WATER FOOTPRINT IN COTTON 2020-2024: A GLOBAL ANALYSIS

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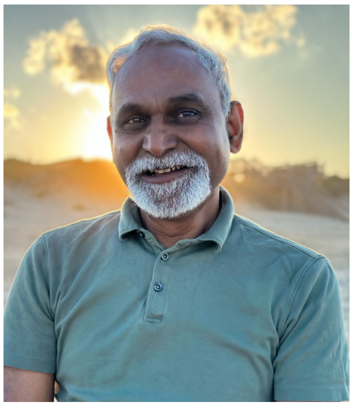

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Introduction

Water is a vital resource for agriculture, and its efficient use is critical for sustainable crop production. Cotton, like any other crop, has specific water requirements that vary depending on climatic conditions, soil properties, and growth stages. Adequate soil moisture is particularly crucial during critical growth stages, such as flowering and boll formation, when water deficits can severely reduce yields (Pettigrew, 2004).

Rainwater is the main source of water for crops, but its availability is often erratic, leading to soil moisture deficits that necessitate supplemental irrigation. In arid and semi-arid regions, where rainfall is insufficient to meet crop needs, irrigation becomes indispensable. However, even in regions with seemingly adequate rainfall, mismatches between crop water requirements and soil moisture availability can occur due to poor soil conditions, runoff, or seepage. Conversely, excessive rainfall during the crop season, especially under poor drainage conditions, can lead to waterlogging and yield losses (Bange *et al.*, 2004).

A critical challenge in cotton production is the excessive use of irrigation water; farmers often apply more than the crop requires, resulting in inefficiencies and waste. This study evaluates daily weather parameters to calculate crop evapotranspiration (*ETc*), crop water requirements, effective rainfall, and irrigation water applied, aiming to identify opportunities for optimizing irrigation water use. Because rainfall is a natural resource beyond human control, the focus should be on practical, water-saving irrigation strategies that are within human control. Emphasis should be placed on harvesting and conserving rainwater while enhancing irrigation efficiency through precision technologies to support sustainable cotton production.

Methodology

This study analyzed water usage data from 271 cotton-growing states or provinces across 38 major cotton-producing countries from 2020–2024.

The analysis focused on key parameters such as irrigated area, yield, effective precipitation (*Pe*), *ETc*, soil water balance (*St*), critical moisture threshold (S_{crit}), irrigation water requirements (*IWR*), irrigation water applied, excess irrigation, irrigation water footprint (WR_{irri}), rainwater footprint (WF_{rain}) and the total water footprint (WF_{total}).

Daily weather data for the 271 locations was obtained from the World Weather Online API (https://www.worldweatheronline.com).

ETc was calculated at daily intervals and subsequently aggregated to monthly values, while other parameters — including effective precipitation (*Pe*), soil water balance (*St*), critical moisture threshold (S_{crit}), and irrigation water requirements (*IWR*) — were computed directly at monthly intervals, using CROPWAT 8.0 (FAO) and the methodologies outlined in FAO Irrigation and Drainage Paper No. 56 (Allen *et al.*, 1998).

National data on water withdrawals was sourced from the AQUASTAT-FAO database. The total amount of water withdrawals for agriculture was calculated for 2020 and 2021, and projections were made for 2022-2024 using data from 2018-2021 on "total water withdrawals" and "agricultural water withdrawal as a percentage of total water withdrawal." Data on cotton area, irrigated area under cotton, cotton production, types of irrigation methods, and irrigation water applied were collected from official government websites and records, supplemented by insights from interviews with subject matter experts, researchers, and government representatives.

Data on irrigation water withdrawals for cotton cultivation was provided by a few countries based via official estimates. Some countries provided detailed information on the number of irrigations applied per season, approximate quantity of water used per irrigation, and the methods used (flood, furrow, sprinkler, and drip), which helped estimate the amount of water applied. Where such data was unavailable, it was assumed that the amount of irrigation water applied exceeded the cotton crop irrigation water requirement (*IWR*) by a factor of 1 to 1.2 times, depending on the method of application, accounting for potential losses due to application methods, runoff, and seepage. This assumption accounts for potential inefficiencies in water application, particularly in systems using less precise irrigation methods such as spate/flood or furrow systems. The amount of water applied through flood irrigation was estimated to be 1.2 times the calculated crop irrigation water requirement (*IWR*), while furrow irrigation applied approximately 1.15 times the required amount. In contrast, sprinkler and drip irrigation systems were assumed to apply water precisely aligned with the crop water requirements, reflecting their higher efficiency and precision.

Reference Crop Evapotranspiration (*ETo*)

ETo was calculated using the FAO Penman-Monteith equation, representing the evapotranspiration from a hypothetical reference crop. It integrates meteorological data to estimate water loss due to evaporation and transpiration.

FAO Penman-Monteith equation:

$$ET_0 = \frac{0.408\Delta(R_n - G) + \frac{900}{T+273}\gamma U_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)}$$

Where:

ETo = reference evapotranspiration [mm day^{-1}],
Rn = net radiation at the crop surface [MJ m^{-2} day^{-1}],
G = soil heat flux density [MJ m^{-2} day-1],
T = mean daily air temperature at 2 m height [°C] = (Tmax + Tmin) / 2
U_2 = wind speed at 2 m height [m s-1],
es = saturation vapor pressure [kPa] = [e^0(Tmax) + e^0(Tmin)] / 2
e^0(T) = 0.6108 * exp(17.27 * T / (T + 237.3))
ea = actual vapor pressure [kPa] = es * (RH / 100)
es - ea = saturation vapor pressure deficit [kPa],
D = slope vapor pressure curve [kPa °C-1] = 4098 * es / (T + 237.3)2
g = psychrometric constant [kPa °C-1] = (cp * P) / (ε * λ)
cp = 1.013 × 10^{-3} MJ/kg/°C, ε = 0.622 and λ = 2.45 MJ/kg

Potential Crop Evapotranspiration (*ETc*)

Potential crop evapotranspiration (*ETc*) for cotton was calculated using the FAO-56 methodology (Allen *et al.*, 1998).

The crop coefficient (*Kc*) represents specific cotton crop coefficient values based on growth stages: 0.35 for the seedling stage (0–30 days), 0.58 for peak squaring stage (30–60 days), 0.89 for peak flowering stage (60–90 days), 1.11 for peak green boll stage (90–120 days), 0.54 for maturation stage (120–150 days), and 0.20 for harvest stage (150–180 days).

These values were multiplied by the reference evapotranspiration (*ETo*), computed using the FAO Penman-Monteith equation, to obtain *ETc* as follows:

ETc = *Kc* x *ETo*

Effective Precipitation (*Pe*)

Effective precipitation (*Pe*) was calculated using the FAO-56 methodology (Allen *et al.*, 1998), accounting for soil water retention and drainage losses of rainwater within the cotton season, computed by *Kp* coefficient values.

Kp is the coefficient for effective precipitation, influenced by soil type, ground cover, crop stage, and climatic conditions.

The *Kp* values applied for different soil types were as follows: clay (0.45), clay loam (0.60), silt loam (0.70), loam (0.78), loamy sand (0.80), sandy loam (0.85), and coarse sand (0.90), with other soil types ranging between 0.70 and 0.85.

Effective precipitation (*Pe*) was then calculated as:

Pe = *P* x *Kp*

Where:

Pe = Effective precipitation (mm)
P = Total monthly rainfall (mm) within the cotton season
Kp = Coefficient for effective precipitation

Irrigation Water Requirement (*IWR*)

The irrigation water requirement (*IWR*) was calculated using a soil depletion approach following FAO-56 guidelines, incorporating a dynamic water stress coefficient (*Ks*) to account for crop water stress under varying soil moisture conditions.

Readily Available Water (*RAW*)

The threshold for irrigation triggering, was calculated as follows:

RAW = *p* × *TAW*

Where:

p = crop-stage-specific depletion factor set at 0.45 for the seedling stage, 0.50 for squaring stage, 0.55 for flowering stage, 0.60 for green boll stage, 0.65 for maturation, and 0.70 for harvest.

TAW = Total Available Water -equivalent to the field capacity (*FC*) for a 1.0 m root zone -was defined for each soil type (e.g., clay loam (400 mm), clay (350 mm), coarse sand (100 mm), loam (200 mm), loamy sand (100 mm), sandy loam (150 mm), silt loam (250 mm), and silty clay (350 mm)).

Root Zone Depletion (*Dr*)

$Dr = TAW - St$

Where:

St = soil moisture storage

St was updated daily via water balance as follows:

$St = St-1 + Pe + I - ETa$

Where:

St = Soil moisture storage (mm)
ETc = Potential crop ET (mm)
ETa = Actual ET adjusted for stress (mm)
Pe = Effective precipitation (mm)
I = Irrigation applied (mm)

Stress Coefficient (*Ks*)

$$K_s = \begin{cases} 1 & \text{if } D_r \leq \text{RAW} \quad \text{(no stress)} \\ \frac{\text{TAW}-D_r}{(1-p)\times\text{TAW}} & \text{if } D_r > \text{RAW} \quad \text{(stress)} \end{cases}$$

Actual ET (*ETa*) adjusted for stress (mm)

$ETa = Ks \times ETc$

$$\text{IWR} = \begin{cases} \max(0, ET_c - P_e) & \text{if } D_r > \text{RAW} \\ 0 & \text{otherwise} \end{cases}$$

Water Footprints

Potential crop evapotranspiration (*ETc*) theoretically represents the total volume of water consumed by the crop during its growth cycle, commonly referred to as Crop Water Use (*CWU*).

This water is derived from two primary sources: the Irrigation Water Requirement (*IWR*) and the Effective Rainfall (*Pe*) received during the crop season.

For each location, the relative contributions of *IWR* and *Pe* were quantified as components of the seasonal *ETc*. These proportions form the basis for calculating the water footprint, which is a theoretical estimate of the volume of water—whether from irrigation or rainfall—used to produce one kilogram of lint.

The water footprint components were calculated using the methodology proposed by Hoekstra (2009). Specifically, the consumptive water footprint from irrigation ($WF_{IWR\text{-}ETc}$), the consumptive water footprint from effective precipitation ($WF_{Pe\text{-}ETc}$), and the total consumptive water use footprint ($WF_{total\text{-}ETc}$) were computed, all expressed in liters per kilogram of lint (L/kg lint). These calculations are based on crop evapotranspiration (*ETc*) reflecting consumptive water use rather than total irrigation withdrawals.

The following formulas (Hoekstra, 2009) were used to compute the water footprints for the consumptive irrigation water footprint ($WF_{IWR\text{-}ETc}$) component and the consumptive effective precipitation ($WF_{Pe\text{-}ETc}$) component of *ETc* and the total consumptive water use footprint ($WF_{total\text{-}ETc}$) expressed in L/Kg lint:

$WF_{IWR\text{-}ETc} = IWR\text{-}ETc / Y$
$WF_{Pe\text{-}ETc} = Pe\text{-}ETc / Y$
$WF_{total\text{-}ETc} = Total\text{-}ETc / Y$

The water footprint of irrigation water applied (WF_{irri}), expressed in liters of irrigation water per kilogram of lint yield (L/kg), was calculated as:

$WF_{irri} = Iw / Y$

Where:

Y = Yield of cotton lint (kg/ha).
IWR-ETc = *IWR* component of *ETc* (L/ha).
Pe-ETc = *Pe* component of *ETc* (L/ha).
Total-ETc = *IWR-ETc* + *Pe-ETc* (L/ha)
Iw = Total irrigation water applied (L/ha).

The *IWR* component of *ETc, Pe* component of *ETc*, total irrigation water applied (I) and the *ETc* values were converted from mm to L/ha using the conversion factor 1 mm = 10 m^3/ha.

Results

Summary results from the data analysis of 273 locations across 38 major cotton-growing countries over five years from 2020 to 2024 are presented in Table 1.

The data indicate that the average global cotton area was 30.98 million hectares, with 44.0% (13.61 million hectares) under irrigation. The global average cotton lint production over the five-year period was 25.54 million tonnes, with an average yield of 786 Kg/ha. Cotton occupies 2.21% of the arable land under arable crops, which totaled 1,397 million hectares (FAOSTAT).

Table-1: Summary of the Data on Area, Production, Rainfall, Evapotranspiration, Irrigation and Water Footprints from 271 Locations Across 38 Cotton-growing Countries. Data presented as Average Values over Five Years (2020–2024) with Standard Error of the Mean.

Area, Production & Irrigation	**Value** (Mean ± SE)
Total Cotton Area (Million Ha)	30.98 ± 0.4
Lint Yield (Kg/ha)	786 ± 8
Lint Production (Million Tonnes)	24.54 ± 0.24
Irrigated Area (Million Ha)	13.61 ± 0.2
% Irrigated Area	44% ± 0.5
Rainfall	
Effective Precipitation (mm/ha)	508 ± 6
Effective Rainwater in Cotton Farms (Trillion L)	157.4 ± 2.8
Evapotranspiration (mm/ha)	
Potential Crop Evapotranspiration (*ETc*)	565 ± 4
Adjusted Evapotranspiration (ET_{adj})	512 ± 5
Consumptive ET-green	370 ± 8
Consumptive ET-blue	142 ± 4
Types of Irrigation (%)	
Flood irrigation (%)	30 ± 1
Furrow irrigation (%)	43 ± 1
Sprinkler/Pivot irrigation (%)	8 ± 0
Drip/Trickle irrigation (%)	19 ± 1
Irrigation	
Irrigation Water Requirement (mm/ha)	344 ± 8
Irrigation Water Applied (mm/ha)	388 ± 8
Excess irrigation (mm/ha)	44 ± 3
Water Withdrawal for Agriculture (Trillion L)	2,760 ± 4.0
Total Irrigation Water Applied (Trillion L)	52.77 ± 0.9
Water Footprints (L/Kg Lint)	
Consumptive Green water Footprint	4,690 ± 128
Consumptive Blue water Footprint	1,593 ± 31
Consumptive Total Water Footprint	6,238 ± 112
Applied Irrigation Water Footprint	2,158 ± 40

Footnotes

- **Effective Precipitation (mm/ha):** The portion of total rainfall during a crop season that is available for plant use, after accounting for losses due to runoff, evaporation, and deep percolation.
- **Effective Rainwater in Cotton Farms (Trillion L):** Total volume of effective precipitation (rainwater) utilized by cotton crops.
- **Potential Crop Evapotranspiration (*ETc*, mm/ha):** The total amount of water lost through evaporation from the soil and transpiration from plants during a specific period, typically measured over a crop's growing season.
- **Adjusted Crop Evapotranspiration (*ETc*, mm/ha):** The actual water used by a crop under non-ideal conditions, accounting for soil moisture stress (partial depletion of available water), environmental factors (e.g., dry winds, salinity) and crop management practices (e.g., mulching, partial canopy cover).
- **rrigation Water Requirement** *(IWR) (ETc-Pe). (mm/ha):* The total amount of irrigation water needed by a crop to meet its evapotranspiration needs and ensure optimal growth over its growing season.
- **Irrigation Water Applied:** Irrigation water applied as mm/ha and total volume of irrigation water applied in trillion liters.
- **Excess irrigation:** Excess irrigation is the gap between theoretical demand (*IWR*) and actual field delivery of irrigation water applied (*IWA*), varying by irrigation method and soil type.
- **Consumptive ET-green:** The portion of crop water use supplied by effective precipitation (rainfall stored in the root zone)
- **Consumptive ET-blue:** The portion of crop water use supplied by irrigation (surface or groundwater)
- **1 mm rainfall** = 10 m^3/ha = 10,000 L/ha
- **Consumptive Blue water Footprint (L/Kg Lint):** Total irrigation water used by the plant (liters) ÷ Total lint produced (kg)
- **Consumptive Green water Footprint (L/Kg Lint):** Total 'effective precipitation' water use (liters) ÷ Total lint produced (kg)
- **Consumptive Total water Footprint (L/Kg Lint):** Total water used by the crop (effective precipitation + irrigation water used) in liters ÷ Total lint produced (kg)
- **Applied Irrigation Water Footprint:** Total irrigation water applied (liters) ÷ Total lint produced (kg)
- **Water Withdrawal for Agriculture (FAO) (Trillion Liters):** Value presented is minus water withdrawn for aquaculture and livestock.

Despite this, cotton's consumptive use of irrigation water (43.99 trillion liters) accounted for only 1.59% of the of the total irrigation water (2,757 trillion liters) used by arable crops (AQUASTAT, FAO). Additionally, the annual average applied irrigation water (52.77 trillion liters) accounted for only 1.91% of the total irrigation water used by arable crops. The annual average effective rainwater received on cotton farms was 157.4 trillion liters per season.

The annual average water footprint of the cotton crop was 6,238 liters to produce one kilogram of lint, comprising 4,690 liters/Kg lint as rainwater footprint and 1,593 liters/kg lint as blue water footprint from irrigation water.

However, the applied irrigation water footprint was 2,158 liters/kg, which indicates a possibility to save 565 liters of irrigation water per Kg cotton lint, which in effect translates to saving of about 17.5 trillion liters of irrigation water. The average annual effective rainfall received in cotton farms was 508 mm (5.08 million liters per hectare), while the average annual potential crop evapotranspiration (*ETc*) was 565 mm. The adjusted crop evapotranspiration (ET_{adj}) was 512mm, comprising of 370mm as green-evapotranspiration (ET-green) derived from effective rain and 142mm as blue-evapotranspiration (ET-blue) from irrigation. The computed crop irrigation requirement (*ETc-Pe*) was 344mm. The estimated annual average irrigation water applied in irrigated fields was 388 mm (3.88million liters per hectare).

In recent decades, cotton farming has increasingly adopted precision irrigation methods like furrow, sprinkler/pivot, and drip irrigation to enhance water efficiency and productivity. Currently, irrigation methods are distributed as follows:

- 29.6% flood,
- 43.0% furrow,
- 8.0% sprinkler/pivot, and
- 19.2% drip irrigation.

This shift reflects efforts to replace inefficient flood irrigation with more water-efficient alternatives, highlighting progress while emphasizing the need for further optimization to minimize water wastage and enhance sustainability in cotton production.

Discussion

Cotton production is often misrepresented, particularly regarding its water consumption, and is frequently labeled a "thirsty crop" based on calculations of water use efficiency, measured as the total water (rainfall plus irrigation) required to produce one kilogram of lint. This study revealed that the annual average water used to produce one kilogram of cotton lint was 6,239 liters, comprising 4,690 liters/kg lint as rainwater footprint and 1,593 liters/kg lint as blue water footprint from irrigation water.

While irrigation water is a critical focus in debates on water efficiency and conservation — as it is essential to avoid wastage and excessive use beyond crop needs — the emphasis on total water use (e.g., stating that 6,239 liters of water are required to produce one kilogram of lint) or even rainwater use alone (4,690 liters/kg lint) distorts the narrative. This approach misleads consumers into believing that cotton is unnecessarily water-intensive, which is a flawed argument for several reasons. First, crops and plants have a natural right to utilize rainwater, which is integral to their growth cycle. Second, humans have no control over rainfall, making it unreasonable to criticize a crop for using rainwater, as it is not a resource that can be managed or conserved like irrigation water. Third, excessive rainwater is detrimental to crop health and often leads to lower yields, further complicating the discussion.

Thus, focusing on rainwater use is misleading and serves no practical purpose in assessing water management. Instead, scientific analysis of irrigation water use can help identify regions where inefficiencies exist, enabling the adoption of precision technologies to optimize irrigation, reduce inefficiencies, and improve sustainability. Therefore, the focus should remain on improving irrigation practices rather than conflating the issue with rainwater use, which is both natural and beyond human control.

Studies by Mekonnen and Hoekstra (2010) and Safaya *et al.* (2016) estimated the global water footprint of cotton at 233 billion cubic meters per year, closely aligning with this study's estimate of 210.2 billion cubic meters per year (2020–2024), with 75.0% from rainwater and 25.0% from irrigation. The commonly cited figure that cotton accounts for 2.6% of global water use (Hoekstra & Chapagain, 2008) is proportionate to its land use, as cotton occupies 2.21% of global arable land (1,397 million hectares) and closely aligns with this study's finding that consumptive irrigation water used by cotton accounts for 1.59% and applied irrigation water use accounts for 1.91% of the total water withdrawn (2,757 Trillion liters) for agriculture (minus aquaculture and livestock). Additionally, 56.0% of global cotton acreage (17.4 million hectares) is rainfed, contributing to more than 45.0% of total cotton production, further countering the "thirsty crop" misconception.

In recent years, water-use efficiency has improved significantly, with traditional flood irrigation increasingly replaced by drip and sprinkler systems. Additionally, growing awareness of regenerative practices—such as no-till farming, cover cropping, mulching, and biochar application—is further enhancing soil moisture retention, reducing runoff, and promoting sustainability, strengthening efforts in water conservation. This study underscores the need to shift the debate on cotton's water use from rainwater inclusion to irrigation optimization. By focusing on irrigation efficiency, stakeholders can achieve higher yields, increased profitability, and improved environmental sustainability, offering a balanced and practical approach to water use in cotton production.

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Table-2: Country-wise Data (mm/ha) of Consumptive Water Use, Evapotranspiration, Effective Precipitation and Irrigation. Data Presented as Average Values of 5 years (2020-2024), with Standard Error of the Mean (Mean ± SE)

Country	Consumptive Water Use (mm/ha, Mean ± SE)			(mm/ha, Mean ± SE)			
	ET-green	*ET-blue*	*ET-adj*	*ETc*	*Pe*	*IWR*	*IWA*
Argentina	466 ± 18	40 ± 8	506 ± 24	623 ± 17	509 ± 16	112 ± 11	200 ± 37
Australia	412 ± 24	155 ± 36	567 ± 14	595 ± 17	426 ± 30	16 ± 10	229 ± 49
Bangladesh	471 ± 8	0 ± 0	471 ± 8	476 ± 7	932 ± 40	0 ± 0	18 ± 10
Benin	298 ± 24	0 ± 0	298 ± 24	582 ± 5	725 ± 34	0 ± 0	70 ± 6
Brazil	513 ± 14	2 ± 2	515 ± 14	536 ± 23	696 ± 19	4 ± 5	42 ± 16
Burkina Faso	449 ± 9	0 ± 0	449 ± 9	499 ± 12	715 ± 24	0 ± 0	18 ± 2
Cameroon	460 ± 27	0 ± 0	460 ± 27	548 ± 11	619 ± 35	0 ± 0	55 ± 12
Chad	413 ± 19	0 ± 0	413 ± 19	483 ± 7	665 ± 24	0 ± 0	24 ± 5
China	172 ± 16	370 ± 18	543 ± 11	598 ± 13	188 ± 17	460 ± 22	414 ± 26
Colombia	393 ± 2	20 ± 9	413 ± 7	419 ± 10	599 ± 23	50 ± 28	98 ± 34
Cote d'Ivoire	370 ± 9	0 ± 0	370 ± 9	370 ± 9	621 ± 32	0 ± 0	0 ± 0
Egypt	4 ± 2	705 ± 14	708 ± 14	779 ± 17	4 ± 2	776 ± 18	823 ± 22
Ethiopia	365 ± 4	0 ± 0	365 ± 4	404 ± 4	761 ± 33	7 ± 4	44 ± 15
Greece	182 ± 26	298 ± 28	480 ± 10	517 ± 12	182 ± 26	342 ± 30	293 ± 21
India	426 ± 10	35 ± 2	461 ± 11	487 ± 7	620 ± 17	128 ± 4	240 ± 10
Indonesia	316 ± 46	183 ± 29	499 ± 17	603 ± 9	324 ± 53	200 ± 41	266 ± 28
Iran	143 ± 27	494 ± 33	637 ± 9	695 ± 14	143 ± 27	574 ± 42	505 ± 36
Kazakhstan	159 ± 17	531 ± 23	691 ± 14	760 ± 16	159 ± 17	625 ± 26	570 ± 25
Kenya	446 ± 7	10 ± 7	456 ± 7	466 ± 8	624 ± 42	27 ± 14	44 ± 16
Malawi	437 ± 13	5 ± 8	442 ± 15	510 ± 12	648 ± 38	8 ± 13	117 ± 16
Mali	444 ± 16	0 ± 0	444 ± 16	500 ± 14	803 ± 19	0 ± 0	52 ± 5
Mexico	183 ± 21	503 ± 25	686 ± 11	748 ± 14	183 ± 21	585 ± 27	648 ± 28
Mozambique	363 ± 11	0 ± 0	363 ± 11	398 ± 6	637 ± 36	0 ± 0	0 ± 0
Myanmar	448 ± 12	0 ± 0	448 ± 12	453 ± 12	605 ± 24	3 ± 4	42 ± 13
Nigeria	412 ± 18	3 ± 2	415 ± 17	591 ± 13	608 ± 38	32 ± 18	235 ± 24
Pakistan	394 ± 32	333 ± 43	727 ± 12	772 ± 16	394 ± 32	410 ± 52	467 ± 58
South Africa	419 ± 25	130 ± 27	549 ± 6	614 ± 10	436 ± 24	222 ± 43	332 ± 33
Spain	85 ± 18	491 ± 22	576 ± 6	655 ± 9	85 ± 18	566 ± 25	508 ± 21
Sudan	168 ± 21	120 ± 2	288 ± 47	706 ± 33	422 ± 36	581 ± 34	698 ± 35
Tanzania	452 ± 23	0 ± 0	452 ± 23	519 ± 11	749 ± 32	86 ± 32	180 ± 60
Togo	416 ± 5	0 ± 0	416 ± 5	443 ± 7	712 ± 18	0 ± 0	0 ± 0
Türkiye	94 ± 18	558 ± 4	653 ± 11	727 ± 14	94 ± 18	646 ± 27	555 ± 25
Turkmenistan	42 ± 9	792 ± 19	834 ± 11	928 ± 14	42 ± 9	952 ± 21	890 ± 24
Uganda	431 ± 15	9 ± 5	440 ± 11	463 ± 13	593 ± 13	0 ± 0	0 ± 0
USA	448 ± 18	89 ± 22	537 ± 4	586 ± 16	499 ± 27	166 ± 33	283 ± 28
Uzbekistan	64 ± 11	642 ± 2	706 ± 12	812 ± 16	64 ± 11	781 ± 26	716 ± 24
Zambia	313 ± 15	0 ± 0	313 ± 15	469 ± 20	675 ± 46	0 ± 0	0 ± 0
Zimbabwe	327 ± 28	1 ± 1	328 ± 28	488 ± 24	543 ± 53	0 ± 0	0 ± 0
World	**370 ± 8**	**142 ± 4**	**512 ± 5**	**565 ± 4**	**508 ± 6**	**344 ± 7**	**388 ± 8**

Footnotes:

- mm/ha: 1 mm = 1 L per M^2 = 10,000 L per hectare
- Excess Irrigation (mm/ha): Excess irrigation water applied beyond crop requirements = Irrigation applied – crop water requirement
- World: global averages calculated across all countries listed

Table-3: Water (Billion Liters) in Cotton Farms, Water Footprint of Irrigation and Consumptive Water Use. Country Data presented as Average Values of 5 years (2020-2024), with Standard Error of the Mean (Mean ± SE)

Country	Water Footprints (L/Kg Lint, Mean ± SE)				Water Withdrawal Agriculture Mean (BL)	Water Used in Cotton Farms Mean ± SE (BL)	
	Applied Irrigation	Consumptive Water Footprints					
		Blue Water	Green Water	Total		irrigation Water	Effective Rainwater
Argentina	542 ± 88	180 ± 31	7,274 ± 238	7,454 ± 256	27,930 ± 0	183 ± 44	2,688 ± 174
Australia	876 ± 199	631 ± 143	1,889 ± 135	2,520 ± 79	9,090 ± 431	912 ± 92	2,037 ± 361
Bangladesh	28 ± 14	0 ± 0	8,744 ± 1,557	8,744 ± 1,557	31,500 ± 0	1 ± 0	325 ± 39
Benin	15 ± 1	0 ± 0	6,178 ± 461	6,178 ± 461	45 ± 0	4 ± 0	4,219 ± 171
Brazil	20 ± 8	2 ± 2	2,938 ± 39	2,939 ± 39	36,293 ± 75	59 ± 20	11,655 ± 871
Burkina Faso	4 ± 0	0 ± 0	10,207 ± 739	10,207 ± 739	421 ± 0	1 ± 0	3,932 ± 358
Cameroon	15 ± 3	0 ± 0	7,739 ± 521	7,739 ± 521	737 ± 0	2 ± 0	1,425 ± 95
Chad	2 ± 0	0 ± 0	20,821 ± 1,274	20,821 ± 1,274	672 ± 0	0 ± 0	1,559 ± 113
China	1,865 ± 123	1,767 ± 91	873 ± 69	2,640 ± 37	361,677 ± 339	10,984 ± 738	5,592 ± 512
Colombia	292 ± 106	142 ± 78	4,072 ± 295	4,214 ± 339	16,086 ± 155	3 ± 1	68 ± 6
Cote d'Ivoire	0 ± 0	0 ± 0	9,124 ± 1,391	9,124 ± 1,391	600 ± 0	0 ± 0	2,585 ± 0
Egypt	11,274 ± 535	9,657 ± 378	50 ± 28	9,707 ± 400	61,350 ± 0	917 ± 110	4 ± 2
Ethiopia	224 ± 77	0 ± 0	5,447 ± 224	5,447 ± 224	9,000 ± 0	12 ± 4	605 ± 51
Greece	2,310 ± 151	2,342 ± 174	1,493 ± 351	3,834 ± 317	8,107 ± 0	688 ± 68	445 ± 52
India	1,987 ± 114	710 ± 37	9,656 ± 265	10,366 ± 286	688,000 ± 0	10,974 ± 609	77,626 ± 3,561
Indonesia	4,243 ± 852	3,064 ± 530	10,055 ± 2,639	13,119 ± 3,002	177,171 ± 0	1 ± 0	3 ± 0
Iran	5,584 ± 430	5,590 ± 425	1,752 ± 330	7,342 ± 275	86,000 ± 0	399 ± 36	125 ± 24
Kazakhstan	5,506 ± 227	5,167 ± 194	1,701 ± 183	6,868 ± 150	11,842 ± 136	594 ± 22	184 ± 24
Kenya	162 ± 185	81 ± 94	40,199 ± 13,501	40,279 ± 13,585	2,937 ± 0	0 ± 0	65 ± 7
Malawi	138 ± 22	8 ± 11	11,613 ± 548	11,621 ± 542	1,166 ± 0	1 ± 0	98 ± 17
Mali	16 ± 2	0 ± 0	12,291 ± 958	12,291 ± 958	5,000 ± 0	3 ± 1	4,524 ± 861
Mexico	3,607 ± 230	2,820 ± 210	1,086 ± 110	3,906 ± 173	66,704 ± 113	921 ± 101	277 ± 46
Mozambique	0 ± 0	0 ± 0	13,931 ± 947	13,931 ± 947	1,005 ± 0	0 ± 0	750 ± 0
Myanmar	285 ± 86	0 ± 0	6,904 ± 211	6,904 ± 211	29,570 ± 0	31 ± 10	1,026 ± 34
Nigeria	198 ± 16	17 ± 9	26,639 ± 1,942	26,656 ± 1,934	4,549 ± 0	14 ± 2	2,764 ± 243
Pakistan	7,116 ± 900	5,108 ± 596	6,261 ± 1,314	11,368 ± 1,574	172,400 ± 0	9,399 ± 869	8,270 ± 955
South Africa	1,534 ± 116	876 ± 168	4,732 ± 443	5,609 ± 312	11,818 ± 40	25 ± 2	80 ± 4
Spain	5,274 ± 1,883	5,095 ± 1774	1,067 ± 410	6,162 ± 2,121	17,367 ± 5	229 ± 1	46 ± 12
Sudan	2,466 ± 623	1,753 ± 438	3,415 ± 765	5,168 ± 852	25,910 ± 0	349 ± 83	1,215 ± 312
Tanzania	1 ± 0	0 ± 0	27,150 ± 1,600	27,150 ± 1,600	4,425 ± 0	0 ± 0	2,799 ± 324
Togo	0 ± 0	0 ± 0	14,323 ± 518	14,323 ± 518	46 ± 0	0 ± 0	595 ± 0
Türkiye	2,978 ± 112	2,967 ± 107	539 ± 120	3,506 ± 140	46,268 ± 164	2,419 ± 227	438 ± 91
Turkmenistan	23,896 ± 940	21,264 ± 867	1,128 ± 247	22,392 ± 747	16,022 ± 11	4,831 ± 258	228 ± 48
Uganda	0 ± 0	0 ± 0	14,139 ± 1,091	14,139 ± 1,091	259 ± 0	0 ± 0	311 ± 43
USA	910 ± 92	447 ± 97	4,668 ± 289	5,115 ± 204	163,007 ± 0	2,889 ± 215	16,501 ± 2,150
Uzbekistan	8,875 ± 413	8,073 ± 367	1,004 ± 160	9,078 ± 223	41,785 ± 1,314	5,929 ± 179	671 ± 118
Zambia	0 ± 0	0 ± 0	12,842 ± 5,176	12,842 ± 5,176	1,152 ± 0	0 ± 0	511 ± 0
Zimbabwe	0 ± 0	0 ± 0	15,071 ± 2,834	15,071 ± 2,834	4,146 ± 34	0 ± 0	1,170 ± 106
World	**2,158 ± 40**	**1,593 ± 31**	**4,690 ± 128**	**6,283 ± 112**	**2,758,999 ± 4,000**	**52,775 ± 962**	**157,413 ± 2,810**

Footnotes:

- World: Global averages represent mean values across all listed countries, with the exception of water withdrawal data (FAO). * For this metric, the total world figure includes water withdrawal from both cotton-growing and non-cotton-growing countries.

Table-4: Distribution of Irrigation Technologies: Country-wise Data presented as Average Values of 5 years (2020-2024), with Standard Error of the Mean (Mean ± SE)

	Area ‘000 Hectares	Yield Kg/ha	Production ‘000 Tonnes	Irrigated Area Mean ± SE		% Distribution of Irrigation Technologies (Mean ± SE)			
	Mean ± SE	Mean ± SE	Mean ± SE	‘000 Ha	%	Flood	Furrow	Sprinkler	Drip
Argentina	528 ± 41	640, ± 29	338 ± 23	92 ± 6	18	31 ± 2	45 ± 1	20 ± 2	5 ± 1
Australia	478 ± 56	2,179 ± 61	1,041 ± 118	398 ± 46	83	8 ± 1	67 ± 1	18 ± 0	7 ± 1
Bangladesh	35 ± 4	539 ± 87	19 ± 5	3 ± 1	7	13 ± 2	87 ± 2	0 ± 0	0 ± 0
Benin	582 ± 26	483 ± 14	281 ± 15	6 ± 0	1	100 ± 0	0 ± 0	0 ± 0	0 ± 0
Brazil	1,674 ± 102	1,746 ± 47	2,923 ± 232	139 ± 8	9	15 ± 2	54 ± 1	26 ± 1	4 ± 1
Burkina Faso	550 ± 56	440 ± 30	242 ± 32	5 ± 0	1	100 ± 0	0 ± 0	0 ± 0	0 ± 0
Cameroon	230 ± 3	595 ± 12	137 ± 4	4 ± 0	2	100 ± 0	0 ± 0	0 ± 0	0 ± 0
Chad	234 ± 20	198 ± 6	46 ± 3	0 ± 0	0	100 ± 0	0 ± 0	0 ± 0	0 ± 0
China	2,981 ± 62	1,976 ± 46	5,891 ± 106	2,656 ± 42	87	7 ± 0	22 ± 3	4 ± 1	67 ± 3
Colombia	11 ± 1	966 ± 79	11 ± 1	3 ± 0	25	0 ± 0	73 ± 2	27 ± 2	0 ± 0
Cote d'Ivoire	416 ± 20	406 ± 49	169 ± 25	0 ± 0	0	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Egypt	111 ± 12	730 ± 20	81 ± 9	111 ± 12	100	62 ± 1	23 ± 1	12 ± 1	3 ± 1
Ethiopia	80 ± 6	671 ± 28	53 ± 4	27 ± 2	36	8 ± 1	90 ± 1	2 ± 0	0 ± 0
Greece	244 ± 14	1,220 ± 81	298 ± 35	235 ± 13	96	0 ± 0	38 ± 3	40 ± 1	23 ± 2
India	12,526 ± 328	441 ± 4	5,524 ± 159	4,564 ± 151	35	38 ± 2	52 ± 1	0 ± 0	10 ± 2
Indonesia	1 ± 0	314 ± 31	0.28 ± 0.08	0 ± 0	54	47 ± 1	53 ± 1	0 ± 0	0 ± 0
Iran	87 ± 5	819 ± 26	71 ± 6	79 ± 4	91	38 ± 2	56 ± 2	1 ± 1	6 ± 1
Kazakhstan	115 ± 3	937 ± 7	108 ± 3	104 ± 3	91	26 ± 1	73 ± 1	1 ± 0	0 ± 0
Kenya	10 ± 1	111 ± 19	1 ± 0	0 ± 0	4	38 ± 3	62 ± 3	0 ± 0	0 ± 0
Malawi	15 ± 2	376 ± 21	6 ± 1	1 ± 0	5	100 ± 0	0 ± 0	0 ± 0	0 ± 0
Mali	563 ± 102	362 ± 30	204 ± 44	6 ± 1	1	100 ± 0	0 ± 0	0 ± 0	0 ± 0
Mexico	152 ± 12	1683 ± 49	255 ± 24	142 ± 11	94	8 ± 1	83 ± 1	9 ± 1	0 ± 0
Mozambique	118 ± 13	260 ± 10	31 ± 4	0 ± 0	0	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Myanmar	170 ± 7	649 ± 5	110 ± 5	75 ± 3	44	0 ± 0	100 ± 0	0 ± 0	0 ± 0
Nigeria	455 ± 43	155 ± 6	70 ± 8	6 ± 1	1	100 ± 0	0 ± 0	0 ± 0	0 ± 0
Pakistan	2,100 ± 76	602 ± 62	1,402 ± 181	2,014 ± 73	96	84 ± 1	16 ± 1	0 ± 0	0 ± 0
South Africa	18 ± 1	886 ± 30	16 ± 1	7 ± 0	39	0 ± 0	47 ± 2	53 ± 2	0 ± 0
Spain	54 ± 2	799 ± 126	43 ± 8	45 ± 2	83	0 ± 0	34 ± 2	19 ± 0	47 ± 2
Sudan	288 ± 71	492 ± 75	142 ± 44	50 ± 11	30	15 ± 1	80 ± 1	5 ± 1	0 ± 0
Tanzania	374 ± 36	166 ± 8	62 ± 5	0 ± 0	0	0 ± 0	95 ± 1	5 ± 1	0 ± 0
Togo	84 ± 6	291 ± 11	24 ± 2	0 ± 0	0	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Türkiye	464 ± 35	1,750 ± 58	812 ± 59	436 ± 32	95	6 ± 1	61 ± 2	20 ± 1	13 ± 1
Turkmenistan	543 ± 15	373 ± 10	202 ± 8	543 ± 15	100	7 ± 0	92 ± 0	0 ± 0	1 ± 0
Uganda	52 ± 8	305 ± 29	16 ± 3	0 ± 0	0	0 ± 0	0 ± 0	0 ± 0	0 ± 0
USA	3,305 ± 262	960 ± 32	3,174 ± 189	1,021 ± 69	30	0 ± 0	36 ± 1	57 ± 1	7 ± 1
Uzbekistan	1,047 ± 7	638 ± 12	668 ± 16	828 ± 5	79	0 ± 0	78 ± 3	0 ± 0	22 ± 3
Zambia	76 ± 19	244 ± 64	18 ± 7	0 ± 0	0	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Zimbabwe	215 ± 13	217 ± 24	47 ± 6	2 ± 0	0	0 ± 0	0 ± 0	0 ± 0	0 ± 0
World	**30,987 ± 369**	**786 ± 8**	**24,538 ± 228**	**13,605 ± 192**	**44**	**30 ± 1**	**43 ± 1**	**8 ± 0**	**19 ± 1**

Footnotes:

- Irrigated Area (%): Percentage of total cotton area that is irrigated.
- Distribution of Irrigation Technologies: Percentage (%) of irrigated area using each irrigation method, such as flood, furrow, sprinkler, drip