the unit of SWP would be jobs/m^3

This indicator permits us to look at and compare the net societal benefits per unit of water used and has a distinctively political nature in the sense that there isn't a single equation for it: the numerator is defined by the social priorities that animate the decision-making process that it can facilitate. Here, a case study will be much helpful in shedding light into the variable nature of social water productivity.

Case study: ***pro-poor water productivity in Ica, Peru***

A decision needed to be made in Southwest Peru regarding the potential diversion of water from the mountains to the coast: from subsistence farmers to plantations producing high value export crops that would have better economic water productivity (about 5 times more for one of the high value crops compared to the subsistence crops produced in the highlands).
Yet most of the money generated by the high value crops would have been pocketed by plantation owners rather than the workers for whom the economic water productivity of the crops was less than half of the subsistence farmers. In this case, **allocating water to crops that do not have high economic value, but have a high societal value** (better distributed economic value and food security as the high value crops were geared towards exportation) yielded the highest social water productivity, an indicator that supports the political will of promoting equity with water use.

(NWP)
Nutritional water productivity :

NWP is the nutritional content of a crop per volume of water used in its production. It can be helpful in guiding the choice of crops towards high-value nutrient-dense ones whilst using resources sustainably.

$$NWP = \frac{\text{crop nutritional content}}{\text{water used}}$$

macro/micro-nutrient content measured in g, mg, μg, kcal per kg of crop

mm or m^3

Optimizing NWP has to do with obtaining **more nutrition per drop**. It could also serve as a farm or scheme-level tool for assessing the impact that different irrigation regimes and other field-management practices can have on the nutritional content of the food crops or as a tool to help ensure that nutrition is prioritized when deciding how to allocate water in agriculture.

Case study: ***the case of orange-fleshed sweet potato***

A prior study analyzed the NWP for orange-fleshed sweet potatoes, which is rich in beta-carotene (a micronutrient that helps prevent vitamin-A deficiency), under two growing regimens: market-oriented farming (for their tubercules) and subsistence-oriented farming (growing them for the tubers

This study shows NWP as the amount of water needed for a person to meet their daily nutrient needs rather than focus on a given area.

More case studies on NWP with the ongoing FAO project Nutrition-Sensitive Agriculture Water Productivity, which works with countries to strengthen the capacities of their smallholder farmers in the adoption of sustainable water management and nutrition-sensitive agricultural practices.

and the leaves). The subsistence-oriented farming modality requires more than three times less water per person per day to meet daily-recommended intake of iron compared the market-oriented regimen. This finding is true under water stress conditions, which makes it a good crop to turn to in times of drought.

SCALE

Water productivity can be considered at different scales depending on the users and their objectives.

Water productivities:

BWP: biophysical
EWP: economic
SWP: social
NWP: nutritional

crop: considering **BWP** can help breed crops/cultivars that yield more for the same water input.

field: **BWP** can help compare and assess the choices of crop and management techniques, **EWP** can help assess the choice of crops that can provide the most financial return to the farmer and **NWP** can help guide crop and field management choices that maximise nutritional value.

farm: considering **BWP** can help track, compare and assess crop production, especially if there are different management practices (such as different types of irrigation).

irrigation scheme: **BWP** can help improve irrigation system performance in relation to the water delivered and help diagnose high and low performing areas, guiding amends.

basin: **BWP** can help guide improvements of water use in agriculture leading to more water availability for other uses, such as environmental flows.
Considering **SWP** can help guide water allocation choices such that they yield the most equitable outcomes (as in example on page 4) .

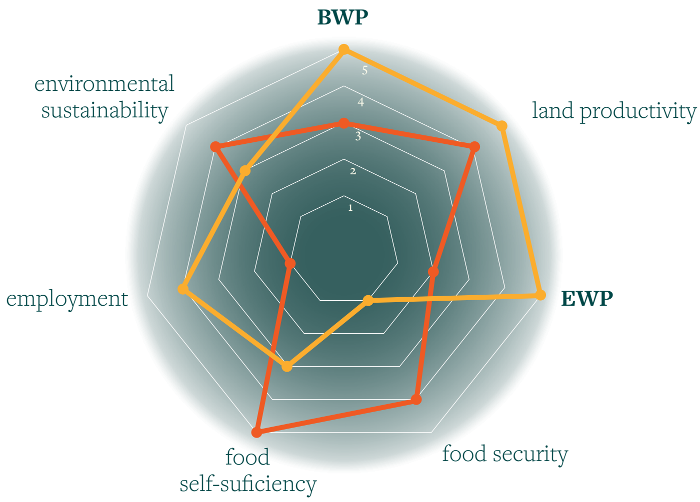
country/region: **BWP** can improve water allocation to achieve food security or bolster trade (national income) at national and regional scale.

WP can be a useful concept that can help different stakeholders achieve different outcomes. Yet, it is not always sufficient to look at WP, and it is not necessarily a variable to be maximized at all costs.
In the case study in page 2, BWP was used in conjunction with other irrigation performance indicators to help paint a more complete picture of the situation in the Gezira irrigation scheme.
In the case study in page 4, pro-poor water productivity (SWP) allowed insights that were different from the EWP that was calculated for the same crops in the same area, providing more information to decision-makers.

Under the **WaterPIP project**, researchers at Wageningen University are currently working on testing a water productivity assessment framework that takes into account **BWP, EWP, environmental sustainability, employment, food self-sufficiency, food security** and **land productivity**.

Visualized as a radar chart, this framework will allow choices relating to agriculture at different scales to be evaluated according to different perspectives/outcomes that is targeted specifically for **policy-making**. Below is an example of two hypothetical scenarios that are measured for these 7 perspectives:

For example, the yellow scenario should not be considered if food security is a priority, but if increased productivity is the goal, it performs better than the red scenario which conversely "performs" better in terms of food security and food self-sufficiency.



At Wageningen University, the main scenarios that are currently being considered in the development of this framework are irrigation development strategies, namely vertical and horizontal development which respectively correspond to agricultural intensification and areal expansion of cultivated areas. The objective is to have a tool that allows us to understand - in a world where producing more is an imperative, and so is the better use of our water resources - what is the best way to achieve these goals in different contexts.

REMOTE SENSING

As can be seen throughout this document, assessing and monitoring water productivity can be quite data-intensive. Open-source remote sensing-derived data can help breach some of the existing gaps where field data is lacking.

This document highlights the different ways in which WaPOR data can function as inputs to the equations for the different water productivities. **WaPOR**, FAO's **portal to monitor WAter Productivity through Open-access of Remotely sensed derived data**, assists countries in monitoring (biophysical) water productivity, identifying productivity gaps, proposing solutions to reduce these gaps and contributing to a sustainable increase of agricultural production.

WaterPIP
Water Productivity Improvement in Practice

To learn more about what is Water Productivity and how to assess and interpret it from multiple perspectives, digging deeper into the themes of this document, consider registering for the free MOOC offered by our partners at **WaterPIP** with funding from:

Ministry of Foreign Affairs of the Netherlands

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www.fao.org/in-action/remote-sensing-for-water-productivity