Energy and Earth Science
Vol. 3, No. 2, 2020
www.scholink.org/ojs/index.php/ees
ISSN 2578-1359 (Print)   ISSN 2578-1367 (Online)

Original Paper

After the Sun: Energy Use in Blue v. Green Water for Agriculture

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Received: May 29, 2020   Accepted: June 8, 2020   Online Published: July 6, 2020

doi:10.22158/ees.v3n2p1   URL: http://dx.doi.org/10.22158/ees.v3n2p1

Abstract

The purpose of this article is to highlight the difference in energy consumption between using blue water versus green water for agriculture in areas where water-intensive crops are grown in water-scarce regions. It focuses on water and energy consumption for greening the desert in United States, the world's largest grain producer. The analysis is limited to the three largest crops by volume and value; corn, cotton, and wheat, which generate billions of dollars for the economy and use billions of gallons of water each day. The primary methodology is to use Geographic Information Systems (GIS) to visually represent the comparative amounts of blue water and green water used to grow water-intensive crops in water-scarce regions, by statistically mapping levels of water stress overlaid with the amounts of blue water versus green water used. It exposes where energy-intensive water practices are occurring due to a high dependence on blue water for irrigation in agriculture. The article concludes by discussing strategies to improve energy efficiency and reduce the vulnerabilities associated with overdependence on blue water such as high energy costs, low energy security, and susceptibility to aquifer reduction and ground water depletion.

Keywords

energy security, water use efficiency, agriculture, sustainable development

1. Introduction

Energy is an integral part of providing water for food security. After the sun, which is the greatest source of energy for growing plants for food, substantial amounts of additional energy are needed to irrigate, produce, harvest, process and transport agricultural crops to support a burgeoning population. Most of the additional energy used in agriculture is for irrigation, which requires large amounts of energy to pump vast amounts of water from long distances or great depths.

Agriculture is the largest water-user and second largest energy-user in the United States. Approximately 300 billion gallons of freshwater are withdrawn daily, requiring energy for pumping and transporting, from surface and ground water sources for agricultural irrigation in the United States (US Geological Survey 2019). With such a high amount of all energy flowing to one sector, we cannot advance sustainable development without addressing the inefficiencies and interdependencies between water and energy in the agricultural sector.

One of the hidden realities in this energy-water-food nexus is that there is a significant difference in the amount of energy used between *blue water* and *green water* in agriculture. *Blue water* is the volume of freshwater used from surface and groundwater sources, g*reen water* is the volume of freshwater in the form of precipitation or stored in the soil. The difference is important because agricultural areas that use *blue water* are highly dependent on irrigation, which requires a tremendous amount of energy to pump, transport, deliver and disperse water.

The purpose of this research is to examine the amount of energy use in *blue water* versus *green water* for agriculture. It examines two problems: 1) Water-intensive crops are grown in water-scarce areas, 2) these crops require a lot of *blue water*, which is energy-intensive. The use of *blue water* for irrigating crops is energy-intensive because it involves pumping, treating, diverting, delivering and moving large volumes from great depths and across vast distances. The conclusion provides empirical evidence of where the is an imbalance in *blue water* versus *green water* consumption in the largest parts of our agricultural sector, emphasizing that *blue water* is highly energy-intensive, and discusses the vulnerabilities associated with overdependence on blue water such as energy insecurity and susceptibility to aquifer depletion.

2. Method

The methodological objectives of this research are to: 1) provide empirical evidence of the comparative amount of *blue water* and *green water* used to grow our three mega crops -corn, cotton, wheat- in water-scarce regions, and, 2) to identify and provide empirical evidence of any imbalances or inefficiencies in energy consumption between *blue* and *green water* in the nexus of energy-water-food security.

This research uses the three largest crops in the U.S. economy, meaning the crops with the highest production volume and highest monetary value. The largest crops by volume and value are corn, cotton, and wheat. These three major crops are all water-intensive and energy-intensive. The data sources for agricultural production are the *Agriculture and Food Statistics: Charting Essentials*, a collection of key statistics on food security, food prices, natural resources, and other information; and the *Agricultural Baseline Database*, a database, report and projection of major field crops including corn, wheat, cotton, and others, from the United States Department of Agriculture (USDA 2020). To indicate the level of water-stress in each region, we use a ratio of water use to water availability. The primary data source for the statistical mapping of water stress is the U.S. Geological Survey National Water Information

System and it is verified and constitutes no data inconsistency (Tinker, 2019) with Aquastat and the U.S. Drought Monitor (USGS NWIS 2020, Aquastat 2020, USDM 2020).

Spatial, production, and economic data are used to locate areas where the three major crops are grown in large quantities in water stressed regions. Geographic Information Systems (GIS) maps are used to represent the data. The graduated levels of water stress are statistically mapped and then overlaid with the quantity of the commodities produced in that region. The overlay illustrates the amount of *blue water* and *green water* used.

3. Result

This research distinguishes between the use of *blue water* and *green water* in the analysis in order to statistically map the water footprint and indicate the difference in energy consumption. Prominent water scholars Hoekstra and Hung note "The distinction between the blue and green water footprint is important because the hydrological, environmental, and social impacts, as well as the economic opportunity costs, of surface and groundwater use for production differ distinctively from the impacts and costs of rainwater use" (Hoekstra et al., 2011, p. 45). *Blue* water is the volume of freshwater consumed from surface and groundwater sources. *Green* water is the volume of freshwater consumed as precipitation or stored in the soil. The difference is important to understand because areas that are dependent on *blue water* are more dependent on irrigation and thus highly dependent on energy for pumping and transporting water. Areas dependent on *blue water* are also more susceptible to aquifer depletion, whereas areas that are dependent on *green water* are less dependent on energy consumption but more vulnerable to factors such as precipitation.

The baseline water stress of the United States is mapped in Figure 1, which uses Geographic Information Systems (GIS) to statistically represent water stress using water data from USGS, USDM, and USDA. The indicator is a ratio; it measures water stress as the difference between water availability and water consumption. The baseline water stress map is the current level of water stress across the U.S.

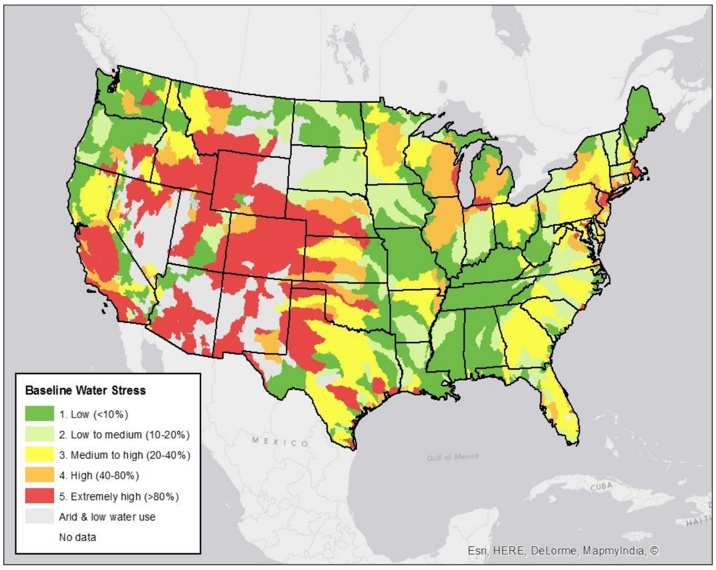

Figure 1. Baseline Water Stress Map of the United States

Source: USGS https://waterdata.usgs.gov/nwis, GIS Kehl and Olshfski.

The baseline water stress map exposes one of the most consequential realities of the water-energy-food nexus: many of our largest food producing regions are growing water-intensive crops in water-scarce areas, such as the Great Plains, Midwest, Southwest, Texas, and California. This reality is highly energy-intensive. These areas rely on *blue water* and depend on irrigation, which is energy-intensive for pumping from increasing depths and transporting from increasing distances. We can expect this reality to worsen with increasing consumptive demands and increasing environmental variability. Mighty rivers such as the Colorado and expansive aquifers such as the Ogallala are being depleted and our dependence on *blue water* from these sources places heavy, expensive, and unsustainable demands on energy.

The results of this analysis demonstrate that several regions have a double dilemma of growing water-intensive crops in water-scarce regions and adding the complication of a *blue-green* water imbalance, which greatly increases the amount of energy required to grow crops.

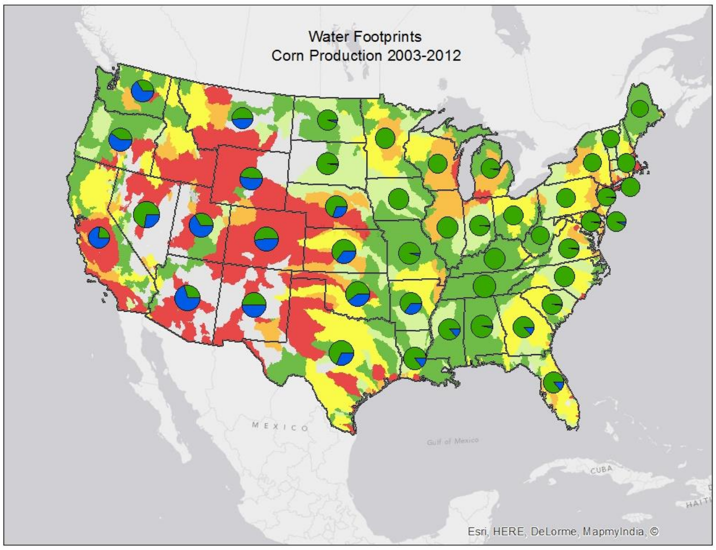

Figure 2. Blue and Green Water for Corn

Source: USGS https://waterdata.usgs.gov/nwis, GIS Kehl and Olshfski.

The primary result is illustrated in the case of double water inefficiency, meaning that a water-intensive crops is grown in a water-scarce region and it is grown using a *blue water-green water* imbalance. Colorado, Wyoming, Utah, Arizona, New Mexico, and California have a double inefficiency in water use in their corn production: They grow a lot of corn in a water-stressed region and they use a lot of *blue water* to do it. See Figure 2. There is extreme water stress and a high volume of water-intensive corn grown in Nebraska and Colorado. There is high water stress and large quantities of corn grown in Illinois, Minnesota, Wisconsin, and Kansas. In areas with relatively high levels of precipitation and *green water*, namely Iowa, Mississippi, Indiana, Ohio, and Kentucky, water efficiency and energy efficiency in corn production are most balanced. These areas do not require a huge amount of additional energy (or inefficient energy consumption) as they do not have a large *blue-green water* imbalance. In contrast, the areas that have the double inefficiency, water scarcity and *blue-green water* imbalance, require a tremendous amount of additional energy to “green the desert” through pumping depleted aquifers and diverting over-extracted rivers across great distances.

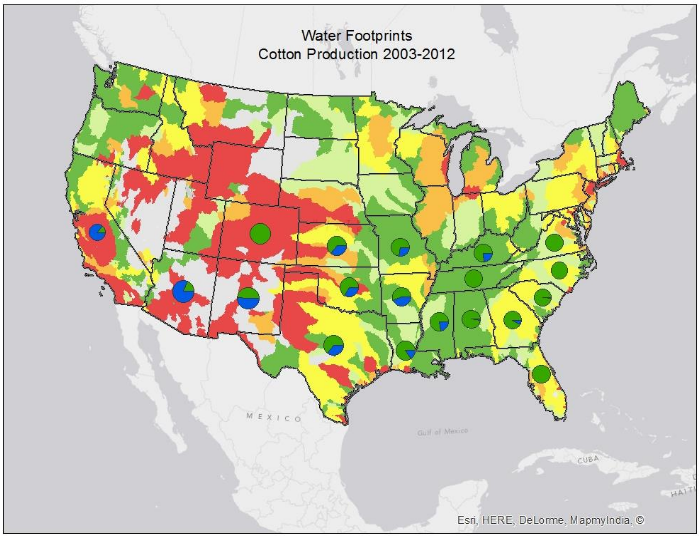

Figure 3. Blue and Green Water for Cotton

Source: USGS https://waterdata.usgs.gov/nwis, GIS Kehl and Olshfski.

There is also an extreme *blue-green* water imbalance with extreme *blue water* inefficiency in growing cotton in California, Texas, New Mexico, Arkansas and Arizona. See Figure 3. Cotton is one of the most water-intensive crops in modern production. It is also highly energy intensive if it is grown in water scarce regions. There is extreme water stress and a high volume of cotton grown in California, Arizona and Texas, and high water stress and a high volume of cotton in Arkansas and Georgia.

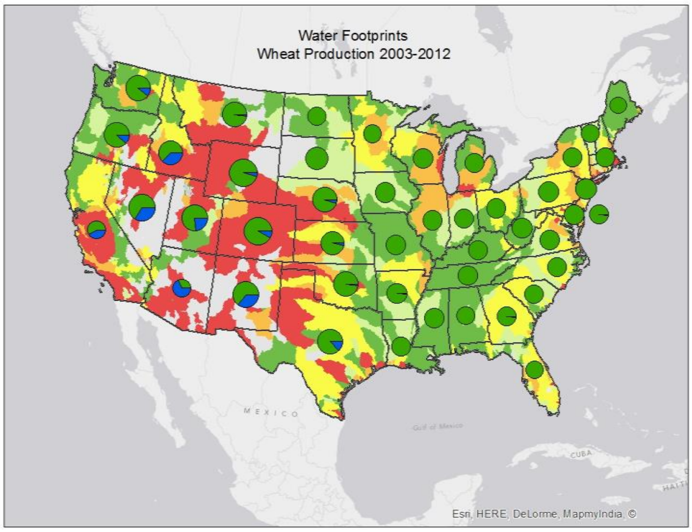

Figure 4. Blue and Green Water for Wheat

Source: USGS https://waterdata.usgs.gov/nwis, GIS Kehl and Olshfski.

California and Arizona show extreme water inefficiency in the use of *blue water* to grow wheat in the desert. There is also *blue-green water* inefficiency in Idaho, Nevada, and New Mexico. See Figure 4. There is extreme water stress and a high volume of wheat produced in Colorado, Montana, Kansas, Nebraska, and Oklahoma. There is high to moderate water stress and high wheat production in Illinois, Minnesota, and Indiana.

The greatest problem in water inefficiency and energy inefficiency in wheat production in the U.S. is in the states that are dependent on the Ogallala Aquifer for water security; Colorado, Montana, Kansas, Nebraska, and Oklahoma. As the Ogallala Aquifer gets depleted due to over-extraction, the feasibility of agricultural production will decrease due to the dependence on pumping scarce water from the rapidly depleting source, as we know, and the more hidden reality of the high cost of large amounts of energy required to pump it from greatening depths. The loss of the capacity to produce a high volume, high value mega cash crop will jeopardize the economic viability of the agricultural sector in the multi-state Ogallala region, not only due to the water inefficiency but due to the interdependent and expensive energy inefficiency that is not cost effective for relatively cheap cash crops.

4. Discussion

It is often overlooked that agricultural practices in water-scarce regions are highly energy-intensive. The use of *blue water* irrigation requires immense amounts of energy to pump water from extreme depths and move water across great distances. Greening the desert is a deleterious distortion that is not environmentally or economically sustainable.

This research provides empirical evidence of energy inefficiency in areas where there is an imbalance in *blue water* versus *green water* use for large agricultural production, as the use of *blue water* is highly energy intensive. The research has provided empirical evidence that wheat, corn, and cotton, all high volume, high value, and water-intensive crops grown in water stressed areas in the U.S., demonstrate the most sever water imbalances and energy inefficiencies in the American West, Southwest and Great Plains, The results indicate that the water imbalance and consequent energy inefficiency is particularly extreme for corn in Colorado, Wyoming, Utah, Arizona, New Mexico, and California; cotton in California, Texas, New Mexico, Arkansas and Arizona; and wheat in Californian and Arizona, which arguably should not be growing these crops and should expedite a transition to crops better suited to the urgency of environmental sustainability and economic durability in the region. Water and energy intensive crops should be grown in areas that have a comparative advantage in water availability and energy efficiency, and a sustainable balance of *blue-green water* consumption, which seems intuitive but is actually the opposite of the empirical reality that our most water-intensive crops are grown in our most water scarce regions. These water scarce regions are highly dependent on energy-intensive *blue water*, which makes them vulnerable to worsening water stress, energy costs, energy insecurity, and the depletion of the aquifers and ground water resources upon which they depend.

As these areas suffer more frequent and severe droughts, which exacerbate the problems of dependence on energy-intensive *blue water* and rapidly depleting aquifers, this study portends a large transition of intensive agriculture to the Great Lakes region, the largest source of surface freshwater on the planet. Great Lakes regional governments, development corporations, producers and consumers are commercially advertising and marketing Great Lakes water to large-scale growers as an abundant and free source of freshwater to attract business. The Great Lakes might consider putting policies in place to manage this anticipated growth with water-efficiency in the interest of sustainable development.

This study introduces the empirical reality and environmental risk, and, arguably, the emerging depravity of continuing to grow water-intensive and energy-intensive crops in highly water-stressed regions. The research has been conducted in the interest of introducing difference in the amount of *blue water* versus *green water* in large-scale agriculture in the U.S. and to expose the energy inefficiency of the high dependency on large quantities of *blue water* to produce water-intensive crops in water stressed regions. Although this work is introductory, it can be expanded and used to prompt additional research on the difference in energy consumption of *blue water* and *green water* in agriculture. It can also be used as part of a larger initiative to restructure agriculture in the U.S. from the perspective of joint water efficiency and energy efficiency, or at least be used as justification to pursue energy efficiency and sustainable sources of energy for water-intensive agriculture.

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