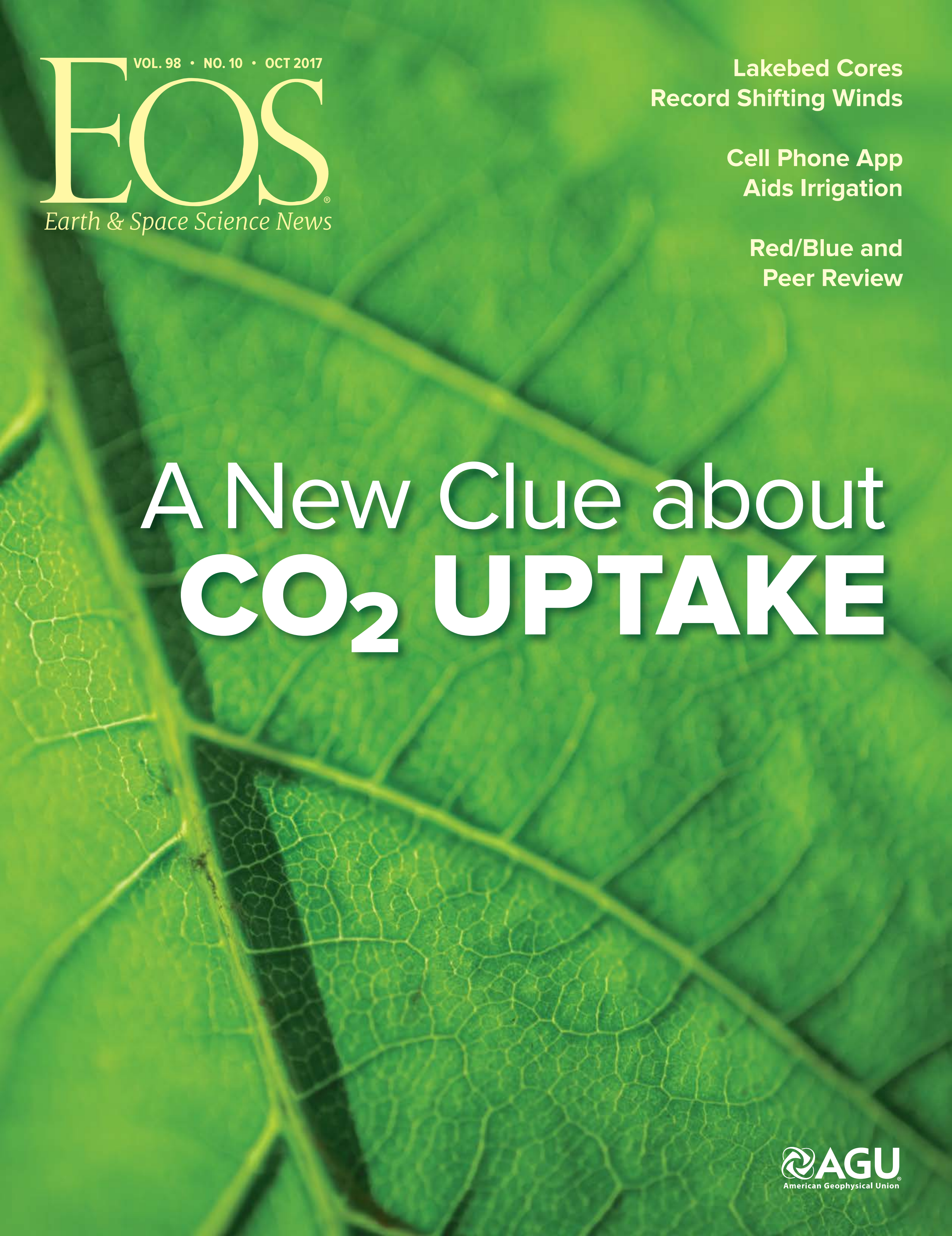

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GROWING MORE WITH LESS USING

CELL PHONES AND SATELLITE DATA

By Faisal Hossain, Nishan Biswas, Muhammad Ashraf, and Ahmad Zeeshan Bhatti

The Indus Valley, which extends from northeastern Afghanistan to Pakistan and northwestern India, once had the world's largest irrigation system using surface water as its source. That irrigation system still exists, but it no longer sustains the surrounding farms the way it did during the 1960s through 1980s. Many farmers in Pakistan's Indus basin look back to those days with nostalgia as they consider abandoning the farming profession that has been handed down to them from previous generations.

Representatives from the Pakistan Council of Research in Water Resources (PCRWR), who were looking for ways to support their nation's farmers, approached the Sustainability, Satellites, Water, and Environment (SASWE) research group of the University of Washington in August 2015. PCRWR, an agency with a mandate to serve its country's citizens through water research, sought to improve groundwater conservation and crop yield. It requested guidance on how to obtain and disseminate information about

A Pakistani farmer checks his cell phone for weather updates and estimates of how much irrigation water he will need over the next few days. The Pakistan Council of Research in Water Resources sends text messages with this information as part of a new program that helps 10,000 farmers optimize the amount of water they use for their crops. Credit: Faisal Hossain and PCRWR

A farmer in a semiarid region of the Indus basin of Pakistan prepares his field for cotton planting. Groundwater pumped from an aquifer fills his irrigation ditch. Credit: Faisal Hossain and PCRWR

crop water requirements based on environmental conditions and location for the entire Pakistan region.

Thus was born a collaboration, the PCRWR Irrigation Advisory campaign (see http://bit.ly/PCRWR-campaign), that brought 21st-century satellite data to bear on the ancient practices of farming, using cell phone networks to spread the information to farmers in remote locations. To see more about how this is being implemented and how farmers are reacting to the new technology, see http://bit.ly/farmer-phone-video.

Same Water Supply, More Crops

When the Indus Basin Irrigation System (IBIS; Figure 1) was designed 60 years ago [*Wescoat et al.,* 2000], the motivation was to bring more area under cultivation by farmers who typically planted one crop per year [*Jurriens and Mollinga,* 1996]. (For more detailed, higher-resolution, and up-to-date information on cropping pattern in local regions, see Figure 5 of *Cheema and Bastiaanssen* [2010].)

However, IBIS is now being used to support the cultivation of two to three crops per year. Aside from natural variations, the amount of surface water that is typically available in any given year has remained the same, but there is now more competition and demand for water among different sectors of the economy (including energy, food, and industry) and also with neighboring India, which is home to the Indus River headwaters and shares groundwater aquifers with IBIS. To address the increased demand for water, the region supplements the surface water of IBIS with pumped groundwater.

Irrigation Economics

A modest pricing scheme exists for farmers using the IBIS surface water irrigation system. However, the only cost to farmers irrigating their lands using groundwater is the cost of digging wells, the pump, and the fuel to run their pumping systems. As a result, groundwater now meets more than 60% of total annual water demand in this region [*Awan et al.,* 2016].

If farmers could be told specifically how much to irrigate, to ease the fears that cause them to overwater, then traditional mindsets could begin to change.

Although pumping groundwater incurs minimal monetary costs, the cost shows up in other ways. The more groundwater that is pumped for this inefficient irrigation approach, the more rapid the decline in the water table is,

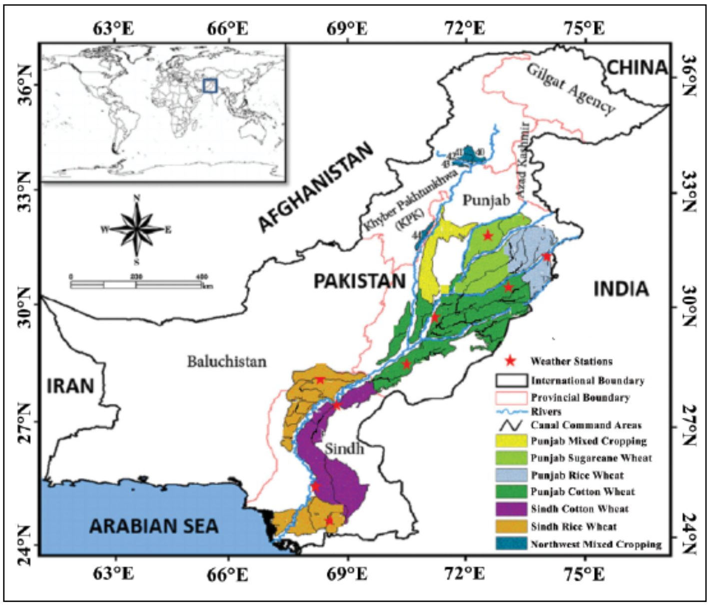

Fig. 1. Location of the Indus Basin Irrigation System in Pakistan. Punjab and Sindh refer to crop varietals. Modified from Usman et al. *[2015].*

and the more fuel it takes to pump water from greater depths.

The situation is further complicated by the fact that modern farmers lack knowledge of the most recent developments in crop water management, relying instead on farming knowledge that has been handed down from previous generations. For instance, the water requirements for rice, which consumes more than 60% of irrigation water in Pakistan, are 600 millimeters in Punjab Province and 1,400 millimeters in Sindh Province according to lysimeter measurements of the water released by plants through evaporation or transpiration (from PCRWR). In contrast, the farmers apply almost 2,200 millimeters, resulting in not only a substantial loss of water but also lower crop yields and an increase in fuel costs to pump water.

The water use efficiency of rice averages 0.45 kilogram of rice per cubic meter of irrigation water in Pakistan compared with the world average of 0.71 kilogram per cubic meter [*Soomro et al.*, 2015]. In a few irrigation districts of the Indus region, this efficiency is as low as 0.08 kilogram per cubic meter. Because overwatering reduces crop yield and increases the cost of maintaining the supply of groundwater, it is no surprise that many farmers find farming not profitable enough to sustain their livelihood.

Estimating Water Requirements for Crops Using Satellite Data

Scientists at the University of Washington's SASWE research group and PCRWR started with the following thoughts: If farmers could be told specifically how much to irrigate, to ease the fears that cause them to overwater, then traditional mindsets could begin to change. The groundwater pumping component of irrigation could then be driven by actual crop water demand and not by practices dating back to when farmers cultivated one crop per year using only surface water, which was abundant because of the lower demand.

One quantitative measure, the crop water requirement for a specific crop, is essentially a proxy measure of the reference evapotranspiration rate (ET_0) that can be calculated for standard crops in well-watered and ambient conditions. PCRWR contacted the SASWE research group, and together they set up an end-to-end ET_0 calculation system, which met PCRWR's specifications for acquiring data once per day over 10-square-kilometer grids for the entire Pakistan region. This system visualizes the dynamic crop water requirement for easy interpretation.

ET_0 was estimated on the basis of a method for computing crop water requirements from the *Food and Agriculture Organization of the United Nations* [1998], which is essentially a modification of a well-known equation [*Monteith and Unsworth,* 1990] using temperature, humidity, wind speed, and solar radiation as inputs.

The computations produced "nowcasts" of how much water a square meter of rice field needed in a given week. The nowcast inputs were obtained from a global Numerical Weather Prediction (NWP) modeling system called the Global Forecast System (GFS). PCRWR performed an independent validation of the nowcast inputs against lysimeter-based ET_0 data, and they found acceptable agreement.

Supply and Demand

For consistent and data-driven messaging, PCRWR set up a Short Message System (SMS) to push text messages with this crop water requirement information out to farmers' cell phones.

But before we could advise farmers on how much to irrigate according to actual requirements (and reduce reliance on groundwater when possible), we first had to provide the actual rationale for following this advice. As was mentioned earlier, farmers typically use a combination of surface water and groundwater irrigation to meet the crop water demand in IBIS. The surface water supply scheme is quite rigid and has little room for flexibility in dynamic adaptation. It is a "use it or lose it" system, unlike groundwater pumping, which can be started or stopped as the farmer desires. However, the groundwater source can be easily conserved if precipitation from the sky has been adequate to meet the crop water demand.

Our rationale is therefore based on comparing demand with supply. We based the demand for water on the crop- and location-specific evapotranspiration (ET) data (Figure 2). The supply was precipitation, supplemented with groundwater pumping.

We obtained the precipitation data from NASA's Global Precipitation Measurement (GPM) data product called IMERG, available at 10-square-kilometer grid resolution. Whenever supply from precipitation exceeded crop water demand estimated from ET, we sent farmers messages reassuring them that they could pump less or no groundwater. Similarly, when crop demand exceeded the precipitation supply, this information was communicated to farmers as an irrigation amount that they were encouraged to comply with by making sure the groundwater supplemented the surface water irrigation from IBIS.

A typical message on a farmer's cell phone would look like this:

> Dear farmer friend, we would like to inform you that the irrigation need for your banana crop was 2 inches during the past week.

or this:

> Dear farmer friend, we would like to inform you that your wheat crop does not need irrigation due to sufficient rainfall during the past week.

These messages are customized according to location and crop type.

Crawling the Web for Rain Reports

Anyone who has worked extensively with multisensor satellite-based precipitation data products knows that the errors associated at scales of land application (such as flood forecasting) can often render the data inaccurate for prime-time operations. In addition to bias and random errors, satellite precipitation data based on passive microwave sensors can have significant detection errors (i.e., inaccurately detecting the rain at a grid cell) [*Hossain and Huffman*, 2008].

The short-latency IMERG data product (available within 12 hours of satellite observation) had similar kinds of errors. There is also a research-grade gauge-adjusted IMERG product that we found to be quite skillful, but adjusted data become available only about a month after collection. This, of course, is too long a lag time for viable nowcasts.

Therefore, SASWE researchers had to address the accuracy issue of the short-latency IMERG product by developing a real-time precipitation correction system based on Web analytics. Essentially, the researchers wrote a Web crawler script to search the Web each day to identify the bona fide agencies (government meteorological services) of the region that post daily in situ (gauge) precipitation data. After downloading the Web-crawled in situ precipitation data, we used a spatial bias map to adjust the IMERG data in an automated fashion.

Currently, the SASWE-based Web-crawling system scours in situ precipitation information

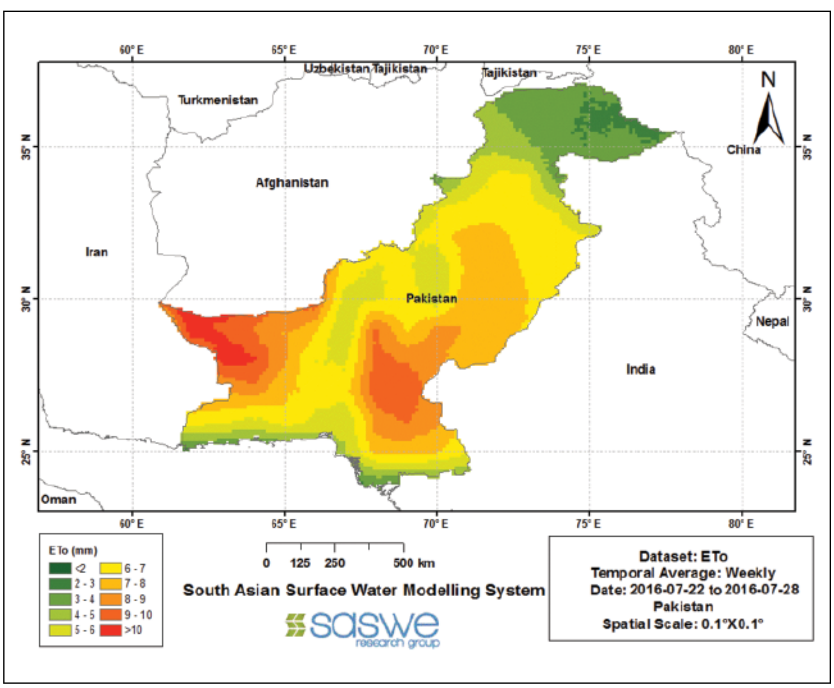

Fig. 2. Sample evapotranspiration (ET$_0$) map produced by the SASWE group using satellite and numerical weather prediction data from the Global Forecast System. The example is a weekly average based on the preceding seven daily ET$_0$ calculations. Red areas indicate where farmers will need to pump groundwater to irrigate their fields; green areas are locations where precipitation is adequate to cover crop needs.

from about 70 meteorological stations for the Indus region. PCRWR feedback revealed that this real-time correction system significantly improves precipitation estimation and the overall irrigation advisory.

Progress to Date

Starting in April 2016, 700 farmers began receiving weekly irrigation notifications via text message. The farmers grow banana, wheat, rice, and cotton crops in the Indus Valley. After completing the pilot project, PCRWR conducted an impact analysis and surveyed the farmers' perceptions of this resource. This information helped to inform PCRWR's plan to scale the program up to 10,000 farmers, which it did in January 2017. It plans to launch this program nationwide once cell phone operators expand coverage.

Before we can scale this system up further, we now require quantitative evidence of what actions farmers took and how these actions saved water and fuel. PCRWR is currently conducting such an impact analysis, and this analysis will be used in scaling up the system to millions of farmers.

Muhammad Ashraf, whose farm is near Sargodha, Pakistan, called on 11 May to provide such feedback.

"I had grown wheat on my 12 acres land this season and continuously received irrigation advisory messages from PCRWR system," he said, speaking in his native Urdu. "Keeping in view the advised water consumption and rainfall forecast, I only applied three irrigations, whereas my neighboring farmers applied six to seven irrigations. I have recently harvested my crop and got 48 maunds per acre [4,742 kilograms per hectare] yield, whereas my neighbors could get 42 maunds per acre [4,149 kilograms per hectare]."

For Ashraf, along with many others, the text alerts worked. He continued, "I am thankful to PCRWR for their advice, which not only let me get better yields but the irrigation cost was substantially reduced."

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Author Information

Faisal Hossain (email: fhossain@uw.edu) and **Nishan Biswas,** University of Washington, Seattle; and **Muhammad Ashraf** and **Ahmad Zeeshan Bhatti,** Pakistan Council of Research in Water Resources, Islamabad