Location:	Pakistan
Contractor:	World Bank, Washington
Period:	2001 - 2002

Scope of the project

The growing world population requires increased food production, while less water resources are available for agriculture. This alarming situation can only be resolved if water is managed more efficiently, so that crop yield per unit of water consumption increases. W*ater productivity,* is an accurate indicator of agricultural productivity in relationship to the crop's consumptive use of water. Evapotranspiration is the term used for total water consumption of the crop; it includes water loss due to evaporation and plant transpiration. Water productivity (kg/m3) is defined as crop yield (kg) per accumulated actual evapotranspiration for the growing season (m^3):

$$WP = \frac{cropyield}{ET_{a,seasonal}}$$

Study approach

Analysis of agricultural yield must include the crop water consumption, especially in semi-arid and arid zones. Crop yield per unit of water consumed, or " water productivity", is a key element in successful water resource management. Although agricultural census data for Pakistan provide crop production statistics, they do not include information on crop water consumption. Therefore, water productivity of the crops has been unknown.

As an alternative to the classical field interview approach, this analysis was achieved with a state-of-the-art remote sensing methodology termed SEBAL (Surface Energy Balance Algorithm for Land) that uses satellite images to compute both crop yield and crop water consumption. The results for a year of average rainfall and water diversions (1984-85) were contrasted with a year of severe drought (2001-02). In addition, the SEBAL results were compared with agricultural water management performance in the neighboring Indian Punjab, which is located in a similar agro-ecological zone.

To cover the vast Indus Basin, this analysis used low-resolution satellite images (1 km resolution). With a

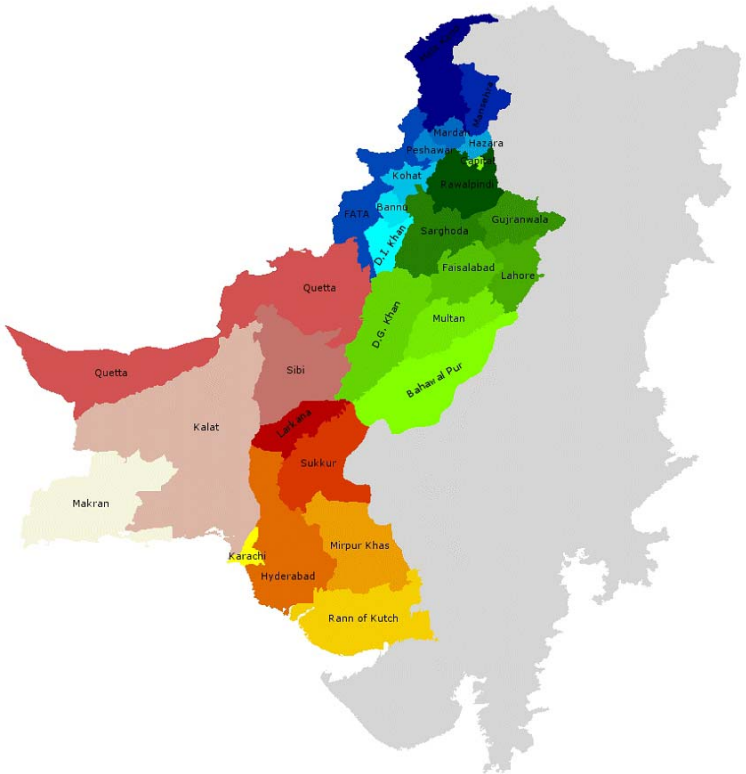


Figure 1: District locations and names, delineated for the presentation of water productivity results in Pakistan

resolution of 1 km, only crop yield and water consumption for large monocultures can be computed. Higher resolution images are required to compute crop yield and water consumption for areas of mixed crops or for areas with less cropping intensity. Crop yield estimates based on the remote sensing methodology and on the agricultural census data were in close agreement for wheat (monoculture) but not for rice (mixed crops). The difference can be ascribed to (i) errors in the field census data (interviews and farmer biased information) and (ii) errors in the remote sensing methodology (precise crop identification is unavailable, and the 1 km resolution images cannot discern a mixture of crop types).

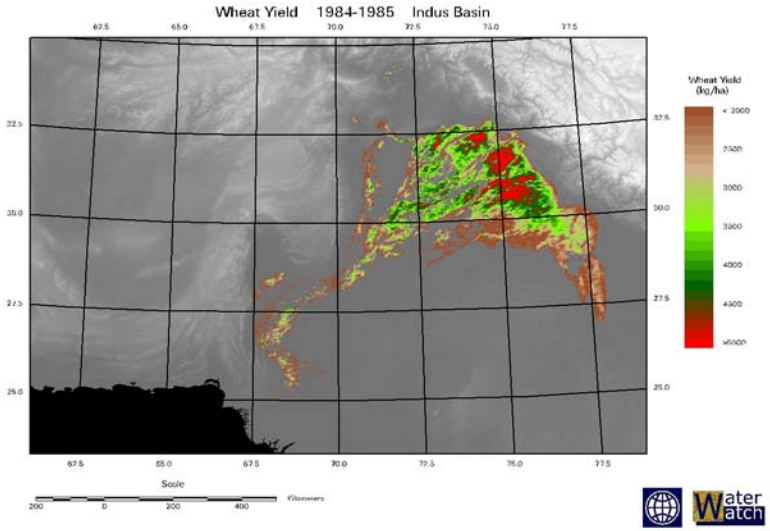
Results

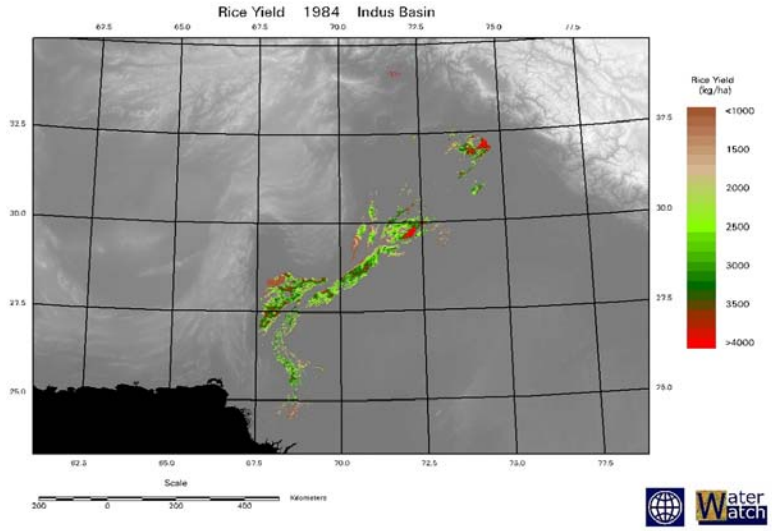
Water productivity values for wheat in 2001-02 (dry year) were higher due to increased solar radiation, which boosts crop growth when good quality groundwater is sufficiently available. During this 17-year period, yield increases were also due to improvements in farming practices and seed quality. In an average rainfall year, the water productivity for wheat in Pakistan (0.76 kg/m3) is 24% less than the global average (~1.0 kg/m3) and, therefore, can be classified as "moderately acceptable". During the drought of 2001-02, water productivities were at the same level as the global average. Hence, drought results in a more efficient utilization of water resources by wheat crops grown in the rabi (the dry winter season).

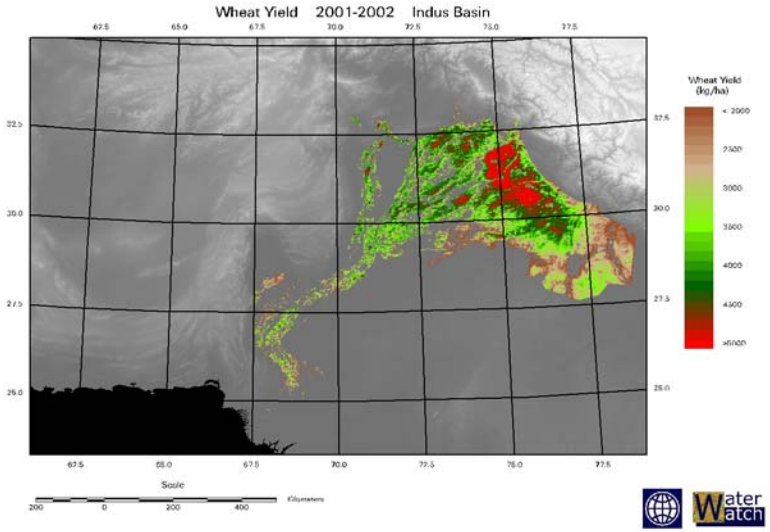
Rice yield in the Punjab is on-average 24% higher than in the Sindh. The water productivity of rice (0.45 kg/m3) is 55% below the average value for rice in Asia (~1.0 kg.m3). Contrary to wheat, the water productivity of rice decreased during the 2001 drought, because rice is sensitive to water stress and to salinity that is intensified through increased tubewell withdrawals.

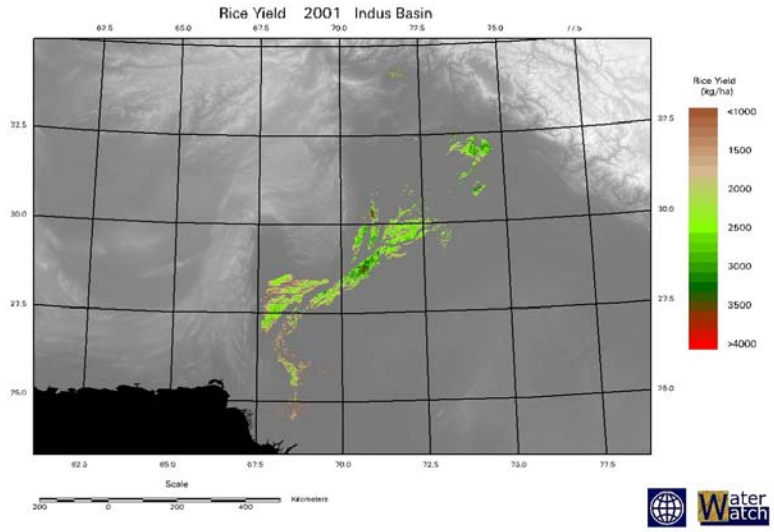
Crop yields show distinct North-South and East-West variations: wheat yields in the Indian Punjab average 29% higher than in the Pakistani Punjab to the west, and wheat yields in the Pakistani Punjab are 33% higher than in the Pakistani Sindh to the south. These spatial patterns of wheat yield are similar for 1984-85 and 2001-02. Because crop evapotranspiration in the Pakistani Punjab and Indian Punjab are similar, the difference in crop yields between these two regions is also responsible for the difference in water productivity values.

This important conclusion implies that increased water productivity can only be achieved by increased crop yields. Experiments of the Pakistan Agricultural Research Council across the country (n=41) have indicated that the overall yield of wheat can be increased by 54%, provided that inputs are optimal. Improved management of water quality (groundwater and canal water) and evacuation of drainage water are important components for improving agricultural production. Seed quality, fertilizers, and pesticide control should also be improved.









Figures 2 and 3: Wheat and rice yields in the Indus River Basin for the 1984-85 and 2001-02 rabi seasons (based on NOAA-AVHRR satellite data and the SEBAL algorithm)

Over the past few years, Pakistan has experienced drier-than-average climatic conditions. Drought anomalies are identified in this study on the basis of deviation from mean water availability, rather than on aridity indices. Water availability for large-scale irrigation systems should be based on a combination of rainfall, canal water and groundwater resources. Soil moisture integrates these factors, and is used to indicate the water availability.

The monsoon season (kharif) for 2001-02 had more access to water than 1984-85 due to increased irrigation intensity. During the winter season (rabi), the Sindh (11% decrease in soil moisture) and the Balochistan (7% decrease in soil moisture) are more prone to drought. On the contrary, the Punjab was 16% wetter in the rabi of 2001-02 as compared to 1984-85, which was due to the expansion of irrigated areas (e.g., the newly constructed Chasma Canals).

Drought vulnerability is expressed as the deviation in biomass production. Districts with the highest vulnerability are identified. Due to the dependence of barani systems and rangeland vegetation on rainfall, vulnerability in kharif is more pronounced than in rabi.

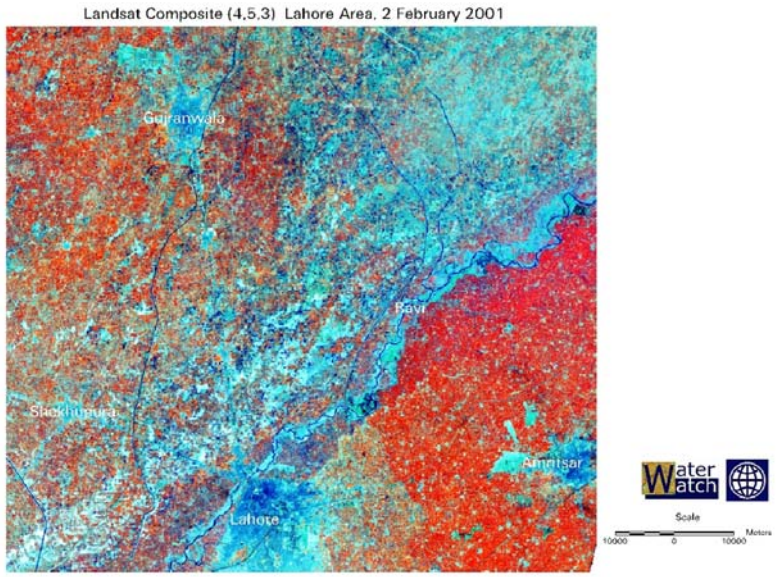


Figure 6: Detailed differences in agricultural production between the Pakistani and Indian Punjab. Red is associated with healthy and vigorous crops

During 2001-02, reduction in biomass production, and thus, reduction in income and economical development of the rural areas, was more than 50% in the Mirpur Khas (Sindh), Kohat (NWFP), Rawalpindi (Punjab), and Peshawar (NWFP) districts. The Sindh (7% decrease in biomass productoin) and the Balochistan (26% decrease in biomass production) experience the largest vulnerability. These downstream provinces rely on the releases from the Tarbela Dam and they experience the adverse impacts of extra upstream water diversions from the Chasma Barrage. This exemplifies the need to manage water resources in context of the entire the basin and for basin-wide initiatives that implement more equal sharing of scarce water resources.

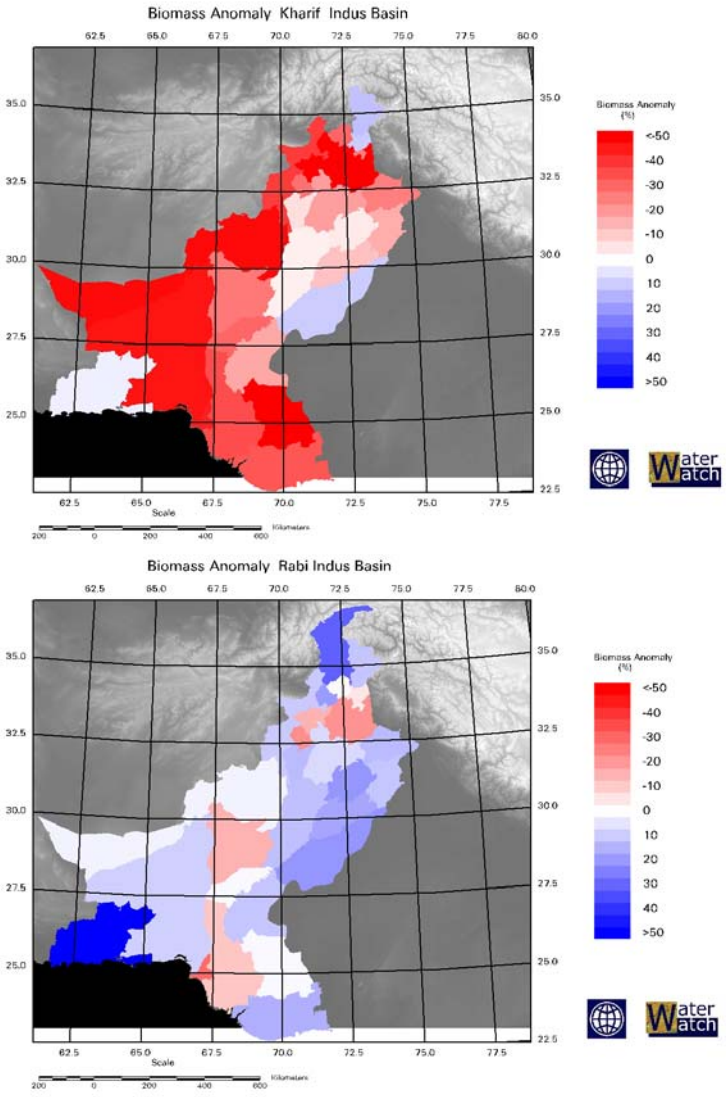


Figure 4: Biomass anomalies for the years 1984-85 and 2001-02 that express vulnerability to drought in Pakistan

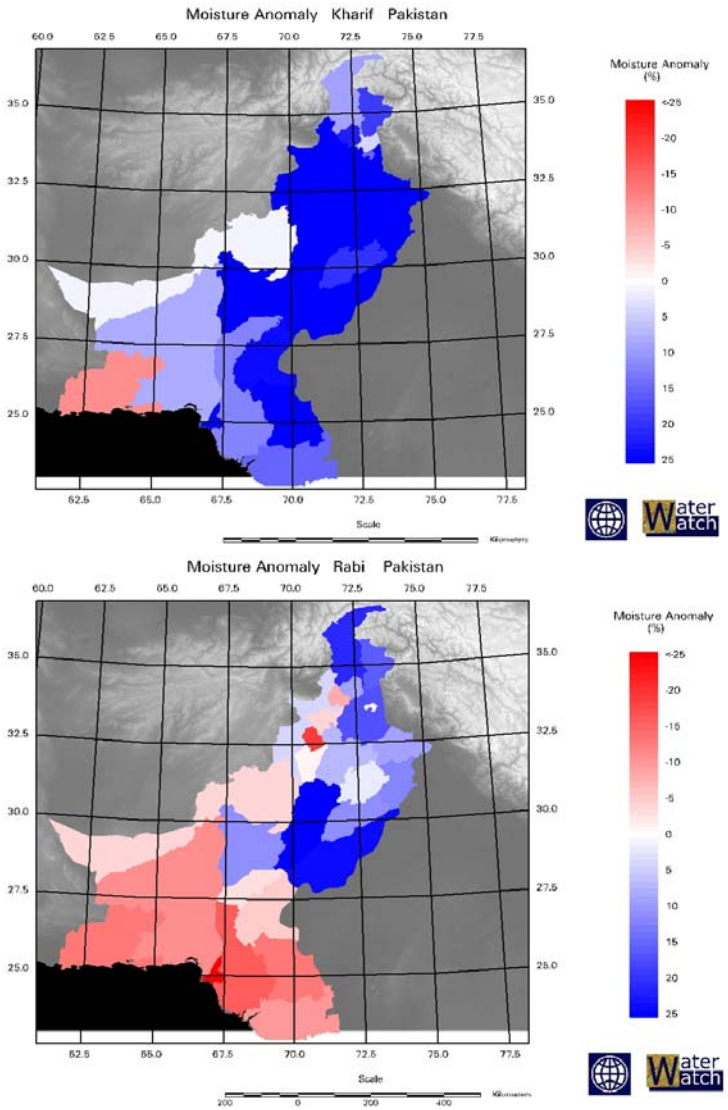


Figure 5: Soil moisture anomalies for the years 1984-85 and 2001-02 that express changes in access to water resources in Pakistan

Conclusions

In spite of favorable conditions of soil, irrigation water and climate, agriculture in Pakistan suffers from under-utilizing its potential resources, resulting in unnecessarily low yields per hectare and per unit of water consumed. Water demand exceeds water availability; therefore, the only remedy is to achieve higher food and feed production per unit of water consumed. Satellite remote sensing techniques can provide vital, periodic, and unbiased information on water productivity across vast areas.

Recommendations

This study recommends the establishment of adequate land and water use databases, using information obtained from both high- and low-resolution satellite data. These databases are necessary for the adequate monitoring of the effects of land drainage, wastewater treatment plants, sharing water resources between provinces, seed genotypes and fertilizer application.

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