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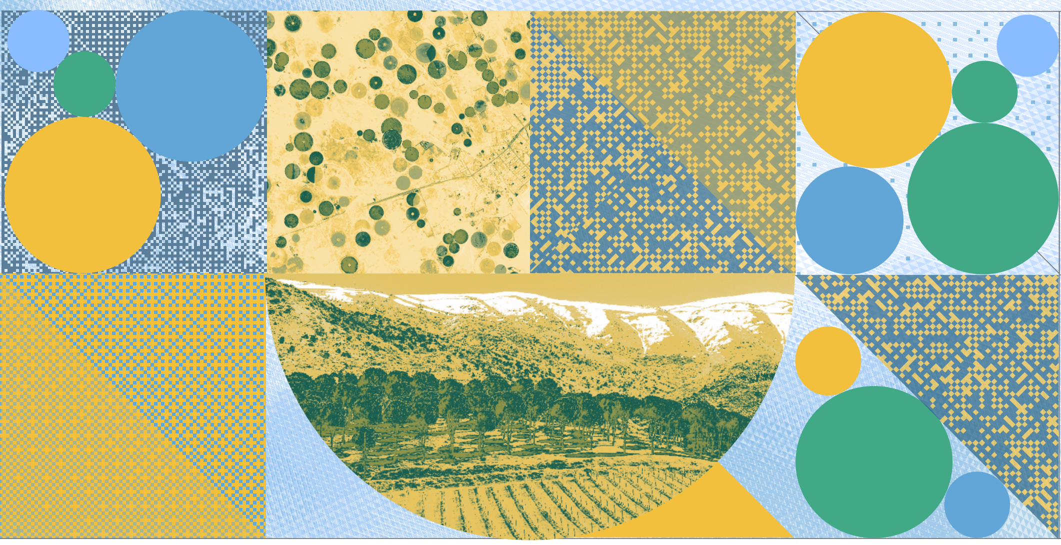
IRRIGATING FROM SPACE
USING REMOTE SENSING FOR AGRICULTURAL WATER MANAGEMENT



FAO INVESTMENT CENTRE

INVESTMENT BRIEF

With water becoming increasingly scarce and irrigated agriculture already accounting for 70 percent of global water withdrawals, governments around the world are supporting efforts to improve the performance of water use in agriculture. Improving water productivity is often the most important route for coping with increased water demand in agriculture (FAO, 2020). While the use of remote sensing to assess and monitor agricultural water productivity is not new, the time is ripe to scale up such technologies and use them for effective policy making, especially in irrigated areas where water is scarce. Remote sensing technologies use high spatial and temporal resolutions to estimate several agrohydrological variables across nested scales – from field to irrigation schemes to watershed. The Food and Agriculture Organization of the United Nations (FAO) and its partners have invested in developing databases and tools that apply remote sensing in agricultural water management, with a focus on low-income and data-scarce contexts.

This brief proposes concrete applications of the FAO-developed tool: WaPOR – Water Productivity through Open access of Remotely sensed derived data portal. It establishes the methodological framework used to estimate key variables that can assist decision-making on improving irrigation water management, such as irrigation water application and economic irrigation water productivity (EIWP). The results from a case study of the Bekaa Valley, Lebanon's most important farming region, show that the correct application of WaPOR combined with economic data can lead to better policy and investment decision-making, and more sustainable agricultural water management in water-scarce regions.

Estimating water productivity in water-scarce regions – why remote sensing makes a difference

Population and economic growth as well as climate change are putting added pressure on available resources. Given water's importance to agriculture, the careful monitoring of water use and opportunities available to improve water productivity are essential. Most efforts to improve agricultural water management focus on increasing yields per unit of water supply – or crop water productivity as defined by FAO (2016) – on the premise that this can contribute to increasing food production and 'save' water for other sectors and ecosystem services.

However, yields are not comparable between crops. While crop water productivity is a useful indicator for improving water use for one crop, this is not the case in systems where multiple crops compete for the same scarce water resources. In these instances, we need a different tool.

That is why economic irrigation water productivity (EIWP) is an important indicator for policy making (see Box 1 for a definition). Calculating EIWP involves dealing with yields and irrigation practices that vary from farm to farm and from year to year, as well as complex multi cropping systems and large numbers of farms. In such contexts, collecting accurate field data can be difficult and expensive using traditional methods that rely on field data to feed theoretical models on irrigation requirements based on hydrological, plant growth and water use parameters. In addition, such theoretical models do not estimate *actual* water supply, nor its spatial and temporal variations. Remote sensing tools offer a powerful and cost-effective alternative way to estimate *actual* EIWP.

Advances in open access, remote sensing products provide new opportunities to undertake these assessments, enhancing the understanding of water consumption and improving agricultural water management (Hellgers *et al.,* 2010). FAO's WaPOR portal is one such tool (see Box 2 for a short introduction to WaPOR). WaPOR helps countries monitor water productivity and identify and reduce water productivity gaps (FAO, 2022). Thanks to near real-time pixel information, irrigation authorities can obtain information on yields and efficient use of water resources through WaPOR, helping them to monitor irrigation water management policies and investment (see Box 3 on using remote sensing to estimate EIWP).

BOX 1

Defining economic irrigation water productivity

Hellegers *et al.* (2010) define EIWP (USD/m^3) as **beneficial biomass multiplied by the market price, deducted from the financial production costs** (except water), all **divided by water consumed** (i.e. the value of water or the **net water return to the producer**).

EIWP = (beneficial biomass × market price – financial production costs) / water consumed

Barker, Dawe and Inocencio (2003) highlight the difference between the **private return and net social return of water.** Net social return of water removes all transfers between agents and price distortions, such as subsidies, taxes or the effects of trade policies. It also accounts for externalities. However, the authors have acknowledged that water management is riddled with externalities that are difficult to monetize (e.g. see Kiptala *et al.* [2018] for more on accounting for ecological services of water).

Definitions of **economic irrigation water productivity** can differ in the literature. For example, Nouri *et al.* (2020) define it as the value of output (farm gate) divided by evapotranspiration (ET) while Schyns and Hoekstra (2014) use the value of output (export) divided by ET. Although these two definitions are easier to apply than the initial one, they ignore production costs. For crops with very different costs, using the gross value of production may not provide a good proxy for the differences in the return of water.

Defining economic irrigation water productivity also requires stipulating what measure to use for **irrigation water volume.** Adeboye *et al.* (2015) and Santos *et al.* (2010) measure irrigation water applied to the field. This definition does not consider conveyance and distribution losses not controlled by farmers but includes all on-farm non-consumptive uses (return flows to the system). It differs from the definitions previously cited by the authors who instead measure only ET. For the purpose of this brief, the authors suggest defining EIWP using the following equations:

Private EIWP = profit / irrigation water applied to field,
Social EIWP = economic profit / irrigation water applied to field

Profit, as defined by FAO (2013) and in line with what Hellegers *et al.* (2010) propose, is yield multiplied by the farm gate price net of the values of intermediate consumption, labour, consumption of fixed capital on farm, as well as interest, rents and taxes. In this case, intermediate consumption includes costs of water abstraction, conveyance and application, but not the price of water. The conversion from private to social profit can be conducted as explained above.

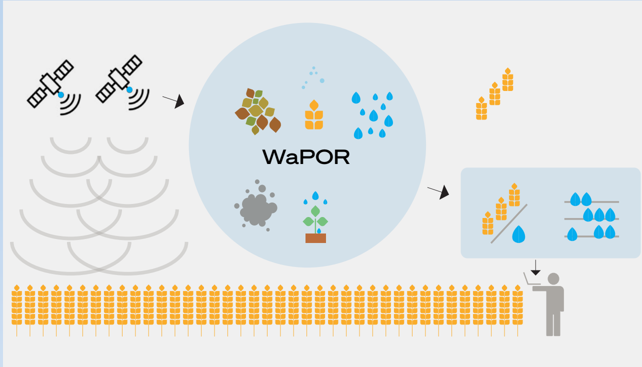
Irrigation water applied to the field is chosen as the preferred metric, as in most cases the price of water is established per cubic metre of applied water. Farm pumping costs are also a function of the applied volume of water. Hence, this metric allows a direct comparison between irrigation water's net return and price (or economic value). However, irrigation water applied in the field may be difficult to measure with high spatial and temporal resolutions (in the absence of water metering). The share of actual ET from irrigation is normally accepted as a good proxy in some contexts. For example, Ahmad, Bastiaanssen and Feddes (2005) and Bastiaanssen and Hellegers (2007) argue that if ET from irrigation originates from groundwater, where no records are available, it is a good indicator of net groundwater consumption.

BOX 2

The WaPOR portal

The WaPOR portal uses remote sensing to provide users with access to a wide variety of real time satellite data on water productivity over a ten-year period. The data, which is open source, provides ten-day (dekadal) maps of actual evapotranspiration (ETa) and net primary production (NPP) by vegetation produced at three spatial levels: **continental** with a spatial resolution of 250 metres; **national** with a spatial resolution of 100 metres, covering selected countries; and **sub-national** with a resolution of 30 metres, covering selected agricultural areas. ET and NPP estimates are obtained from the processing of several satellite input data at different spatial and temporal resolutions.

More information on WaPOR, its methodology, quality assessments and collection of reports on applications of WaPOR in several geographical areas are available at: www.fao.org/in-action/remote-sensing-for-water-productivity/en/.
The WaPOR portal can be accessed at: https://wapor.apps.fao.org/home/WAPOR_2/1



WaPOR data sources and output

Source: FAO. 2022. WaPOR, remote sensing for water productivity. www.fao.org/in-action/remote-sensing-for-water-productivity/en

SOURCE: Authors' own elaboration.

BOX 3

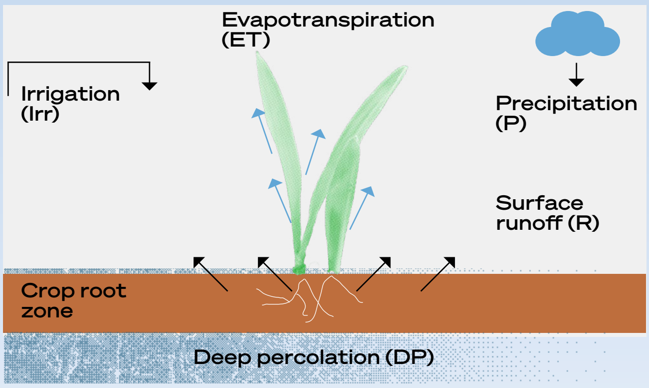
Measuring EIWP

Measuring profit

- Remote sensing can help estimate crop yields as follows: (i) land cover and biomass increase (NPP*) maps are obtained from remote sensing-derived information; (ii) a field survey assesses crop types in a number of locations; (iii) based on these two sources of information, an algorithm classifies the non-surveyed pixels with the corresponding crop type; (iv) crop-specific parameters are applied to each crop to translate observed biomass increase into yields.
  * NPP is the conversion of carbon dioxide into biomass driven by photosynthesis (FAO, 2020).
- Output prices, production costs, taxes and subsidies are estimated from data and information collected through field surveys, price monitoring and secondary sources of information.

Measuring water applied to the field through irrigation

Water applied to the field through irrigation can be measured directly through on-farm water metering or estimated as ET + surface runoff (or drainage flow) + deep percolation + Δ water storage in the root zone – rainfall.

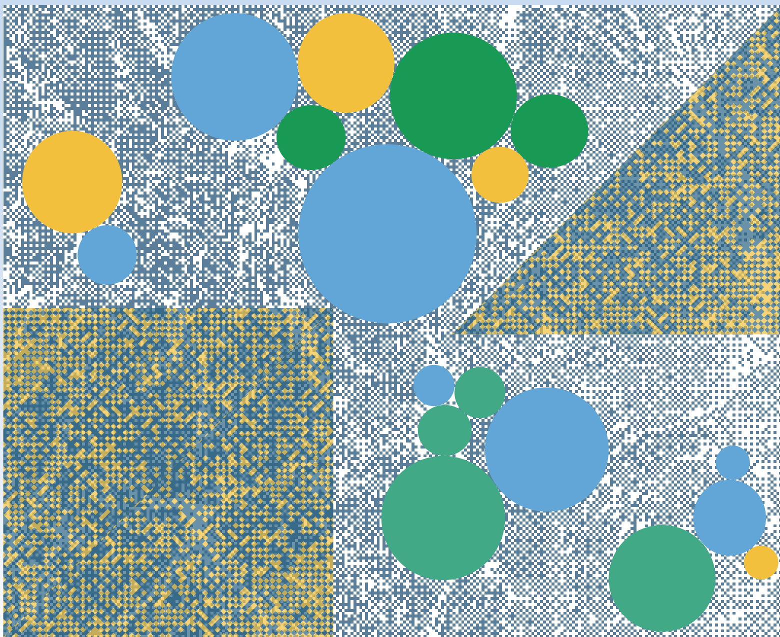


Irrigation application

Source: Adapted from Vasudha Sharma. 2019. Evapotranspiration-based irrigation scheduling or water-balance method. https://extension.umn.edu/irrigation/evapotranspiration-based-irrigation-scheduling-or-water-balance-method

WaPOR does not calculate actual irrigation water applied to the field, but measures ET and maps the irrigated and rainfed fields, which allows for an estimate of ET from irrigation, all in a dekadal time step and per pixel. Remote sensing can also help to estimate rainfall (for instance, the Climate Hazards Center InfraRed Precipitation with Station [CHIRPS] data set), but with lower spatial resolution. It cannot estimate non-consumptive uses of water – deep percolation, surface runoff – nor changes in soil moisture in the root zone.

In their review, Karimi and Bastiaanssen (2015) concluded it was possible to estimate ET with an overall accuracy of 95 percent (standard deviation 5 percent), to identify land use with an overall accuracy of 85 percent (standard deviation 7 percent), and to estimate rainfall with an overall absolute accuracy of 82 percent (standard deviation 15 percent). A review by Blatchford *et al.* (2019) concludes that crop water productivity (CWP) estimates from remote sensing differ from in *situ* measurements by 7 percent to 22 percent for the highest reported performing remote sensing products.



Case study: Application of WaPOR in Lebanon's Bekaa Valley

COMBINING REMOTE SENSING-BASED WATER PRODUCTIVITY ASSESSMENT WITH ECONOMIC ANALYSIS

Why the Bekaa Valley
The fertile Bekaa Valley, Lebanon's breadbasket, produces major food crops like wheat, potatoes and grapes. Similar to many other irrigated areas in water-scarce regions, the Bekaa Valley contributes significantly to the country's agricultural gross domestic product and is an important source of employment. But the long-term sustainability of its output depends on good water management. The Bekaa Valley is an interesting case study, which can provide lessons to many regions in the world facing similar challenges. It was one of the first areas to have data on crop yields and ET at a subnational scale (30 metre resolution) in WaPOR.

Steps taken
The team applied the methodology (described in Boxes 1, 2 and 3) in three Bekaa Valley governorates (West Bekaa, Zahle and Baalbeck) from the 2014/15 to 2018/19 seasons.

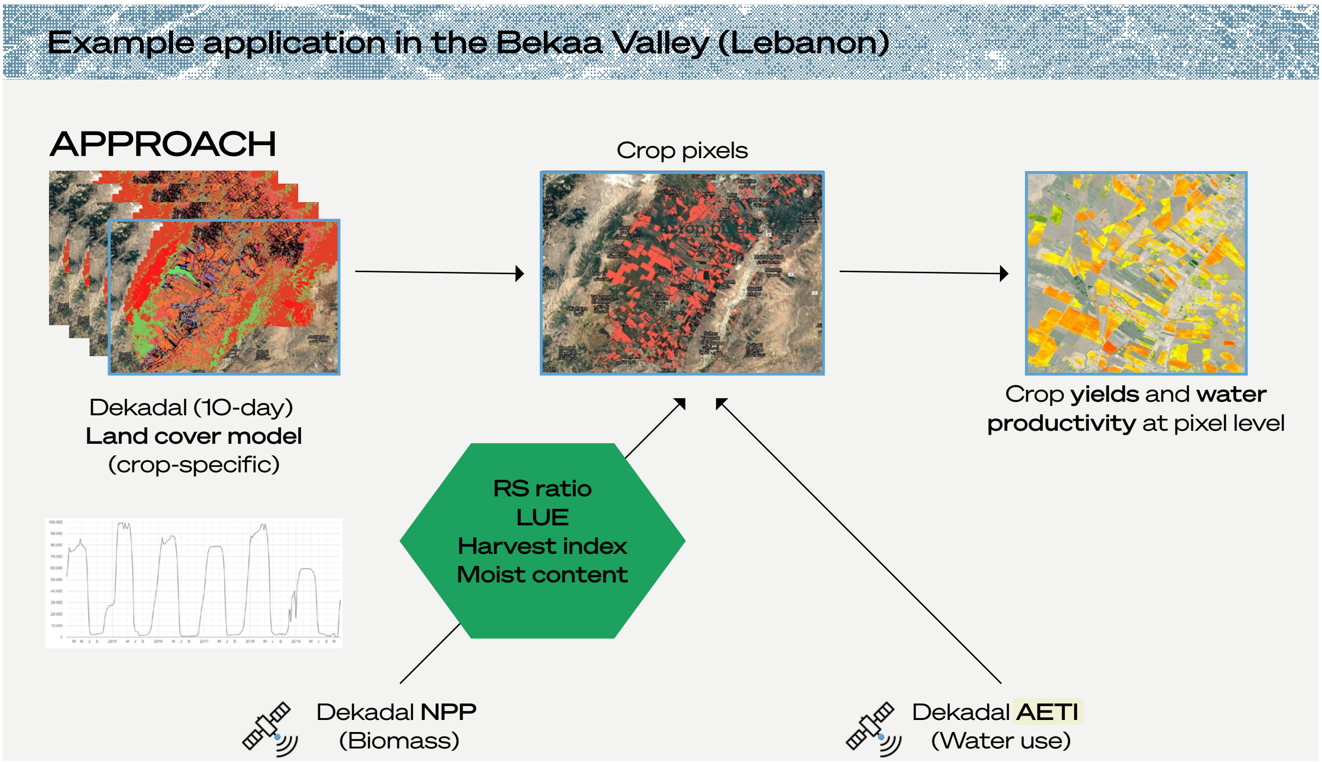


Figure 1
Crop yields and ET maps

NOTE: RS- root shoot; LUE – light use efficiency; AETI - actual evapotranspiration and interception

SOURCE: Authors' own elaboration.

STEP 1

Crop maps and actual ET and yields estimation. WaPOR produced (i) **actual evapotranspiration (ETa)** and **NPP maps** at 30 metre spatial resolution from the 2014/15 to 2018/19 seasons; and (ii) dekadal (every ten days) **crop maps** based on potato and wheat field data collected in 2016/17. **NPP was used to estimate yields** using crop parameters obtained from existing literature.

STEP 2

ET from irrigation water estimation. ET from irrigation water was estimated as total ET obtained from WaPOR minus ET from rainfall. In the case of wheat in the Bekaa Valley, most rainfall and soil infiltration occur in January and February. A share of ET in wheat fields from March onwards, when supplementary irrigation starts, is due to rainfall stored in the crop root zone during the previous months. To calculate ET based on rainfall stored in the root zone from March to harvest date, a soil water balance (SWB) was undertaken using soil characteristics from a representative field and meteorological data from the previous months from one weather station.

STEP 3

Identification of actually irrigated fields. The crop maps in WaPOR automatically distinguish between irrigated and rainfed pixels, however, this classification is not always accurate for crops under supplementary irrigation. Hence, for wheat in the Bekaa Valley, all pixels initially classified as irrigated with volumes below 50 mm (the difference between ET and rainfall after the rainy season) were reclassified as rainfed. All potato fields were considered as irrigated.

Runoff was deemed insignificant, as the land areas are flat. **Deep percolation** could not be measured, as it requires in-depth surveys of irrigation practices. Applying regional averages would not contribute to measuring irrigation water applied per pixel or per crop as intended. The estimation of irrigation water applied to the field in this case corresponds to actual ET from irrigation (ETa_{irr}). This means that possible irrigation water losses due to deep percolation from suboptimal irrigation technology and practices may not have been captured. Yet, ET comprises the largest share of total irrigation water applied to the field and is still a powerful proxy for use in policymaking (see Box 1).

STEP 4

Profit per pixel estimation. This was undertaken using three crop budgets for wheat (irrigated high yields, irrigated low yields, rainfed) and two for potatoes (high and low yields). **EIWP** was calculated as the incremental profit from irrigation (profit irrigated-profit rainfed wheat) per cubic metre of irrigation water. This exercise did not estimate economic profit, in other words, EIWP is evaluated from the perspective of farmers (see Box 1).

STEP 5

EIWP estimation per pixel. EIWP is the ratio between the increase in profit caused by irrigation (profit from irrigated crop minus profit from rainfed crop) and ETa_{irr}.

Limitations and their impact on the analysis. Estimation of EIWP in the Bekaa Valley was constrained by limited data and resources. First, field data on crop types were collected for only one year, and crop parameters were not based on field estimates for the region's specific conditions, meaning that crop mapping and yield values would have been more accurate with additional information. Second, effective rainfall was calculated based on one soil water balance, although different soil types and weather stations should be used. Production cost estimates do not reflect the full diversity of production systems (adopted practices, production costs) in the region. Finally, the case study only evaluated private profit informing how farmers perceive it (market prices, taxes, subsidies) and how it may influence their decisions. Economic profit can inform policymakers of the EIWP through society's perspective, that is, one that internalizes externalities, and eliminates price distortions and transfers within that society, such as taxes and subsidies.

Without additional field data collection, these limitations make it difficult to estimate ETa_{irr}, yields, profits and EWIP accurately enough to enable decision-making on farm-specific interventions. However, data collected can be used to compare pixels in space and time with high resolution. These relative results can be used to make policy decisions and strengthen governance mechanisms at water system level as argued in the next sections.

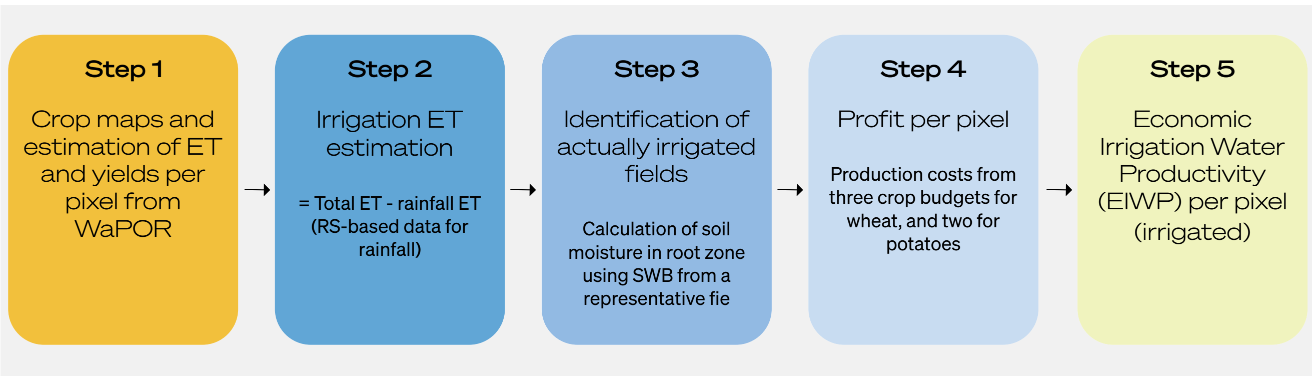


Figure 2
Methodology for the calculation of EIWP

SOURCE: Authors' own elaboration.

MAIN RESULTS OF THE ANALYSIS

The case study analysed actual ETa_{irr},[1] yield, profit and economic irrigation water productivity per crop (wheat and potatoes) in three Bekaa Valley governorates (West Bekaa, Zahle and Baalbeck) from 2014/15 to 2018/19, as well as precipitation levels.

Figure 3 shows EIWP for wheat as a function of irrigation in the three governorates and for years with different rainfall levels. For wheat in West Bekaa and Zahle, crop pixels concentrate around irrigation levels that correspond to the peak of marginal EIWP, i.e., when for the same increase in irrigation the increase in EIWP is lower (the peak of the curves in Figure 3). This pattern is not observed in Baalbek or during dry years in West Bekaa.

This suggests that in Baalbek and during dry years in West Bekaa, greater application of irrigation water may result in higher yields and profits. Fieldwork is necessary to determine what prevents increased water application for wheat.

Figure 3 also reveals that even in West Bekaa and Zahle there is a considerable share of pixels with irrigation volumes and EIWP below the mean, as well as pixels where more irrigation water is applied and larger yields obtained. More in-depth analysis of available remote sensing data or field work could explore the reasons behind the performance of each group of pixels (lower or higher percentiles of irrigation water supply and EIWP). For instance, in some locations, the volume of irrigation water applied may not be a limiting factor for yields. Hellegers *et al.* (2010) described the potential crop yield if all production factors, including water supply, are adequate as the production frontier. In some locations pumping costs may be higher than estimated and increased irrigation water supply and irrigation costs may not translate into the increases in EIWP depicted in Figure 3.

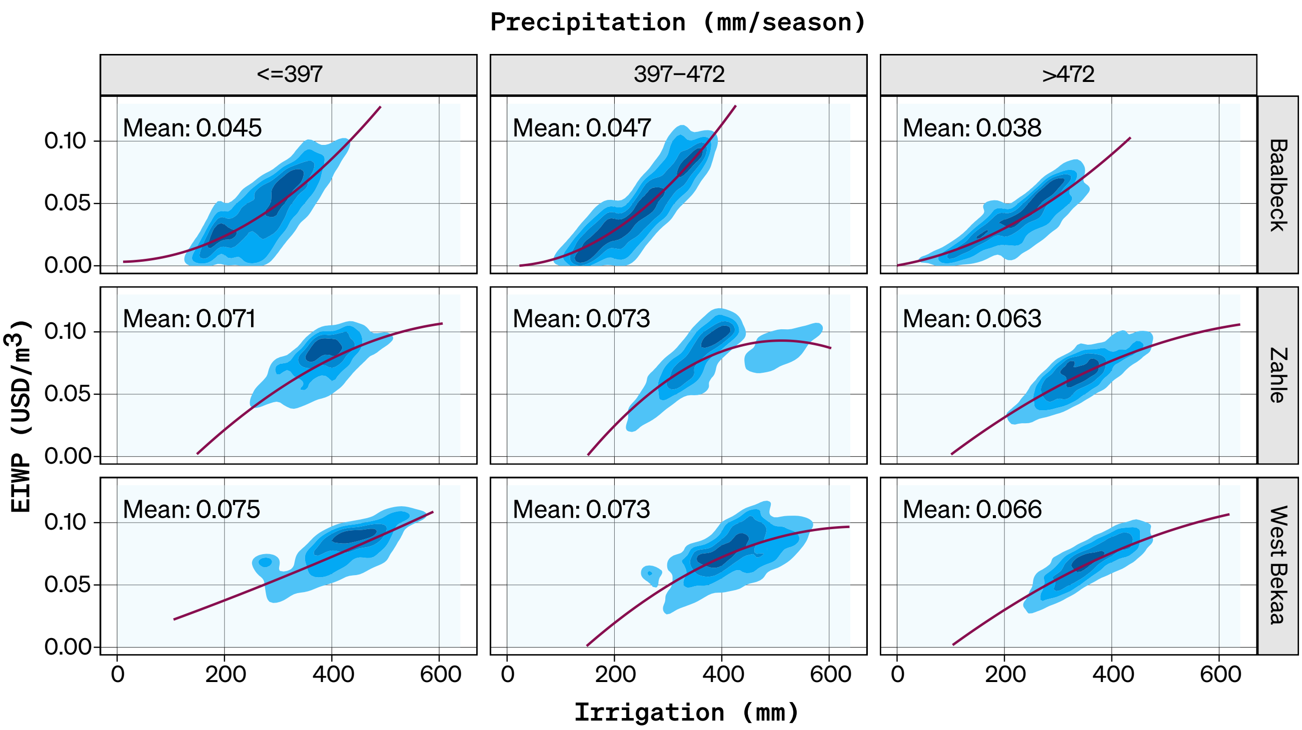


Figure 3

Correlation between EIWP (USD/m³) and irrigation water supply (mm) for the three governorates and three rainfall classes

NOTE: differences in precipitations and governorate are statistically significant. Colour gradient represents pixel concentration (scaled for a maximum of 1) from 2014/15 to 2018/19 for wheat.

SOURCE: Authors' own elaboration.

For potatoes, the correlation between yield and irrigation water application is lower in some years than for wheat (see Figure 4). Inter-year variations in the coefficient of determination (R^2) – a measure of correlation between variables – are particularly evident for West Bekaa and Zahle. The years when the highest average volume of irrigation water is applied (2016 and 2017) show lower correlation between the two variables analysed. One possible explanation is that being a high value crop, many farmers tend to provide the required amount of water or over irrigate so as not to risk lower yields. In such cases, other factors like soil fertility, seed selection, planting density, land preparation, crop rotation or crop protection can determine yield differences. Field work could help to assess the contribution of factors other than irrigation volumes to irrigation water productivity in selected critical areas with particularly low or high EIWP.

[1] ETa_{irr} is used as a proxy of irrigation water applied to the field and is henceforth referred to as irrigation.

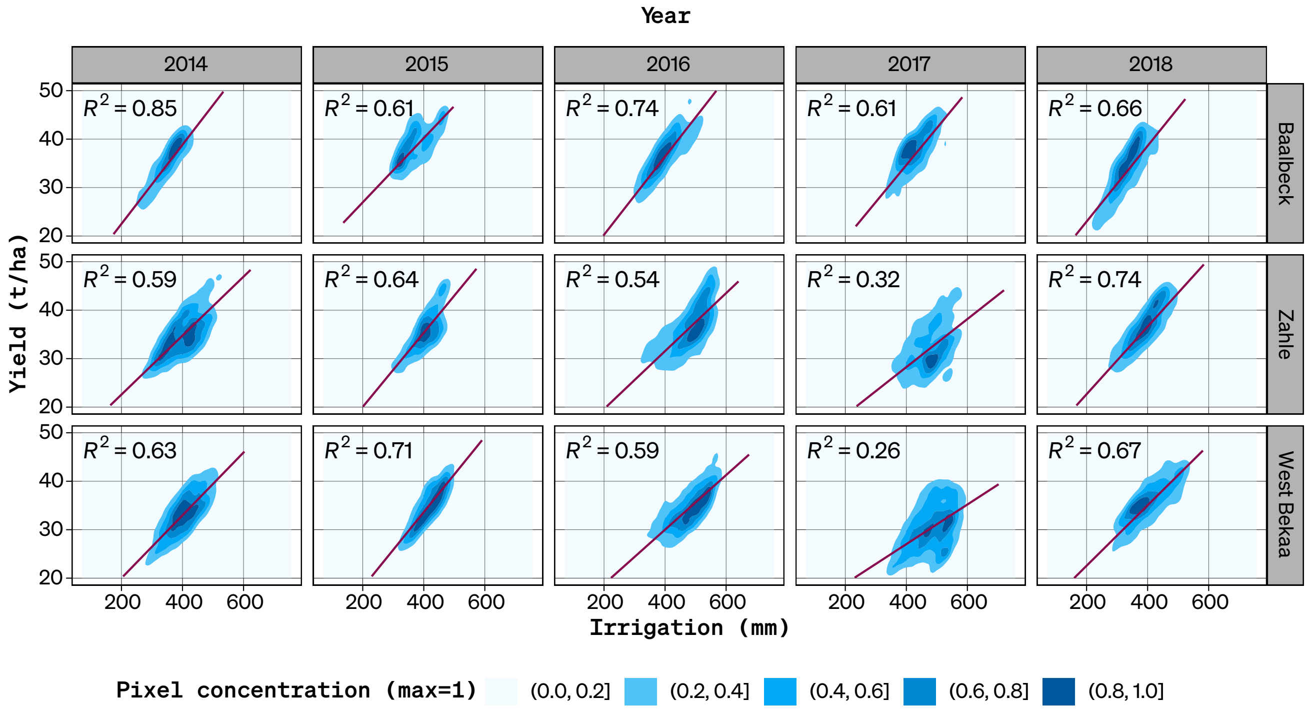


Figure 4

Correlation between yield (kg/ha) and irrigation (mm) for the three governorates and for each year

NOTE: differences between regions are statistically significant. Colour gradient represents pixel concentration (scaled for a maximum of 1) for potatoes. R^2 is the coefficient of determination.

SOURCE: Authors' own elaboration.

ANALYSIS AT THE SAME CROP LEVEL: REMOTE SENSING CAN HELP IDENTIFY UNDERPERFORMING FARMS AS WELL AS POTENTIAL BENCHMARKS

The results obtained from WaPOR help assess whether EIWP is strongly correlated to irrigation volumes or whether other factors such as weather, soil conditions and agricultural practices also play an important role. High performing (bright spots) and low performing pixels (hotspots) can also be located on a map. Figure 5 shows pixels classified by EIWP and identifies bright spots for potatoes (above) and wheat (below) in the Bekaa Valley during the 2016/17 season. In this case, bright and hot spots are defined as pixels above the 80th and below the 20th percentiles, respectively, both for yield and EIWP. The thresholds were selected to match the values used by Safi *et al.* (2022).

The identification of bright spots and hot spots helps explore the causes of low performance in clearly identified areas. Safi *et al.* (2022) used remote sensing data to assess how crop water stress, irrigation uniformity, soil salinity, nitrogen application, crop rotation and soil type influence water productivity and yields for wheat, potatoes and grapes in the Bekaa Valley in 2017. Field surveys with farmers can also identify agronomic practices that determine differences in yields and EIWP in selected areas that either perform strongly or underperform. The upper right panel of Figure 5 illustrates the importance of exploring causes other than irrigation volume for differences in EIWP in the case of potatoes, as the chart clearly shows the same EIWP can be obtained for considerably different irrigation volumes.

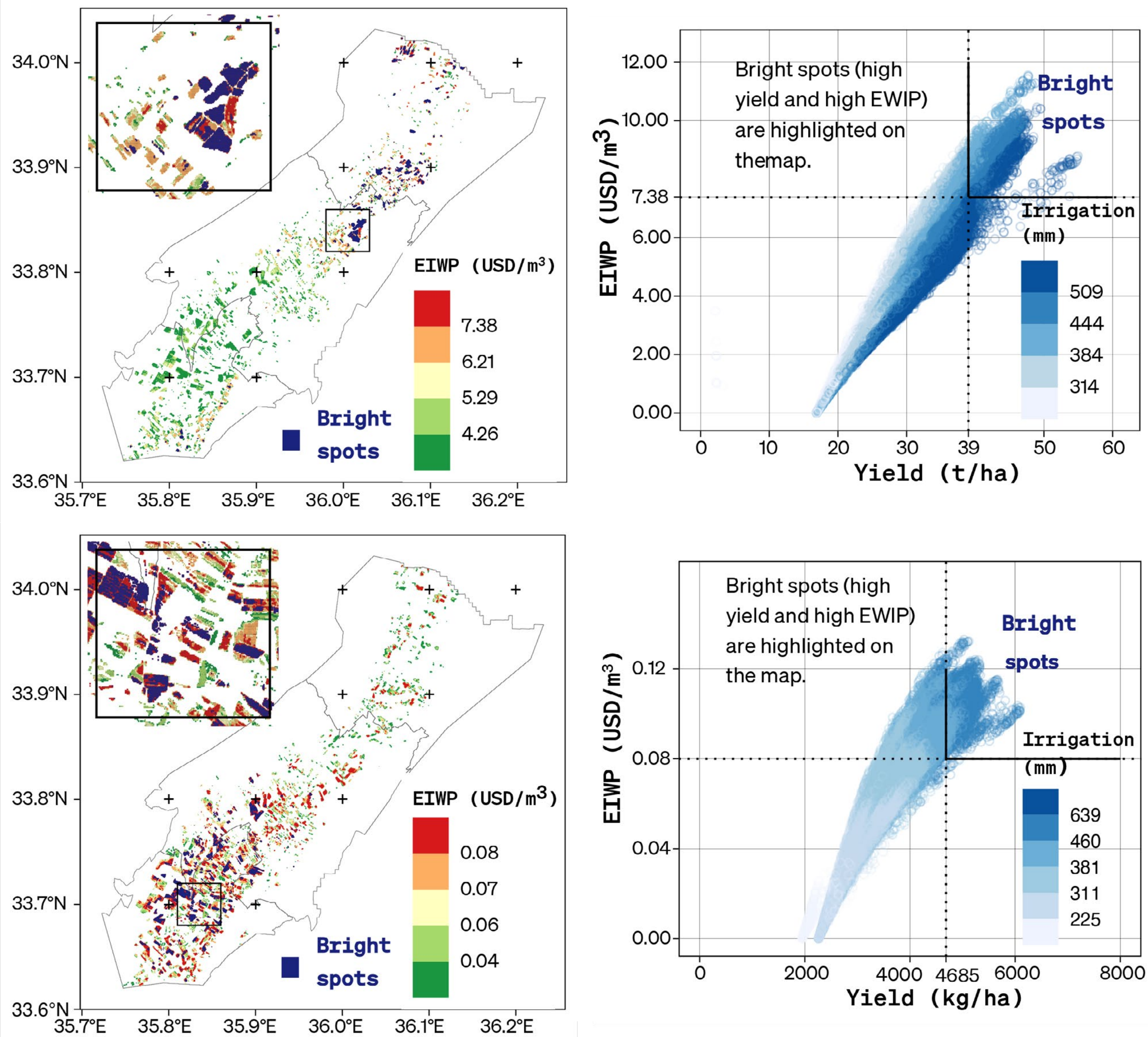


Figure 5

Maps of EIWP for potatoes (above) and wheat (below) in the Bekaa Valley during the 2016/17 season, highlighting the bright spots

NOTE: For potatoes, the same yield can be obtained for many levels of irrigation ET, signalling that irrigation alone does not explain yield. For wheat, water consumption is highly correlated to yield.

SOURCE: Authors' own elaboration.

In theory, obtaining the maximum value per drop of water in a system with only one irrigated crop and scarce water means that: (i) each farmer should apply water until the EIWP peaks; and (ii) water applications should be confined to fields capable of producing the highest EIWP. However, water systems rarely serve only one crop, and limiting water supply to the most productive fields will hardly be acceptable. The next section provides some insights as to why crop system-wide analysis can provide more complete and powerful information for decision-making.

CROP SYSTEM-WIDE ANALYSIS, THE REAL GAME CHANGER

Data from the Bekaa Valley show that early season potatoes are ten times more profitable and have a much higher EIWP than wheat (with averages of about 0.1 to 7 USD/m^3) (see Figures 3 to 5). Although potatoes cannot replace wheat (they are often part of the same rotation), **the choice of crops and cropping systems can have a much larger impact than adjustments in current agricultural practices for one crop.**

However, shifting to crops or practices with high EIWP can also mean higher water consumption. On average, potatoes need more irrigation water than wheat. Shifting to high water-productive systems may then require control (and a decrease) of irrigated areas and/or restrictions or caps on water withdrawals, if consumption is to remain stable. Remote sensing can help monitor these changes.

Overall, such a system-wide analysis may deliver more conclusive results in terms of changes to achieve higher average EIWP and the impact of water policies on the region's overall irrigation water consumption.

Looking ahead: policy and investment implications and areas for further application

The Bekaa Valley case study shows the potential for WaPOR to contribute to water productivity assessments in data-scarce contexts. Analysis of wheat in the Bekaa Valley identified that two governorates (West Bekaa and Zahle) achieved the highest marginal EIWPs for yields up to 3500 and 4500 kg/ha and irrigation up to 350 mm (see Figure 3). Areas that irrigate the most and have the highest value added do not necessarily indicate the highest marginal EIWP.

The study provides decision-makers with possible policy directions regarding wheat irrigation, assuming they aim to save water and maximize its economic productivity. For example, decision-makers could promote a concentration of wheat in the most productive areas, and either support a shift to rainfed agriculture (compensating farmers for income loss) or assess if land in less water productive areas can be converted to more water productive crops with similar water requirements. However, such policies should consider overall rotation and any possible substitutions for this rotation.

There is a case for investigating which factors other than applied irrigation water determine potato yields. Depending on key determinants – location or agricultural practices – a new set of policies could be devised. For example, policies could offer incentives such as payment for environmental services to farmers who stay below a certain irrigation water use threshold. Producers could use that to compensate for lower yields or invest in improvements to produce more with less water – a voluntary quota system. Technical assistance could help optimize production for the given water allocation.

The Bekaa Valley case study also suggests that crop system-wide analyses using data from WaPOR could contribute significantly to policy making on water management and therefore be key for water governance systems. As explained in the next paragraphs, the type of analysis undertaken for the Bekaa Valley can be applied to any water-scarce system to: (i) assess water systems; (ii) prepare, implement and monitor management plans; and (iii) design and evaluate legal, regulatory, and incentive frameworks as well as investment programmes.

WaPOR can help estimate water consumption and EIWP under different scenarios of agricultural and irrigation practices as well as land use, and thus provide direction in terms of desirable policy shifts. Likewise, WaPOR can monitor actual changes in irrigation water use and its economic productivity as a result of such policies.

Data from WaPOR can also contribute to establishing targets to adopt cropping systems and practices and their irrigation water use performance. Such targets are often powerful communication tools that help shape more concrete policies. As illustrated in Table 1, WaPOR can underpin an even wider range of agricultural water management policies and investments in regions similar to the Bekaa Valley.

Table 1

Remote sensing informs and underpins a range of agricultural water management policies and investments

Key policy/investment options	Description/aim	Limitations	Use of remote sensing
Control of irrigated areas	License a limited number of hectares for irrigation.	Needs to be coupled with control of cropping patterns; even if irrigated land expansion is controlled, agricultural intensification may still increase demand for water.	Can identify cropping systems and areas with high ET that are not licensed; requires adaptation of the legal framework.
Change cropping patterns	This can be made either through a limited number of licences for each type of cropping system per year or designing incentives to adopt cropping systems that are suitable for the policy objectives (decrease irrigation or increase EIWP or both whenever possible).	Licence schemes are not easily accepted and it takes time to come to an agreement with stakeholders; political costs can be high, especially if they do not produce the expected results. It is difficult to foresee the level of adoption of an incentive scheme and its actual changes in cropping patterns. It may cause unwanted distortions that offset the incentives (lower output prices).	Can identify irrigated areas (if calibration is adequate and field validations are possible); can also monitor the effects of the policies both in cropping patterns and ET, enabling swift policy adjustments.
Promote irrigation best practices	Incentives to increase on-farm irrigation efficiency: low elevation spray from pivot, drip irrigation, soil levelling, soil moisture control to adjust irrigation schedule and supply; better choice of rootstocks.	Increase in field-level irrigation efficiency is often translated into greater value of production per drop of water, but not necessarily in basin-wide water saving. Requires complementary measures in terms of water accounting, caps on water abstraction and limitations on expansion of irrigated areas.	It can monitor changes in ET and yields of farmers adopting best practices. However, there must be specifications and a ground/drone-based monitoring scheme to adopt selected practices.
Promote new planting seasons and varieties	Promote shifts in varieties and planting seasons that reduce plant water requirements.	These may or may not be less productive varieties. In some cases, they may require compensation or other measures (e.g. higher water prices) to incentivize the shift.	
Promote conservation agriculture measures	This includes a large array of soil, crop and climate specific technologies, such as plastic mulching, deep furrowing to harvest rainfall, no-tillage.	Different techniques will reveal different shortcomings: some soil preparation techniques may imply lower yields even if they conserve water; mulching is associated with drip irrigation; no-tillage, may not be suitable for all crops, etc.	

SOURCE: Authors' own elaboration.

WAPOR CAN BE USED IN MANY WAYS

There are also opportunities to apply WaPOR to more traditional irrigation water management policies. WaPOR could be used to monitor caps on water withdrawals (quotas). Establishing water quotas is usually linked with historic users' rights and irrigation requirements for each crop. Remote sensing-based water productivity assessments are useful to establish baselines and monitor compliance, particularly in places with many independent, small farmers. This is particularly true when remote sensing is coupled with cadastral data as well as field measurements that continuously improve and adjust estimations. China has set tariffs on water consumption and quotas and penalties for over abstraction based on remote sensing ET measurements (Kang *et al.*, 2017).

WaPOR can also be applied in tandem with surveys to set the value of water and establish water prices. Surveys could provide more detailed information on production costs and the price elasticities of water application (how much price influences demand for water), which are likely to vary depending on the crop. The results for EIWP from WaPOR could be used to set the water price; this will not necessarily ensure savings, though, as cropping systems with higher water productivity may consume more water per hectare. Finally, data obtained through WaPOR could be useful in a dialogue around energy prices in agriculture. For instance, in the Bekaa Valley, most wheat systems produce an EIWP below USD 0.1/m^3. An increase in the cost of abstracting water by the same amount would make them financially unfeasible.

While WaPOR makes the data available, its uptake and application still require investments in field data collection and capacity building in key institutions to provide adequate inputs and interpret the results. Trust and usability of the results depend on the accuracy and resolution of land cover and planting and harvest season maps. Irrigation water supply estimates should be based on weather and soil data with enough granularity. Meaningful yield estimation requires field calibration, and economic data require well conducted surveys of a sample representative of existing cropping systems. Yet WaPOR clearly provides an opportunity to design well informed water management policies and investments, as well as monitor their results in real time.

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Abbreviations and acronyms

CHIRPS	Climate Hazards Center InfraRed Precipitation with Station data
CWP	crop water productivity
EWP	economic water productivity
EIWP	economic irrigation water productivity
ET	evapotranspiration
ETa	actual evapotranspiration
ETa_{irr}	actual evapotranspiration from irrigation
FAO	Food and Agriculture Organization of the United Nations
NPP	net primary production
RS	remote sensing
SD	standard deviation
SWB	soil water balance
WaPOR	Water Productivity through Open access of Remotely sensed derived data
WP	water productivity

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