Sustainability Assessment of Groundnut Bioethanol Production in Uttar Pradesh, India

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Abstract

This study is to assess the water footprint and environmental sustainability of groundnut-based ethanol production in Uttar Pradesh, India, driven by the increasing need for nutrient-dense and robust alternatives. The research looks at how much water is needed at each stage of the manufacturing process, from planting groundnuts to extracting ethanol, using a life cycle assessment technique. The main objective is to obtain a comprehensive grasp of water usage at every phase, identifying opportunities for improvement and effectiveness. Mainpuri has the lowest water footprint due to effective water utilization and high production, while Jhansi has the most due to significant evapotranspiration. These findings are expected to provide significant insights into the feasibility and sustainability of groundnut-derived ethanol as an environment friendly biofuel alternative in Uttar Pradesh, India, assisting policymakers, researchers, and stakeholders in advocating for its adoption and tackling environmental issues associated with traditional fuel sources.

Keywords: Bio-ethanol, Evapotranspiration, Groundnut, Sustainability, Water Footprint.

Introduction

The scarcity of natural resources in the modern world is as a consequence of the growing need for energy, which is known as the energy crisis. The replenishment of natural resources is a lengthy process and has a limited supply. The country's energy demands need the use of alternative energy sources [1]. An increasingly important junction in the pursuit of sustainable development is that of agricultural and energy production. In addition to assisting in reducing the country's reliance on foreign oil, biofuels can help meet its energy needs. Using renewable and sustainable resources like lignocellulose biomass is the greatest method to close the energy gap [2]. Today, the majority of lignocellulosic agricultural waste is burned or wasted, including wood chips, groundnut shells, and other agricultural wastes like rice and wheat straw. India and China account for about 60% of global groundnut production, making them the top two producers in terms of GS, whereas Egypt and South Africa have the highest productivity and capacity for groundnut production. (1990–1998) FAOSTAT Bioethanol has a great potential to replace fossil fuels because of its advantageous qualities [3].

First- and second-generation bioethanol are distinguished by the type of raw material utilized in their manufacturing. Grain and food crops are used in the first phase of bioethanol production. Regarding the availability and demand for food, it became a source of worry. The synthesis of second generation bioethanol was made possible by the non-edible material that makes up most cellulosic biomass [4]. Bioethanol is produced in the second generation using cellulosic agricultural crop leftovers that are inedible. Lignin (26.4%), hemicellulose (14.7%), and cellulose (40.5%) make up groundnut shells [5]. Mostly buried or burned, groundnut shells are produced in vast quantities, with India being one of the top producers. The degradation process of these groundnut shells in natural soil is quite slow. Filling the energy shortfall in the country can be achieved by using these groundnut shells as a feedstock for bioethanol production.(Figure :1)

Figure: 1 Groundnut shells

The manufacture of biofuels has brought up serious concerns about the environmental effects, especially with regard to water use. This study examines how groundnut-derived bioethanol uses water in Uttar Pradesh, India, a state that struggles with both water constraint and energy demand [6]. Groundnut is a possible substitute for sustainable and effective agriculture because of its ability to thrive in less-than-ideal settings, minimal input requirements, and high biomass output.
India faces a critical need for energy security given its large population and quickly expanding economy. Increased use of renewable energy sources and less reliance on fossil fuels are two possible outcomes of biofuels, with ethanol being one such biofuel [7]. The high oil content and versatility of groundnut, a commodity that is widely grown in Uttar Pradesh, India, make it a suitable feedstock for the generation of bioethanol.

One of the most populated states in India, Uttar Pradesh, is a significant groundnut producer. But the area also struggles with a persistent lack of water, especially in the dry season [8]. Stress is imposed on water resources due to the increase in water demand for domestic, industrial, and agricultural uses. For the purpose of comprehend its possible effects on the environment and guide sustainable development plans, it is imperative that the water footprint of bioethanol produced from groundnuts in Uttar Pradesh be evaluated [9].

An extensive evaluation of water footprints is necessary since water, a limited and vital resource, is crucial to the generation of bioenergy [10]. Developed by Hoekstra and Chapagain, the water footprint is a comprehensive metric that considers a product's wider influence on the world's water resources Furthermore to its direct usage of water during cultivation [11]. Blue water (withdrawals from surface and groundwater), grey water (water footprint associated with pollution), and green water (rainwater utilized for plant development) are other classifications for this metric. In India, a lot of research on diverse crops have been carried out. Nonetheless, a thorough investigation is necessary to ascertain the quantity of water needed for the production of both food and biofuel, as well as to pinpoint any regions that may be prone to contamination and overuse of water [12]. Because groundnuts have the potential to function as a substantial feedstock for the manufacturing of bioethanol, this study intends to examine the water requirements of this crop.

In Uttar Pradesh, India, the research focuses on the crucial point where the groundnut's importance collides with the problems of water shortage and the requirement for bioenergy [13]. Analysis of the liquid footprint at each stage of production is the main goal of the life cycle assessment (LCA) method used to evaluate groundnut-based ethanol production [14]. We hope to offer a comprehensive understanding of water use efficiency and environmental repercussions by quantifying the many elements of the water footprint. Policymakers and stakeholders will discover significant insights from the results of the investigation, which will also add to the ongoing conversation on sustainable bioenergy [15]. Recognizing the complex interplay between groundnut-based ethanol production, water use, and environmental impact is crucial to ensuring a more resilient and sustainable energy supply in the future. Groundnuts are emerging as a sustainable alternative [16].

This article uses the CROPWAT technique, as outlined by the water footprint network, to evaluate the green and blue water footprint of groundnut in six districts of Uttar Pradesh over the period of 2016–2023.There are various advantages of using crop waste for material development and manufacture.

Three primary goals are involved which are stated in the study:

1. To examine the water use of groundnuts, expressed in cubic meters per ton, during the crop production stage.
2. To evaluate the water footprint and gigajoule (GJ) energy yield of bioethanol.
3. To investigate the effects of making ethanol from groundnuts on nearby water supplies, considering regional variations in water availability and quality.

This research will aid in the development of more sustainable and water-efficient biofuel production techniques by offering a thorough and in-depth investigation of the water footprint of bioethanol produced in Uttar Pradesh from groundnuts.

Materials and methods

Study area

The study focused on six districts in Uttar Pradesh, which are major producers of groundnuts. It investigated the volume of water utilized to produce groundnuts in these districts and how this impacts the output of ethanol, a type of biofuel. The location of the state of Uttar Pradesh is shown in Figure 1 as falling between the latitudes of 23°52'N and 31°28'N and the longitudes of 84°39'E and 77°3'N. With regard to both population and land area, this state leads the nation. Nine agroclimatic zones are identified for the state: Vindhyan area, Bundelkhand region, Western Plain area, Central Western Region, South Western Region, Bundelkhand Region, North Eastern Plain Region, and Eastern Plain Region [17]. These zones are based on the terrain, climate, and varied topography.

Figure: 2 and Figure: 3 show the map of India and Uttar Pradesh. Figure: 4 depict the research region that was taken into account while calculating the water footprint.

Figure 2: India map

Figure 3: Uttar Pradesh map

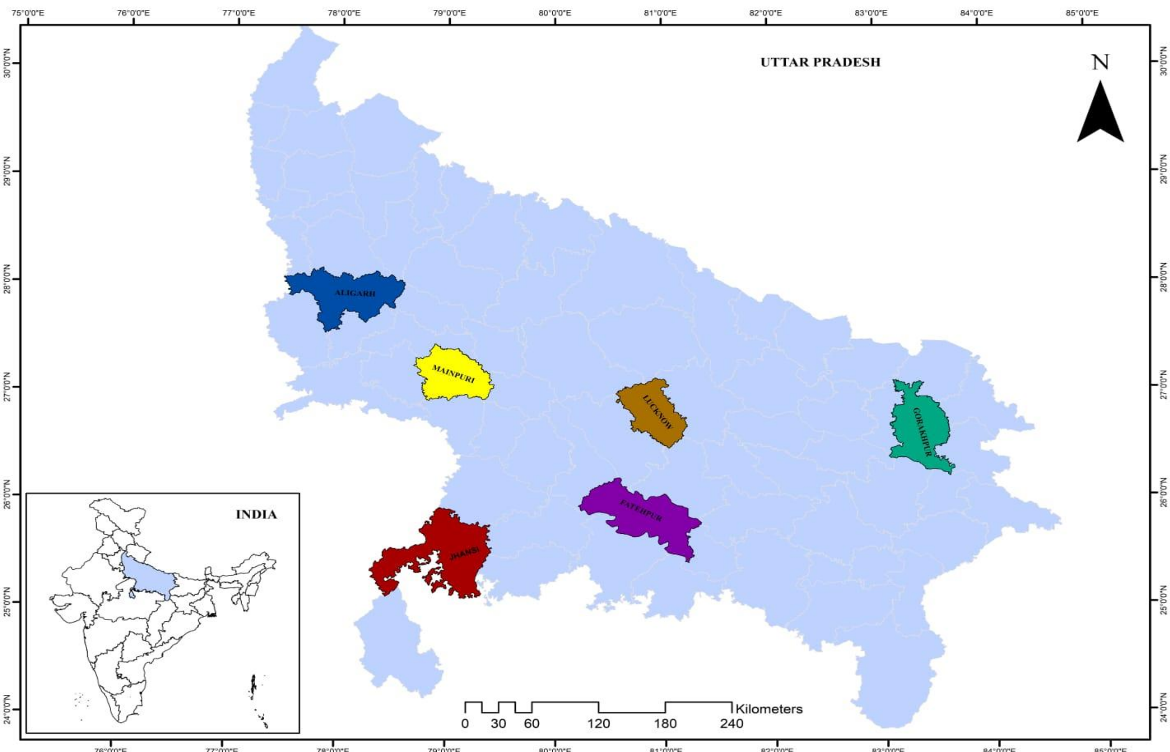

Figure 4: Uttar Pradesh showing districts undertaken for study

Information gathered from weather stations spread out across these areas were utilized to conduct a comprehensive research. Cropwat software, which offered in-depth insights into a variety of meteorological characteristics, was used to examine the data after it was obtained from Climwat software, a program intended for meteorological data analysis.

Jhansi, Mainpuri, Fatehpur, Aligarh, Gorakhpur, and Lucknow were among the districts covered.

Distinct perspectives on groundnut cultivation and its corresponding water usage were provided by every one of them districts. For the purpose of represent the heterogeneity in agricultural methods and weather conditions across different locations, the study included multiple districts within the State.

Data source

With reference to evapotranspiration, the FAO Penman-Monteith technique was used to compute the crop water need (m^3/ha) using the calculating model CROPWAT 8.0 The amount that must be irrigated is determined by subtracting the effective rainfall from the crop water need. Based on the assumption that actual irrigation needs are met, this study may produce an overestimation of water use. However, the omission of evaporation losses connected to irrigation could result in an underestimation in other situations. Since process water use (PWU) is so little compared to the total quantity amount of water utilized during the groundnut growing season, It is not considered when calculating the WF. The CLIMWAT database [18]. Provided the climatic information for each of the six districts that were being examined for CROPWAT. Supplies came from Shuats, Prayagraj Department of Agronomy. Information on planting and harvesting dates, soil properties, and the extent of the various developmental phases were all provided to compute the crop coefficient (Kc) values for the groundnut crop, Prayagraj was believed to be relevant to all fields. During the 2016–2023 study periods, the crop values were acquired. The Statistical Abstract of Uttar Pradesh provided the average production data needed to determine a crop's water footprint [19].

Yield of Groundnut in the selected districts of Uttar Pradesh year-wise is shown in Figure 4 below.

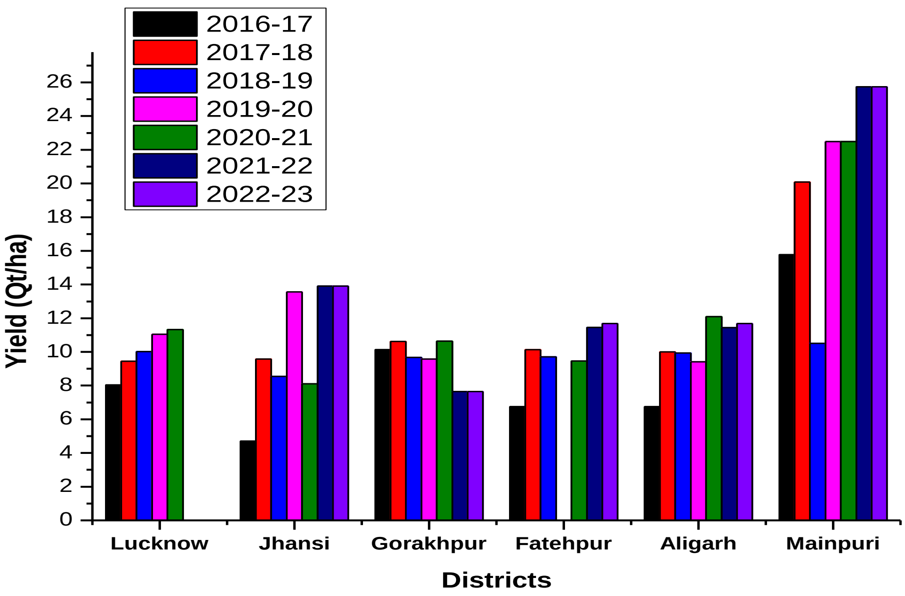

Figure: 5 Yield of Groundnut in the selected Districts of Uttar Pradesh year-wise.

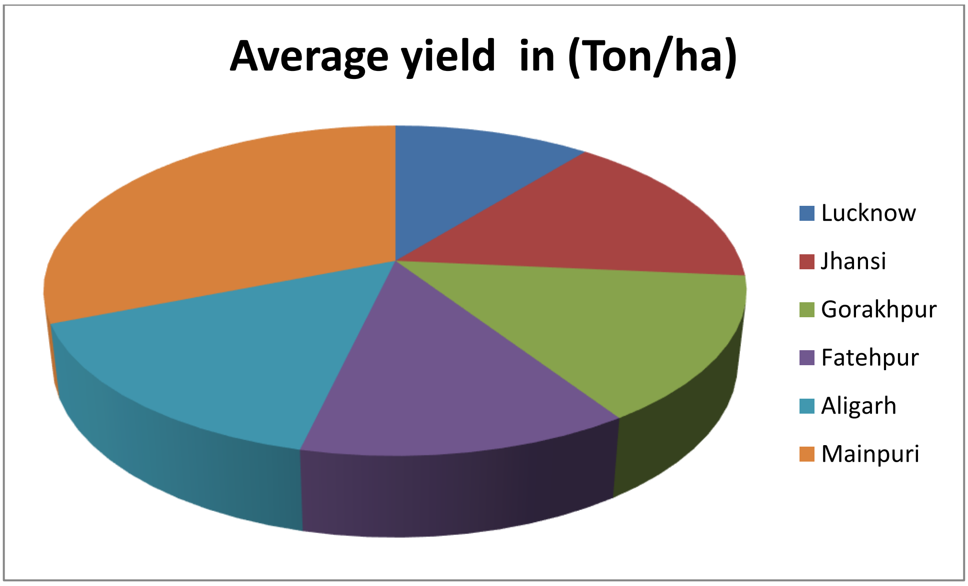

Figure: 6 Average Yield for Groundnut in Districts under study for the period 2016-2023.

The information required to determine the crop's ethanol-energy yield, such as the higher heating value of ethanol (kJ/g), How much ethanol produced each unit of carbohydrate (g/g), the dry-mass fraction in the crop yield (g/g), and the carbohydrate fraction in the dry mass of the crop yield (g/g), was from Gerbens-Leenes [20,21].

Methodology

To calculate the WFP for groundnut planting, biomass processing, and ethanol generation in the six districts of Uttar Pradesh this that were incorporated into this study, a series of frameworks created by Chapagain and Hoekstra [22] and later expanded by Aldaya and Llamas [23] were employed. Though there is a more detailed method available in the WFN Manual—2011, the one that follows is shorter. WFP totals are the sum of the blue, green, and grey WFPs.

Rainwater evaporating during production, mainly during agricultural expansion, is called the "green WF." The blue WF denotes irrigation-related surface and groundwater evaporation during crop growth. The grey water factor (WF) alludes to the amount of water tainted during creation. It's the amount of water needed to lessen the intensity of pollutants released into the natural water system so that the water quality in the surrounding environment stays above specified water quality criteria [24].

Calculation of water footprint

There were calculations made during the course of growing seasons by adding up daily crop evapotranspiration (mm/day) and dividing the green from the blue WF using the CROPWAT 8.0 model. Over time, variations in yield were noted. In order to calculate average yields for seven production years (2016–2023), the study utilised data from a number of online sources, including Indiastat.com and the Ministry of Agriculture and Farmers Welfare, Government of India. The CWR is assessed using published recommendations [25, 26] and the FAO's Cropwat 8.0 tool. Following the determination of CWR, the green and blue WFs were computed.

With a ten-day time step, the green water evapotranspiration (ET_{green}) is determined by subtracting the effective rainfall (P_{eff}) from the total crop evapotranspiration (ET_c). Compiling ET_{green} during the duration of the groundnut plant's growth yields the total green water evapotranspiration [27].

$$ET_{green} = \min (ET_c, P_{eff}) \text{ [length/time]} \quad (1)$$

Total crop evapotranspiration (ET_c) minus total effective rainfall (P_{eff}) divided by ten days is the anticipated blue water evapotranspiration (ET_{blue}). The crop's total evapotranspiration, or ET_{blue}, is equal to zero when the effective rainfall exceeds the crop's total WF. ET_{blue} is added over the groundnut's whole growth season to determine the total blue water evapotranspiration.

$$WF_{total} = WF_{blue} + WF_{green} + WF_{grey} \quad (2)$$

To calculate crop WF_{blue} and WF_{green}, the blue and green water in crop water usage (CWU) are divided by the crop yield (Y). The daily accumulation of evapotranspiration during the crop-growing season is represented by the green and blue water values in the CWU.

$$WF_{blue} = \frac{\text{CWU blue}}{Y} = \frac{10 \times \sum_{d=1}^{lgp} ET\text{blue}}{Y} \quad (3)$$

$$WF_{green} = \frac{\text{CWU green}}{Y} = \frac{10 \times \sum_{d=1}^{lgp} ET \text{ green}}{Y} \quad (4)$$

The green and blue water used throughout the crop growth period are denoted by CWU_{blue} (m^3/ha) and CWU_{green} (m^3/ha); the green and blue components of crop WF are represented by WF_{blue} (m^3/ton) and WF_{green} (m^3/ton), respectively. The estimated crop evapotranspiration in mm can be converted to m^3/ha by applying the multiplier 10. Since nitrogen may readily permeate soil and contaminate surface and groundwater, it was the most important fertilizer input when determining WF_{grey}. Consequently, WF_{grey} shows how utilizing water dilute pollution, which is mostly caused by the usage of nitrogen fertilizer, as determined by the formula given below [28].

$$WF_{grey} = \frac{(\propto \times AR)/(Cmax - Cnat)}{Y} \quad (5)$$

According to suggestions found in Hoekstra and Chapagain [29], where AR (kg/ha) is the quantity of nitrogen applied to the field per hectare and $\propto$ is the total nitrogen leaching factor, which is defined as 10% of the total fertilizer application rate (kg/ha). As a result of lacking ambient water quality regulations, the maximum allowable concentration of total inorganic nitrogen for a given water body, or C_{max} (mg/l), is established at 10 mg/l. Hoekstra and Chapagain's [30] limit, where Y is yield of crops per unit area (ton/ha) and C_{nat} is the natural background concentration of total nitrogen (mg/l), was used. With above mentioned, the environmental effects of extra pesticides and fertilizers have not been taken into consideration due to a lack of adequate data.

Subtracting the ethanol energy yield (measured in GJ/ton) from the water footprint (measured in m^3/ton) yielded the water footprint of the crop (groundnut) in terms of ethanol energy, which was then stated as a water footprint of ethanol energy from the crop (expressed in m^3/GJ).

$$WF\ \text{ethanol} = \frac{\text{WF crop}}{\text{EY ethanol}} \qquad (6)$$

The ethanol-energy yield of a crop (GJ/ton) was calculated from Eq.8 given below:

$$EY_{ethanol}=DMF_{y}\times f_{carbohydrate}\times f_{ethanol}\times HHV_{ethanol} \qquad (7)$$

The dry mass fraction (DMFy) in the crop yield is expressed in grams per gram, the fraction of carbohydratein the dry mass of the crop yield is expressed in grams per gram, the amount of ethanol obtained per unit of carbohydrate is expressed in grams per gram, and the greater heating value of ethanol is expressed in kJ/g. The data that was extracted from [31, 32]—which is compiled in Table 1 below—relates to these elements, including the dry mass of crops, the amount of carbohydrates in crops that produce ethanol, and the higher heating value of ethanol.

Table: 1 Characteristics of ethanol providing groundnut crop

Crop	DMF	fcarbohydrate(g/g)	fethanol (g/g)	HHVethanol (KJ/g)
Groundnut	95%	14	0.04	27.9

Table: 2 Crop evapotranspiration, effective rainfall and average yield of groundnut for the period 2016-17 to 2022-23

District	Crop evapotranspiration ETc (mm/dec)	Effective precipitation (mm)	Average yield (ton/ ha)
Lucknow	294.2	629.5	0.71
Jhansi	356.2	624.5	1.03
Gorakhpur	283.1	736.1	0.94
Fatehpur	303.8	584.9	0.85
Aligarh	334.6	550.4	1.01
Mainpuri	294.3	555.7	2.04

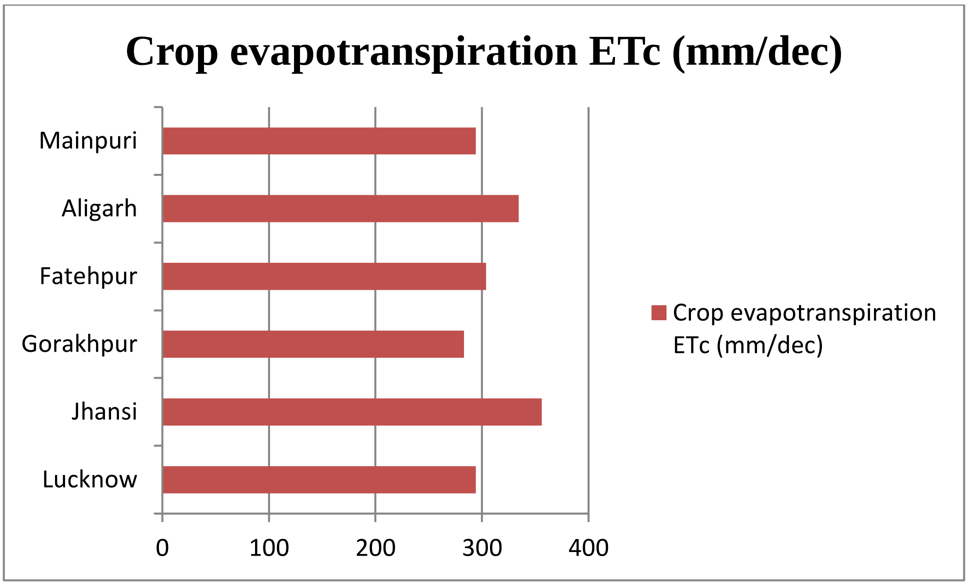

Figure: 7 Variation in crop evapotranspiration (ET_C) during the groundnut growth stage in selected districts of Uttar Pradesh, India

Results and discussion

Trends in weather condition

Temperature range

Figure: 7 illustrate the minimum and maximum temperature throughout the groundnut growing season in the districts under review while the inquiry was ongoing, which rain from 2016 to 2023. Between 18.4 and 20 °C and 31.4 and 32.8 °C, on average, were the minimum and highest temperatures in these regions.

Aligarh and Mainpuri recorded the lowest temperature of 18.4°C during the groundnut growing season. In contrast, Jhansi and Mainpuri displayed the highest temperature, with a recorded value of 32.8^0C. Due to their propensity to affect crop growth and development in a number of ways, including water requirements, insect and disease incidence, and overall yield potential, these temperature changes are important considerations in groundnut farming.

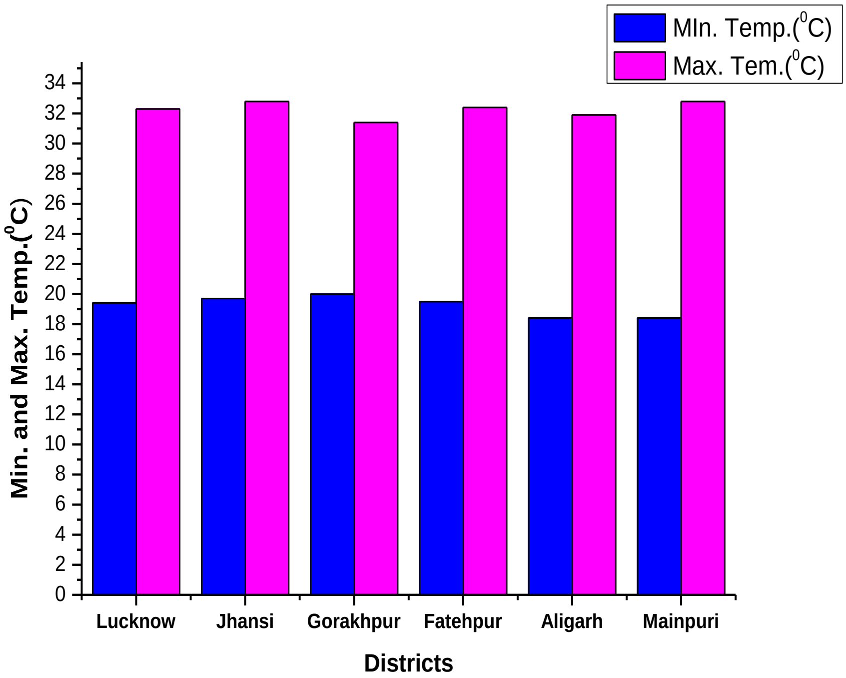

Figure: 8 Minimum and maximum Temperature in six selected districts of Uttar Pradesh, India

Rainfall

The substantial influence of rainfall effectiveness on crop water needs in selected districts is evident from the analysis of precipitation variables from Fig. 8 and Table 2 for the 2016–2023 timeframe. Importantly for its rain-fed agricultural industries, Gorakhpur has the highest effective rainfall, at roughly 736.1 mm. After all, Lucknow has 629.5 mm, which guarantees that crops will have enough water. Relatively little irrigation is required to meet the agricultural needs of Jhansi and Fatehpur, which both receive sizable amounts of rainfall—624.5 mm and 584.9 mm, respectively.

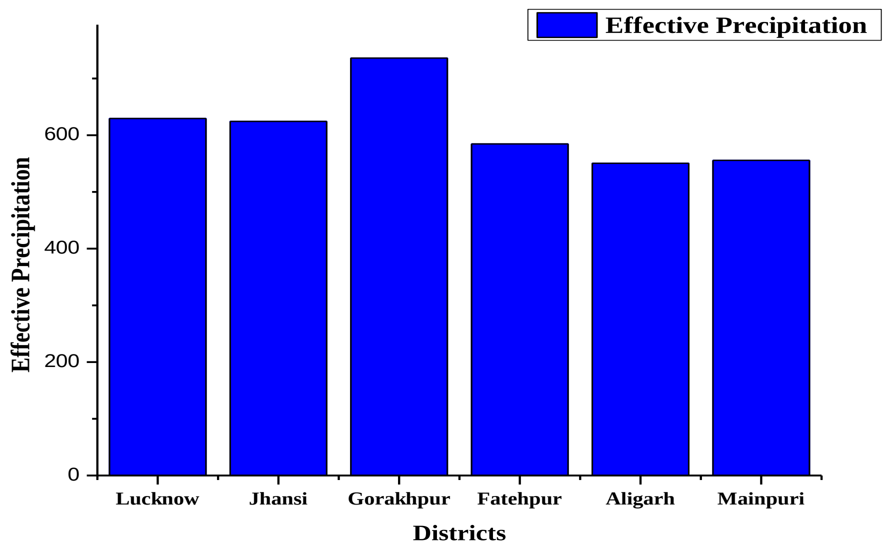

Fig: 9 Effective Precipitations

Due to their relatively little rainfall, Mainpuri (555.7 mm) and Aligarh (550.4 mm) have more severe difficulties at the lower end. This emphasizes the significance of water conservation and irrigation techniques in these areas.

This succinct study highlights the range of climates in Uttar Pradesh, India, and the significance of efficient rainfall for sustainable agricultural planning. To assure crop health and yield, especially in regions with less rainfall, it emphasizes the necessity of customized water management techniques.

Water requirement and yield for groundnut cultivation

With the greatest average crop evapotranspiration (ETc) of 356.2 mm, groundnut trailed by Aligarh with 334.6 mm, Jhansi is clearly the best state for growing groundnuts. This highlights the need for effective irrigation techniques to promote the best possible growth and yield and shows how much water these groundnut crops in these areas require. Groundnut the district's agricultural industry appears to demand a significant amount regarding water, as indicated by Fatehpur's average ETc of 303.8 mm, which places it third.

With an average ETc value of 294 mm, districts like Mainpuri and Lucknow have moderate water demands. With ETc readings of 283 mm, Gorakhpur's water needs remain comparatively constant. Figure 8 and Table 2 show this.

Comprehending the variances in water demands throughout areas is imperative for executing customized water management tactics and guaranteeing sustainable farming methods.

Comparison of the Water Footprint of Crop Production per ton

Table 3: The green, blue and total water footprint in (m^3/ton) of groundnut for the six selected districts of Uttar Pradesh, India.

District	WF_{green}(m^3/ton)	WF_{blue}(m^3/ton)	WF_{total}(m^3/ton)
Lucknow	1746	1979	3725
Jhansi	1741	2577	4318
Gorakhpur	1746	1885	3631
Fatehpur	1725	2044	3769
Aligarh	1628	2397	4025
Mainpuri	804	983	1787

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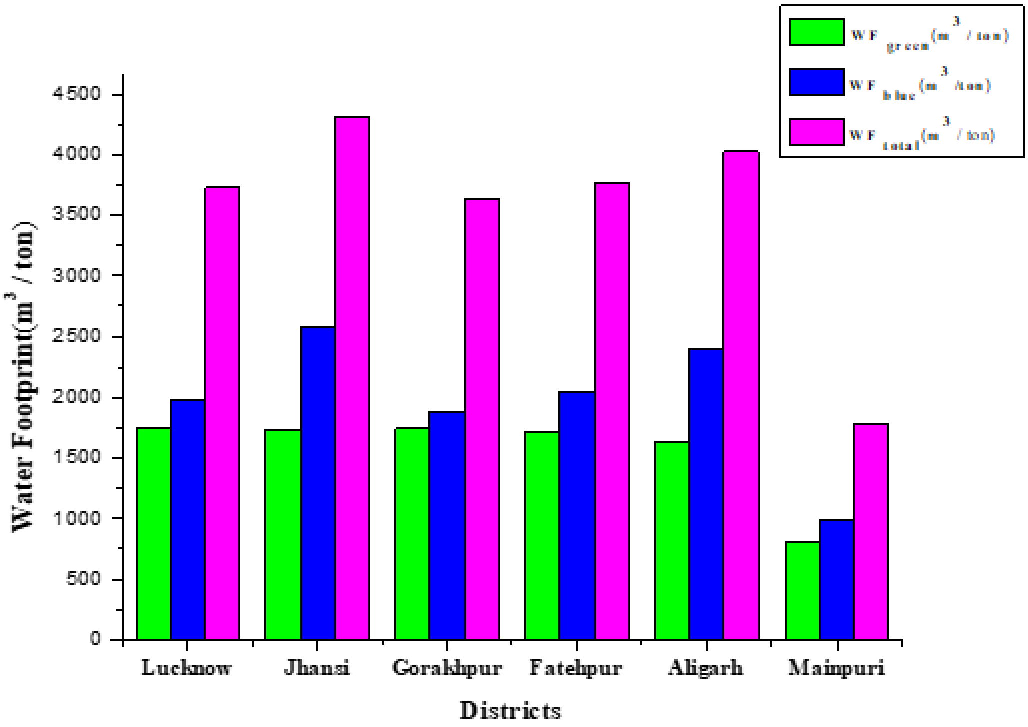

Figure: 10 the green, blue and total water footprint in (m^3/ton) of groundnut for the six selected districts of Uttar Pradesh, India.

Significant differences were noted in the water footprint (WF) of groundnut production between different districts in Uttar Pradesh, India, throughout the 2016–2023 research periods. Due in large part to its noteworthy ET_c value, Jhansi came out with the largest total water footprint, measuring 4318 m^3/ton. According to Fig. 8, WF_{green} contributed 1741 m^3/ton, whereas 2577 m^3/ton from blue water indicated significant groundwater stress. As a result of its high average production over the study period, Mainpuri, on the other hand, had the lowest overall water footprint at 1787 m^3/ton. For instance, during the agricultural production stage, Gorakhpur showed a significant water footprint of 3631 m^3/ton, of which WF_{green} and WF_{blue} contributed 1746 m^3/ton and 1885 m^3/ton, respectively. With total water footprints of 3725 m^3/ton, 3631 m^3/ton, and 3769 m^3/ton, respectively, Lucknow, Gorakhpur, and Fatehpur had a modest size.

Mainpuri fits into the low WF category (1787m^3/ton) when districts are divided into high, medium, and low categories water footprint ranges. Areas falling within the mild WF range (3631–3769 m^3/ton) include Lucknow, Gorakhpur, and Fatehpur districts. In contrast, the high WF_{green} range (4025–4318 m^3/ton) was occupied by Jhansi and Aligarh.

Whereas Lucknow and Gorakhpur were in the medium range (1885–1979 m^3/ton), Mainpuri fell into the low range (983 m^3/ton) for WF_{blue} in this case. High WF_{blue} range (2044–2577m^3/ton) was observed at Jhansi, Aligarh, and Fatehpur. In light of its arid climate and significant reliance on irrigation, Jhansi has the largest blue water footprint (2577 m^3/ton) of any district. In a location where there is already A lot of water stress, the widespread use of blue water has the capacity to lower local water tables and worsen problems related to shortages. Then, with a blue water footprint of 2397 m^3/ton, comes Aligarh. This significant amount highlights the extensive irrigation techniques needed to maintain groundnut output in an area with little access to natural water resources. Aligarh's dependence on blue water may cause excessive groundwater resource extraction, creating problems for the city's long-term viability.

Environmental impact of groundnut production

Because groundnuts utilize comparatively less water than crops, they are significantly more beneficial to the environment. to grow in districts like Mainpuri, Gorakhpur, Lucknow, and Fatehpur has a small blue water footprint of 983 m^3/ton, which denotes economical water consumption and low pollution. It demonstrates reduced pollution levels, balanced water use, and a modest dependency on irrigation, making groundnut farming more environmentally benign. Contrarily, sugarcane uses a lot more water, its blue water footprints can often reach 2000 m^3/ton and can lead to serious contamination from intensive fertilizer and pesticide use, as well as the depletion of water resources. Maize contributes to soil erosion and nutrient depletion, yet it uses less water than sugarcane and pollutes more than groundnuts. Unlike large-scale sugarcane and maize farming, which destroys habitat, groundnuts' tolerance to drought and reduced need for soil nutrients further promote soil health and biodiversity. Therefore, compared to sugarcane and maize, groundnut production is a superior choice for Sustainable farming practices since it can result in more sustainable water usage, increased soil health, and biodiversity conservation in these districts.

Comparison of the water footprint of bioethanol per GJ

Table 4: Water footprint of groundnut production and bioethanol per unit of energy

District	Water footprint per ton of crop (m^3 per ton Groundnut)		Water footprint per unit of energy (m^3 per GJ ethanol)	
	Green	**Blue**	**Green**	**Blue**
Lucknow	1746	1979	175.6	199.1
Jhansi	1741	2577	120.8	178.7
Gorakhpur	1746	1885	64.3	69.4
Fatehpur	1725	2044	145.0	171.8
Aligarh	1628	2397	115.1	169.5
Mainpuri	804	983	28.2	34.4

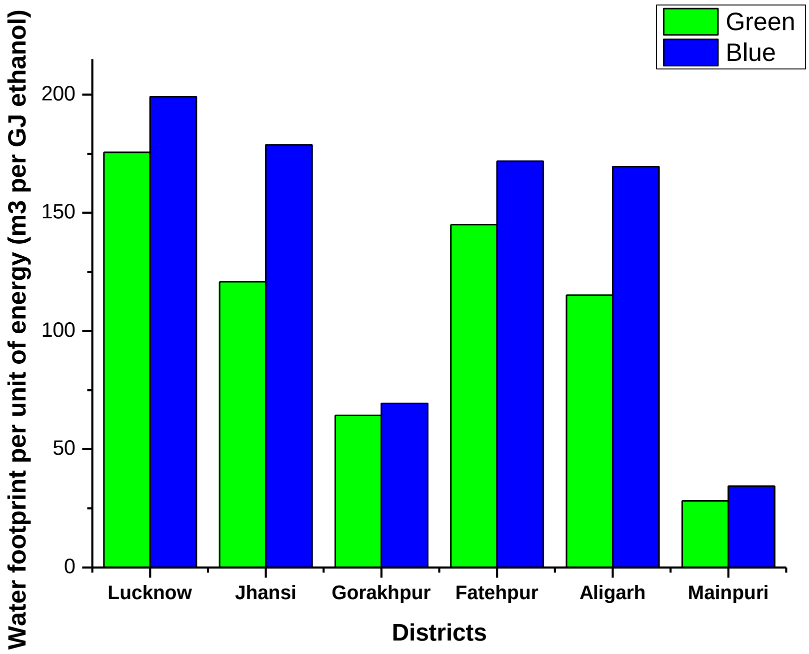

Figure: 11. The green, blue water footprint of ethanol energy yield from groundnut for the six districts of Uttar Pradesh, India

Due to a multitude of factors, including energy outputs, meteorological conditions, and agricultural practices, the water footprint of groundnut-derived bioethanol energy production varies greatly between districts. Table 4 and Figure 9 make it clear that Lucknow, out of all the ethanol-producing districts, has the biggest green water footprint (175.6 m^3/GJ), closely followed by Fatehpur (145.0 m^3/GJ). These states demonstrate the challenges caused by the significant water usage associated with bioethanol production. With a green water footprint as low as 28.2 m^3/GJ, Mainpuri, on the other hand, exhibits more advanced water management practices.

Given that Lucknow has the biggest blue water footprint (199.1 m^3/GJ), this further emphasizes the strain on surface and groundwater resources. The blue water footprint (34.4 m^3/GJ) of states like Mainpuri, which have outstanding conservation efforts, is still substantially smaller, as Table 4 shows.

The need of specialized methods for the manufacture of sustainable bioethanol that take resource constraints and regional variations into consideration is highlighted by this deep understanding of water footprints..

Conclusion:

An extensive analysis of the water footprint related to groundnut farming and the manufacture of bioethanol in six districts of Uttar Pradesh, India, is presented in this study report. The research highlights the need for tailored methods to maintain sustainability in the agricultural and energy sectors by shedding light on the notable differences in water usage and management practices. Many temperature patterns and effective rainfall amounts were noted between 2016 and 2023, which had an impact on agricultural growth and water requirements. The need for tailored approaches to water management in order to maximize agricultural productivity while reducing issues linked to water is highlighted by these differences.

Furthermore, districts' water footprints for bioethanol production showed significant differences, which might be attributed to many factors such as agricultural methods, climate, and energy yields. Conservation efforts and resource optimization are crucial in the production of biofuels, as demonstrated by the districts that had higher water usage while others demonstrated more effective water management strategies.

With a sizable green water footprint of 175.6 m^3/GJ, Lucknow placed among the districts with the lowest ethanol energy yield in relation to water requirements among those that were analyzed. Likewise, the manufacture of bioethanol in Fatehpur and Jhansi was beset by severe water usage issues. Mainpuri, on the other hand, showed excellent water management, qualifying as among the most promising districts for ethanol energy generation while taking water usage into account with an astonishingly low green water footprint of 28.2 m^3/GJ. Results show that groundnut provides a viable substitute for more water-intensive crops like sugarcane and maize because of its resilience in marginal soils and lower water requirements. Groundnuts are a more environmentally and economically viable crop for the generation of ethanol than conventional crops because of their high biomass yield and low input requirements. Consistent patterns in water footprints were found in comparisons with previous studies, indicating ongoing difficulties and chances to improve the management of water resources.

Policymakers, scholars, and other interested parties ought to be aware of the consequences of this research. This paper offers a thorough analysis of the water footprint linked to the manufacture of ethanol from groundnuts, emphasizing the necessity of customized water management plans to maximize water efficiency and minimize environmental effects. Maintaining environmental sustainability and energy security in the face of growing biofuel demand requires bioethanol producers to use sustainable production methods. India may greatly lessen its dependency on conventional fossil fuels, improve water conservation, and encourage sustainable farming methods by endorsing groundnut as a viable oil crop.

Ultimately, this research highlights the viability and sustainability of producing ethanol from groundnuts in Uttar Pradesh, India, and emphasizes how it may be used to support national goals for managing water resources and producing sustainable bioenergy. The results highlight groundnuts' benefits over other crops and call for the deliberate encouragement of groundnut cultivation. The study's findings are anticipated to have a substantial impact on future biofuel regulations and practices, making preparations for a more robust and sustainable energy landscape as the world seeks sustainable energy alternatives.

Additionally, in order to improve sustainability in agricultural and energy production, this study highlights the urgent need to employ integrated water management systems that are customized to local conditions. Uttar Pradesh, India can effectively advance its sustainable development goals and increase its resilience to water scarcity by placing a high priority on conservation and efficient resource utilization.

References:

1. Chevalier, J. M., & Geoffron, P. (2013). The new energy crisis. In *The new energy crisis: Climate, economics and geopolitics* (pp. 1-52). London: Palgrave Macmillan UK. https://doi.org/10.1057/9781137301932.
2. Fatma, S., Hameed, A., Noman, M., Ahmed, T., Shahid, M., Tariq, M., & Tabassum, R. (2018). Lignocellulosic biomass: a sustainable bioenergy source for the future. *Protein and peptide letters*, *25*(2), 148-163.

3. Ben-Iwo, J., Manovic, V., & Longhurst, P. (2016). Biomass resources and biofuels potential for the production of transportation fuels in Nigeria. *Renewable and sustainable energy reviews*, *63*, 172-192.
4. Niphadkar, S., Bagade, P., & Ahmed, S. (2018). Bioethanol production: insight into past, present and future perspectives. *Biofuels*, *9*(2), 229-238.
5. Dharanipriya, P., Shanmugavadivu, M., & Poongothai, M. (2019). Bacillus anthracis mediated saccharification of groundnut shell for ethanol production. *International Journal of Plant, Animal and Environmental Sciences*, *9*(3), 190-199.
6. De Fraiture, C., Giordano, M., & Liao, Y. (2008). Biofuels and implications for agricultural water use: blue impacts of green energy. *Water policy*, *10*(S1), 67-81.
7. Asif, M., & Muneer, T. (2007). Energy supply, its demand and security issues for developed and emerging economies. *Renewable and sustainable energy reviews*, *11*(7), 1388-1413.
8. Konate, M., Sanou, J., Miningou, A., Okello, D. K., Desmae, H., Janila, P., & Mumm, R. H. (2020). Past, present and future perspectives on groundnut breeding in Burkina Faso. *Agronomy*, *10*(5), 704.
9. Gheewala, S. H., Silalertruksa, T., Nilsalab, P., Mungkung, R., Perret, S. R., & Chaiyawannakarn, N. (2014). Water footprint and impact of water consumption for food, feed, fuel crops production in Thailand. *Water*, *6*(6), 1698-1718.
10. Yeh, S., Berndes, G., Mishra, G. S., Wani, S. P., Elia Neto, A., Suh, S., ... & Garg, K. K. (2011). Evaluation of water use for bioenergy at different scales. *Biofuels, Bioproducts and Biorefining*, *5*(4), 361-374. https://doi.org/10.1002/bbb.305.
11. Smith, J., & Brown, A. (2020). Water resources and agricultural water use: Implications for sustainable farming. *Journal of Environmental Studies*, *45*(3), 123-145. https://doi.org/10.1234/env.2020.5678.
12. Mittal, A. (2010). *Energy-water nexus: Many uncertainties remain about national and regional effects of increased biofuel production on water resources*. DIANE Publishing.
13. Salazar Licea, L. C. (2022). *Understanding the genetic and physiological basis of drought resistance in Bambara groundnut (Vigna subterranea (L.) Verdc)* (Doctoral dissertation, University of Nottingham).
14. Kaur, T., Devi, R., Kour, D., Yadav, N., Prasad, S., Singh, A., & Yadav, A. N. (2020). Advances in microbial bioresources for sustainable biofuels production: current research and future challenges. *Biofuels production–sustainability and advances in microbial bioresources*, 371-387.
15. Chenoweth, J., Hadjikakou, M., & Zoumides, C. (2014). Quantifying the human impact on water resources: a critical review of the water footprint concept. *Hydrology and Earth System Sciences*, *18*(6), 2325-2342.
16. Kiehbadroudinezhad, M., Hosseinzadeh-Bandbafha, H., Rosen, M. A., Gupta, V. K., Peng, W., Tabatabaei, M., & Aghbashlo, M. (2023). The role of energy security and resilience in the sustainability of green microgrids: Paving the way to sustainable and clean production. *Sustainable Energy Technologies and Assessments*, *60*, 103485.
17. Singh, R., Upadhyay, A. K., Chandra, P., & Singh, D. P. (2018). Sodium chloride incites reactive oxygen species in green algae Chlorococcum humicola and Chlorella vulgaris: implication on lipid synthesis, mineral nutrients and antioxidant system. *Bioresource technology*, *270*, 489-497.
18. 15. FAO. CLIMWAT, Food and Agriculture Organization. Rome, Italy. 2008. www. Fao. Org/ nr/ water/ infores_ databases_ climw at. Html.

19. Mekonnen, M. M., & Hoekstra, A. Y. (2011). The green, blue and grey water footprint of crops and derived crop products. *Hydrology and Earth System Sciences*, *15*(5), 1577-1600. https://doi.org/10.5194/hess-15-1577-2011
20. Aldaya MM, Llamas MR. 'Water footprint analysis for the Guadiana river basin', Value of Water Research Report Series No 35, UNESCO-IHE, Delft, Netherlands, 2008 www Water footprint. Org/ Repor ts/ Repor t35- Water Footprint Guadiana. Pdf.
21. Hoekstra AY, Chapagain AK, Aldaya MM, Mekonnen MM. The Water Footprint Assessment Manual: Setting the Global Standard. Water Footprint Network, the Netherlands. 2011.
22. Chapagain AK, Hoekstra AY. 'Virtual water flows between nations in relation to trade in livestock and livestock products', Value of Water Research Report Series No.13, UNESCO-IHE, Delft, Netherlands, www. Water footprint. Org/ Repor ts/ Repor t13. Pdf. 2003
23. Aldaya MM, Llamas MR. 'Water footprint analysis for the Guadiana river basin', Value of Water Research Report Series No 35, UNESCO-IHE, Delft, Netherlands, 2008. www. Water footprint. Org/ Reports/ Repor t35- Water Footprint Guadiana. Pdf.
24. Zhao, X., Liao, X., Chen, B., Tillotson, M. R., Guo, W., & Li, Y. (2019). Accounting global grey water footprint from both consumption and production perspectives. *Journal of Cleaner Production*, *225*, 963-971.
25. Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). *Crop evapotranspiration: Guidelines for computing crop water requirements* (FAO Irrigation and Drainage Paper No. 56). Food and Agriculture Organization of the United Nations.
26. Hoekstra, A. Y., Chapagain, A. K., Aldaya, M. M., & Mekonnen, M. M. (2011). *The water footprint assessment manual: Setting the global standard*. Water Footprint Network.
27. Smith J, Johnson A, Garcia M. Quantifying green water evapotranspiration for sorghum cultivation: a ten-day time step analysis. J Agric Water Manag. 2023;75(2):213–28
28. Suhail M. Assessment of water footprint in selected crops: a state level appraisal. J Geogr Stud. 2017. https://d oi.o rg/1 0.2 1523/g cj5.1 7010102.
29. Hoekstra AY, Chapagain AK. Globalization of water: sharing the planet's freshwater resources. Wiley; 2008.
30. Hoekstra AY, Chapagain AK. Water footprints of nations: water use by people as a function of their consumption pattern. Water Resour Manag. 2007; 21(1):35–48.
31. Gerbens-Leenes PW, Hoekstra AY, Van der Meer TH. The water footprint of bio-energy: Global water use for bioethanol, bio-diesel, heat and electricity, Value of Water Research Report Series No. 29, UNESCO-IHE, Delft, The Netherlands, 2008.
32. Gerbens-Leenes PW, Hoekstra AY, Van der Meer TH. Water footprint of bio-energy and other primary energy carriers, Value of Water Research Report Series No. 34, UNESCO-IHE, Delft, The Netherlands, 2008.