Syrian crisis altered region's land and water resources, study finds

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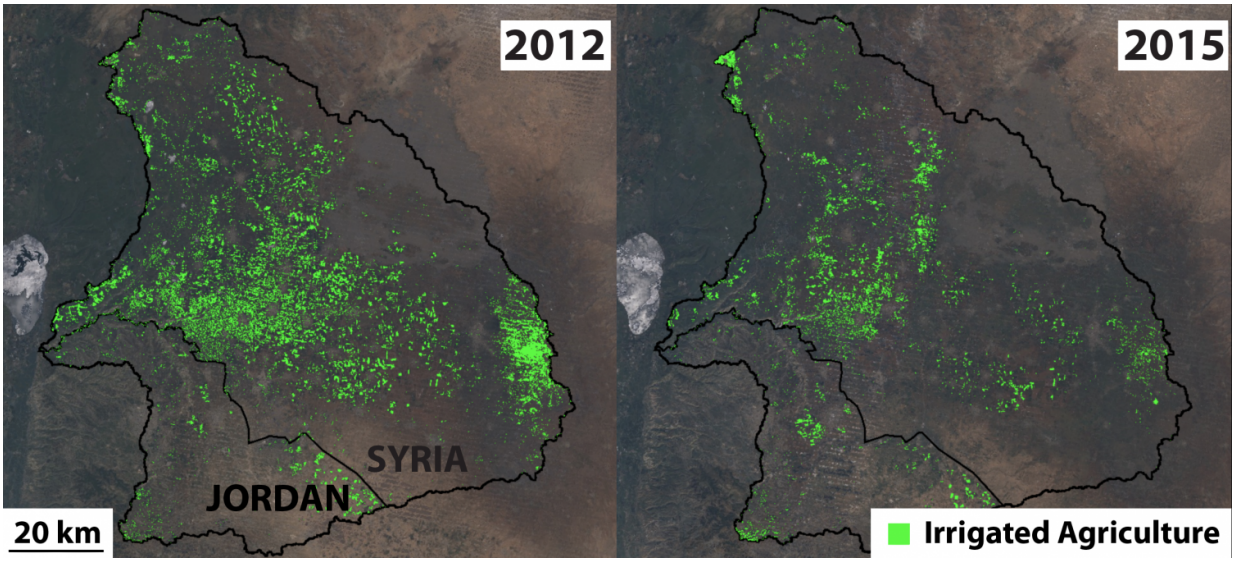

Irrigated land area decreased by 50 percent in the Yarmouk Basin during the Syrian civil war. Credit: Image credit: Landsat 7

The Syrian civil war and subsequent refugee migration caused sudden changes in the area's land use and freshwater resources, according to satellite data analyzed by Stanford researchers.

The findings, published in the Dec. 5 issue of *Proceedings of the National Academy of Sciences*, are the first to demonstrate detailed water management practices in an active war zone. Using satellite imagery

processed in Google Earth Engine, Stanford researchers determined the conflict in Syria caused agricultural irrigation and reservoir storage to decrease by nearly 50 percent compared to prewar conditions.

"The water management practices in Syria have changed and that's visible from space," said study co-author and principal investigator Steven Gorelick, the Cyrus Fisher Tolman Professor in Stanford's School of Earth, Energy & Environmental Sciences. "The Syrian crisis has resulted in a reduction in agricultural land in southern Syria, a decline in Syrian demand for irrigation water and a dramatic change in the way the Syrians manage their reservoirs."

The study focuses on impacts from 2013 to 2015 in the Yarmouk-Jordan river watershed, which is shared by Syria, Jordan and Israel. Study co-author Jim Yoon, a PhD candidate in Earth system science at Stanford, thought of the idea to study the Syrian war's impact on water resources when he noticed an increase in Yarmouk River flow based on streamflow data from Jordan's Ministry of Water and Irrigation.

"The big challenge for us was that it was going to be next to impossible to get on-the-ground data in Syria," Yoon said. "We couldn't really close the story without this information in Syria - that was what led us to use remote sensing data."

Using composite images of the 11 largest Syrian-controlled surface water reservoirs in the basin, researchers measured a 49 percent decrease in reservoir storage. Irrigated crops are greener than natural vegetation during the dry summer season. This characteristic was used to show Syria's irrigated land in the basin had decreased by 47 percent.

Gorelick and his team looked at water management and land use on the Jordanian side of the Yarmouk basin and in Israel's Golan Heights as a baseline for understanding areas unaffected by the refugee crisis.

New precedent

"It's the first time that we could do large-scale remote sensing analysis in a war zone to actually prove a causal relation between conflict and water resources," said lead author Marc Muller, a postdoctoral researcher in Gorelick's lab. "With these new tools, you can do analysis and iterate very quickly - the effects were so strong, it was really easy to see right away."

The research sets a precedent for using remote sensing data to understand environmental impacts in war zones or other areas where information otherwise could not be collected.

"To be able to get this type of detailed information about a region where data on the ground are scarce is an important contribution," said Gorelick, who is also a senior fellow at the Stanford Woods Institute for the Environment. "This shows in the extreme case how relevant information can be obtained in an efficient and scientifically valid manner."

Refugees in Jordan

Syria's abandonment of irrigated agriculture, combined with the region's recovery from a severe drought, caused increased Yarmouk River flow to downstream Jordan, one of the most water-poor countries in the world. However, Jordan has absorbed hundreds of thousands of refugees from Syria since 2013.

"It's slightly good news for Jordan, but it's not a big bonus compared to what Jordan has had to give up and sacrifice for the refugees," Gorelick said. "Even in terms of providing water for the refugees, this transboundary flow is not compensation."

Despite this unexpected result, Jordan's flow from the Yarmouk River remains substantially below the volume expected under bilateral agreements with Syria, a result of legal and illegal reservoirs built in Syria, according to Gorelick.

The Jordan Water Project

Gorelick and his team have cooperated with Jordan on water management research since 2013 through the Jordan Water Project (JWP), a National Science Foundation-funded international effort to analyze freshwater resource sustainability. While experts speculate climate change can lead to conflict, Yoon said it was interesting to examine Syria from a different perspective.

"In the past few years, there's been increasing focus on how climate change and drought influences conflict, but there hasn't been as much research on how conflict can actually lead to impact on the environment and water resources," Yoon said.

Ranked as one of world's top three water-poor countries, Jordan faces serious potential impacts from climate change. One of the key goals of the JWP is to develop an integrated hydro-economic model of the Jordanian water system in order to explore policy interventions.

Gorelick also directs the Global Freshwater Initiative at Stanford and runs the Hydrogeology and Water Resources Program at Stanford's School of Earth, Energy & Environmental Sciences.

Other co-authors on the study, "Impact of the Syrian refugee crisis on land use and transboundary freshwater resources," include doctoral student Nicolas Avisse and Professor Amaury Tilmant from Université Laval in Quebec. Funding for the study was provided by the National Science Foundation through the Belmont Forum and the Stanford

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More information: Impact of the Syrian refugee crisis on land use and transboundary freshwater resources, *PNAS*, www.pnas.org/cgi/doi/10.1073/pnas.1614342113