# Water sustainability of sub-Saharan African cotton industry: evidence from Mali

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DIADIE SACKO HUA CHENG

**ABSTRACT – REZUMAT**

**Water sustainability of sub-Saharan African cotton industry: evidence from Mali**

*The world's cotton industry plays a significant role in the global economy, with cotton being used in around 50% of all clothing, household items, and other products. However, the production of cotton is also known to have a significant impact on the environment, particularly freshwater resources. Sub-Saharan Africa is particularly vulnerable, with 40% of the world's water-deprived people living in the region. Cotton is a vital cash crop in sub-Saharan Africa, serving as the main source of livelihood for over 2 million rural families, but its production is also water-intensive, requiring around 20,000 litters of water per kg of cotton yield. In addition, cotton farming in the region is largely dependent on rain, but countries are looking to expand their production and acreage through increased irrigation, putting further pressure on already stretched water resources. This essay investigates the sustainability of sub-Saharan Africa's cotton industry, using Mali as a case study. The region can increase its output significantly, but this must be done sustainably to avoid exacerbating the negative impact on freshwater resources. The study also discusses the water crisis in sub-Saharan Africa, cotton farming in Mali and the region, and the potential consequences of increased cotton production on families and the environment. Mali, currently the highest cotton producer on the continent is a convenient case study reflecting conditions in other sub-Saharan countries. By studying the scientific literature on the progression of cotton production and attendant problems in Mali and some other West African countries, I hope to inform policymakers in the region about some proven ways to improve cotton yield and processing while leaving water resources pristine. The plan centres on producing cotton in an eco-friendly manner through the adoption of organic cotton, and GM cotton and irrigation in suitable areas. At the same time, there is a need to reduce the grey water footprint by reducing chemical usage and treating effluents before discharge.*

***Keywords:*** *water footprint, sustainability, organic cotton, grey water, blue water, green water, millennium sustainable development goals*

**Sustenabilitatea gestionării apei în industria bumbacului din Africa Subsahariană: dovezi din Mali**

*Industria mondială a bumbacului joacă un rol semnificativ în economia globală, bumbacul fiind folosit în aproximativ 50% din toate articolele de îmbrăcăminte, articole de uz casnic și alte produse. Cu toate acestea, se știe că producția de bumbac are un impact semnificativ asupra mediului, în special asupra resurselor de apă dulce. Africa Subsahariană este deosebit de vulnerabilă, 40% dintre persoanele lipsite de apă din lume trăiesc în această regiune. Bumbacul este o cultură comercială vitală în Africa Subsahariană, fiind principala sursă de trai pentru peste 2 milioane de familii rurale, dar producția sa este, de asemenea, consumatoare de apă, necesitând aproximativ 20.000 de litri de apă per kg de bumbac. În plus, agricultura de bumbac din regiune depinde în mare măsură de ploaie, dar țările caută să-și extindă producția și suprafața prin irigare sporită, punând și mai multă presiune pe resursele de apă deja reduse. Acest studiu investighează sustenabilitatea industriei bumbacului din Africa Subsahariană, folosind Republica Mali ca studiu de caz. Regiunea își poate crește producția în mod semnificativ, dar acest lucru trebuie făcut într-o manieră sustenabilă pentru a evita exacerbarea impactului negativ asupra resurselor de apă dulce. Studiul abordează, de asemenea, criza apei din Africa Subsahariană, agricultura de bumbac din Mali și din regiune și consecințele potențiale ale producției crescute de bumbac asupra familiilor și a mediului. Mali, în prezent cel mai mare producător de bumbac de pe continent, este un studiu de caz concludent care reflectă condițiile din alte țări subsahariane. Studiind literatura științifică despre progresia producției de bumbac și problemele aferente din Mali și din alte țări din Africa de Vest, este posibil ca factorii de decizie din regiune să fie înştiinţaţi cu privire la câteva modalități dovedite de a îmbunătăți randamentul și procesarea bumbacului, lăsând în același timp resursele de apă curate. Planul se concentrează pe producerea de bumbac într-o manieră mai ecologică prin adoptarea bumbacului organic și a bumbacului modificat genetic și irigarea în zone adecvate. În același timp, este necesar să se reducă amprenta de apă gri prin reducerea utilizării produselor chimice și tratarea efluenților înainte de evacuare.*

***Cuvinte-cheie****: amprenta de apă, sustenabilitate, bumbac organic, apă gri, apă albastră, apă verde, obiectivele de dezvoltare durabilă ale mileniului*

## INTRODUCTION

Cotton is the most important textile crop in the world, being used in as much as 50% of all clothes, household items and other products [1]. At the same time, the growing and processing of cotton is considered to have one of the biggest negative footprints on the environment. This effect is particularly taxing on freshwater resources and sub-Saharan Africa as a region is among the most vulnerable. According to a

report by UNICEF, 40% of the world's water-deprived people live in sub-Saharan Africa, a proportion that amounts to 320 million people. Cotton is an important cash crop in sub-Saharan Africa, being the main source of livelihood for more than 2 million poor rural families [2]. At the same time, the crop and its products are water-intense, requiring around 20,000 litres for every kg of cotton yield [3]. As a result, about 73% of global cotton farming is dependent on irrigation, putting pressure on already overstretched water resources [4]. Producing a single jeans trouser can take up to 10,800 [3] during the processing phase, providing further context to the full extent of the effect of cotton on the water ecosystem.

The sub-Saharan African cotton farming industry is largely dependent on rain but most countries harbour ambitions to expand production and acreage and increased irrigation is one of the ways that they have earmarked to do this. Although the cotton industrial chain is one of the most important economic industries in the sub-Saharan region, the totality of its output is a small fraction of the $1.3 trillion global cotton industry [2]. As such, the region can increase its output immensely but it comes with dire implications on the environment, particularly water resources if it is done in an unsustainable manner. This essay investigates the continued viability of sub-Saharan Africa's way of growing cotton with Mali's cotton industry as the main example. The main challenge for the future is to increase Saharan Africa's cotton production without exacerbating the negative footprint that the industry already has on freshwater resources.

## CONTEXTUALISING THE PROBLEM

### Cotton farming in Mali and Sub-Saharan Africa

While there are reports of cotton being grown in southern Africa as early as the 16th century, commercial cotton was largely introduced to sub-Saharan Africa during the turn of the 20th century by colonial authorities looking to exploit large underutilized fertile farmland. Today, more than 20 countries in sub-Saharan Africa grow cotton for both domestic and international consumption. Cotton is an extremely important cash crop in sub-Saharan Africa, earning more than $15.5 billion in export revenue for farmers across the region [5]. The acreage under cotton cultivation increased steadily between the 1960s and the 1980s but has since stagnated and fluctuated periodically, with the early 2000s having seen a significant decline that has since rebounded in most countries [6]. Cotton in sub-Saharan Africa is mainly grown by smallholders on small farms together with other crops such as maize, potatoes and cassava. Currently, Africa only accounts for 4% of global cotton production [7], but most countries have been looking to up their production by many times their current levels. Many scholars agree that the current production levels are significantly below capacity owing to a combination of factors limiting optimal yield, especially at the cultivation stage.

Mali has been farming cotton since the 1950s and though production has fluctuated significantly, it has been on an upward trend in recent years. Figure 1 shows some of Africa's main cotton-farming countries, Mali is currently Africa's largest cotton producer, having produced about 760,000 tons in the 2021/2022 season. The crop is the second largest source of export revenue after gold, underlining the important economic value that it has on Malian households. The government has laid out ambitious plans to increase yield with a goal of at least 1.2 million tonnes by 2025. The country's cotton industry occupies a relatively precarious place, exacerbated by various local and international factors. This was demonstrated during the mid-2000s and early 2010s when a currency crisis coupled with low cotton prices saw a significant dip in cotton production in the country [8]. In a study conducted in the Sikasso region of Mali, a major cotton-producing area, Cooper and West [9] found a correlation between cotton cultivation and malnutrition and the destruction of natural capital. This suggests that despite cotton bringing in much-needed cash, could compete with food crops and create harsh conditions for families.

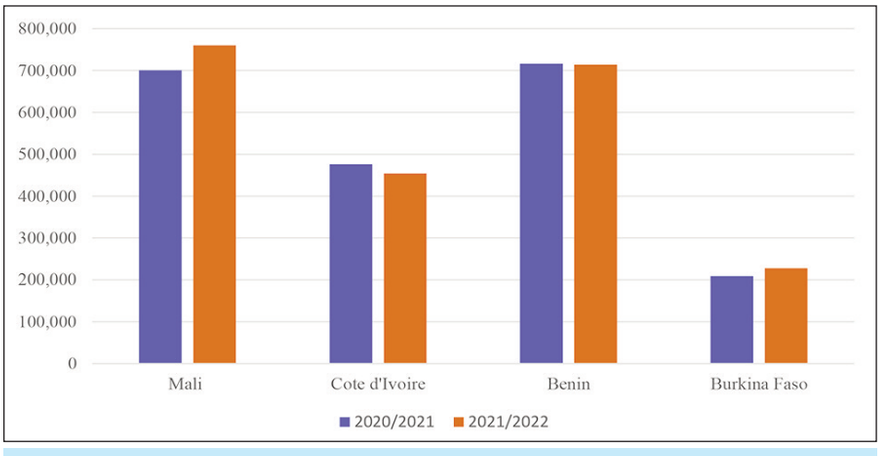


Fig. 1. Cotton production in selected West African countries (*Source: Adapted from https://ipad.fas.usda.gov/countrysummary/Default.aspx?id=DM&crop=Cotton*)

### *Sub-Saharan Africa's water crisis*

Water availability is one of the most important elements under the Millennium Sustainable Development Goals. Africa faces the highest jeopardy of missing out on these goals and clean water shortage is one of the most important factors for this. Despite making up 22% of Earth's landmass, Africa has just 9% of the freshwater resources, making it the most water-scarce continent [10]. In addition, the resources are unevenly distributed, with 72% being concentrated in

central and western African regions where just 34% of the population of the continent lives [11]. Currently, Africa has the fastest-growing population of all the continents, with its population expected to double by 2050 [10]. As a result, the pressure on the continent's already threatened water resources will continue to pile up. According to McClain [11], sub-Saharan Africa must increase its crop production by 2% annually to meet the needs of the growing population. Considering that the region has also experienced the lowest rates of agricultural innovation, much of that increase will likely be met by increasing land under agricultural cultivation rather than increasing the productivity of existing farmland. Currently, only about 4% of sub-Saharan Africa's cultivated land is under irrigation and the region's leadership is hedging on increasing this figure to meet the agricultural and economic needs of the region's population [12]. In Burkina Faso for example, at least 3% of savannah is being converted to farmland every year, in line with the 3.3% population growth rate in the country [13]. The implication that this has is the further destruction of wetlands, forests and water bodies that the freshwater ecosystem depends on. As such, cotton cultivation and processing acts as a competing activity for precious resources and poses an existential threat to Earth's most vulnerable region.

With mixed arid and wet climactic conditions across the country, Mali mirrors the climactic conditions prevalent across sub-Saharan Africa and therefore is a fair representation for the rest of the region. While the north of the country is dominated by hot desert conditions, the south has a wet tropical climate. This contrast mirrors the uneven distribution of water resources that is also endemic in the rest of the region. According to UNICEF, over 20% of the country's population does not have access to safe drinking water and that proportion is expected to rise due to a rising population and the threat of political instability.

*The water footprint of cotton*

The water footprint of textiles has been a prominent topic of discussion in recent years and environmental sustainability has become an important consideration across various industries. When measuring the impact of the cotton production cycle, three types of water use are identified. Green water use refers to rainwater that helps sustain plants; blue water refers to irrigation water drawn from groundwater sources, and grey water refers to water that is used in the industrial stage to extract and condition fibre from the cotton fluff [14, 15].

Niinimäki et al. [1] estimate that in 2015, the textile industry used a total of 44 trillion litres of water, with cotton cultivation accounting for 95% of that figure. This figure represents 3.14% of global freshwater use [16] and the crop has a disproportionate effect in terms of negative outcomes. In fact, by some estimates, cotton cultivation and processing is responsible for 17% of global damage to freshwater resources [4, 16]. The most glaring example of the havoc that cotton cultivation can wreak on water ecosystems is the drying of the Aral Sea in central Asia which happened as a result of the diversion of major rivers feeding the lake to water large cotton farms located upstream. In central Africa, a similar effect has been observed, with Lake Chad reducing in size by 90% over the past 50 years. Among other factors, the United Nations attributes this effect to overuse of the lake water for irrigation [17]. The lake basin supports more than 30 million people and the continued devastation is a representation of the calamity that can be expected at an even larger scale in Africa without proper plans to mitigate irresponsible water use.

In a government-sponsored research effort on the impact of cotton farming on freshwater resources in Ethiopia, Zerihun et al. [18] found that there was a mismatch between water availability and water needs, with cotton largely being grown in areas where water scarcity is rampant. The government's sustainability plan sought to mitigate this scenario and boost cotton production in the country by increasing acreage in areas such as Omo, Abay and Mereb where water resources are more abundant [18]. This scenario replicates itself across the sub-Saharan Africa region. In West and Central Africa, a region that supplies 12–15% of the region's cotton fibre, the past decade has seen a sustained decline in yield, with diminishing water resources being one of the major culprits [19]. In South Africa, the availability and demand for water show an increasing mismatch. In the Limpopo basin for example, where a vast agricultural infrastructure exists, peak demand for cotton happens between July and November which is also the period when the basin is at its driest. As a result, over 52% of the Limpopo River's flow is abstracted to support the farming of cotton and other crops [14]. In Ghana, an environmental study found that the construction of dams for irrigation disrupted both upstream and downstream river ecosystems, leading to far-reaching negative implications on the water security of populations in those areas [20]. Equally, many irrigation-driven cotton projects in Africa are sustained by breaching environmental flow and are thus detrimental to the environment.

Aside from diverting water resources, the processing of cotton, as with other textiles introduces dangerous pollutants in freshwater bodies. The pollution of water resources by the cotton production chain starts during the cultivation stage. Herbicides and fertilizers used during the growing of cotton as well as chemicals used in processing eventually leach into waterways. This has the effect of further diminishing water resources because it makes available water unusable. Cotton is a pesticide-intensive crop. Cotton crop accounts for 6% of global pesticide use, and in sub-Saharan Africa, that figure rises to 50% [4]. A global study on the effects of fertilizer use in cotton farming on water quality found that Mali had some of the highest pollution rates. With the primary varieties being nitrogen-based fertilizer, the country's cotton

industry leached more than 1500 tons of contaminated water into the environment [15]. Nitrogen compounds contamination is associated with a wide variety of effects including bacteria balance and neurological diseases.

The curing of cotton fibre and dyeing of fabric requires the use of complex chemicals that are extremely harmful to human and animal life. These include chemicals like cyanide, sodium compounds, heavy metals and organic compounds. Sub-Saharan countries have lower approval and enforcement standards for effluent treatment which means that these chemical agents are highly likely to end up in waterways that are used for drinking water. In the Nigerian Lagos region, one of the most polluted zones in the world, textile manufacturing has been attributed as one of the most important contributors to the problem [21]. Similar effects have been observed in other regions. In Tanzania, the Msimbazi River was found to have a pH of up to 12, with the main culprit being jeans-making companies that release their effluents untreated into the river [22]. In Ethiopia, an ecological study sponsored by the government found that a thriving textile industry along the Borkena River was responsible for over 70% of metal effluents in the river despite coexisting along with a host of other industries such as steel mills, a brewery and meat processing plant that have more water usage in absolute terms [23]. These cases illustrate the harmful effects that the cotton fibre extraction process has on water resources, further compounding the hiving of water resources that the cultivation process creates.

## SUSTAINABLE AND ALTERNATIVE METHODS

Whereas cotton production in other regions, primarily in developed countries, has largely moved towards sustainability by optimizing water use, sub-Saharan Africa has largely remained stagnated. For example, according to a report by the WWE, irrigation-dependent cotton farming in the United States has improved water efficiency by 75% in the last two decades [24]. This has been enabled by a combination of developments including the use of drip irrigation, seed improvement technology, and changing to more productive strains. Aside from a slow start in adopting technology, sub-Saharan Africa has also been hesitant to start growing improved cotton varieties because of the belief that they are harmful. According to Marquardt et al. [7], only eight sub-Saharan countries had adopted genetically modified cotton by 2018, accounting for just 9% of their joint production. Meanwhile, countries outside sub-Saharan Africa had a 90% adoption rate of GM cotton in 2020. There must be interventions at all levels of the cotton supply chain, which is illustrated in figure 3.

### Genetically modified cotton

GM cotton has been in use around the world for many decades. The concept of genetic modification allows for the production of varieties that are more resistant to several hostile conditions such as water scarcity, pests and temperature variations. In sub-Saharan Africa, there has been a lag in the adoption of GM cotton, with the few countries that have done so leaning towards pest-resistant varieties. Most of the top producers in the region including Mali, Cameroon, Burkina Faso and the Ivory Coast have banned genetically modified cotton. Those that permit GM cotton such as Kenya, South Africa, Malawi and Eswatini grow cotton at a lower production rate. Currently, there are three types of GM cotton that are available commercially. The first type, insect-resistant (IR), is genetically coded to handle toxins from Bacillus thuringiensis. The second type is herbicide tolerant (HT), which tolerates compounds such as glufosinate, glyphosate, and dicamba at a much higher concentration rate. The third type is a combination of these two attributes [7].

### Organic cotton

The growth of organic cotton has been a highly advocated step that is now proliferating across sub-Saharan Africa. Initiatives such as Cotton Made in Africa (CmiA), Better Cotton Initiative and Organic Cotton Accelerator have been active in many countries setting standards and activating preference among farmers towards organic cotton. These initiatives are aimed at encouraging the growth of organic cotton by providing incentives to farmers. They largely discourage farmers from using genetically modified cotton and irrigation as well as a host of synthetic pesticides. Among the incentives that farmers receive include improved seeds, higher prices and exclusive access to select markets worldwide. Organic cotton is beneficial to the water ecosystem because it limits the use of pesticides and fertilizers, thereby limiting the pollution of waterways. The variety has shown promise when executed according to stringent standards that ensure every input is provided accurately. In Benin, farmers who converted to organic farming experienced a 50 percent leap in yield per hectare with costs dropping by up to 30 percent between 2017 and 2019 [7]. While this initiative was done in a highly controlled case study, organic cotton generally yields lower output than conventional cotton. In Zimbabwe and Senegal for example, the yield was observed in another study to reduce by 10 to 20% when farmers switched to organic cotton. However organic cotton fetches consistently higher prices and this more than offsets the yield gaps. Globally, the demand for cotton is increasing by 20% annually as multinational brands seek to position themselves as embracing environmental sustainability [24]. As such, organic cotton is one of the solutions that poor farmers in sub-Saharan Africa should be looking towards in protecting their local water resources. Aside from the cultivation stage, various organic cotton strains have benefits that cleanse the processing and fabric production stages. For example, naturally coloured cotton strains such as Tanguis and Peruvian Pima reduce the need for dye application. According to Radhakrishnan [3], naturally coloured cotton does

better under organic growing conditions, thereby making it advantageous throughout the cycle. It also requires less water and other inputs.

## LOOKING TO THE FUTURE

### How the issue will evolve

It appears that different profiles of farmers will benefit from unique cotton-growing approaches. For the longest time, Sub-Saharan Africa has been held back by lower technological prowess exacerbated by a lack of economic resources. In its clamour to improve its cotton production, solutions that have worked in other regions are ill-suited to the region. Irrigation becomes a poor fit because of the water-scarce nature of the sub-Saharan region. The solution for intensification of cotton yield for Sub-Saharan Africa has to be different from what other regions have actuated. In areas where rain-fed cotton farming is applied, organic farming seems to be the most viable alternative since the price differential for organic cotton compensates farmers for potentially lower yield over conventional cotton.

As shown in figure 2, the cotton exports for West Africa's major cotton-growing countries have been on the rise for the past five decades. However, as a percentage of total global water consumption for cotton processing, Sub-Saharan Africa's impact is negligible. 90% of the cotton produced in sub-Saharan Africa is destined for export [24]. This means that currently, the processing happens elsewhere and thus it helps to spare the region of most of the pollution that is associated with the processing of cotton fibre and fabric. In future, as the region develops its industrial capability and local demand for high-quality textiles increases, countries within the region will look to retain much of the cotton processing within the region. As such the water footprint associated with cotton processing will rise alongside that of cultivation. This reality further contextualizes the problems that the cotton industry will continue to pose to Africa's freshwater resources. The entire sustainability push for the cotton industry will require a multi-pronged approach that arrests the effect at different stages of the cotton production chain. Such an approach should be cognizant of the varied scenarios that farmers across the region and within individual countries face and seek to optimize their yield according to their unique challenges.

### Optimising the cultivation stage

Because sub-Saharan Africa's cotton crop is mostly rain-fed and hand-cultivated, there has generally been a lower effect on the environment as compared to other regions that do more intensive farming reliant on irrigation. Many governments have been looking to move towards large-scale irrigation as a way to increase their countries' cotton yield but this poses the threat of competition for already limited water resources. Rain-fed cotton cultivation generally has a lower impact on water resources but has a much lower yield than irrigated cotton. The biggest obstacle to intensification remains the fact that most farmers in sub-Saharan Africa are resource-poor, thereby denying them the ability to fund improvements and endure disruptive effects that new technologies and farming techniques may temporarily bring about [25]. Further, low-tech interventions such as mulching which helps to increase water retention and percolation to plant roots have largely been underutilized [11]. The blueprint for sustainable water use in arid Africa has largely been anchored on increasing water retention while reducing evaporation to make the best of erratic rains.

Water harvesting has been advanced as a potential solution to water shortages in areas where rainfall is limited and highly seasonal without increasing the

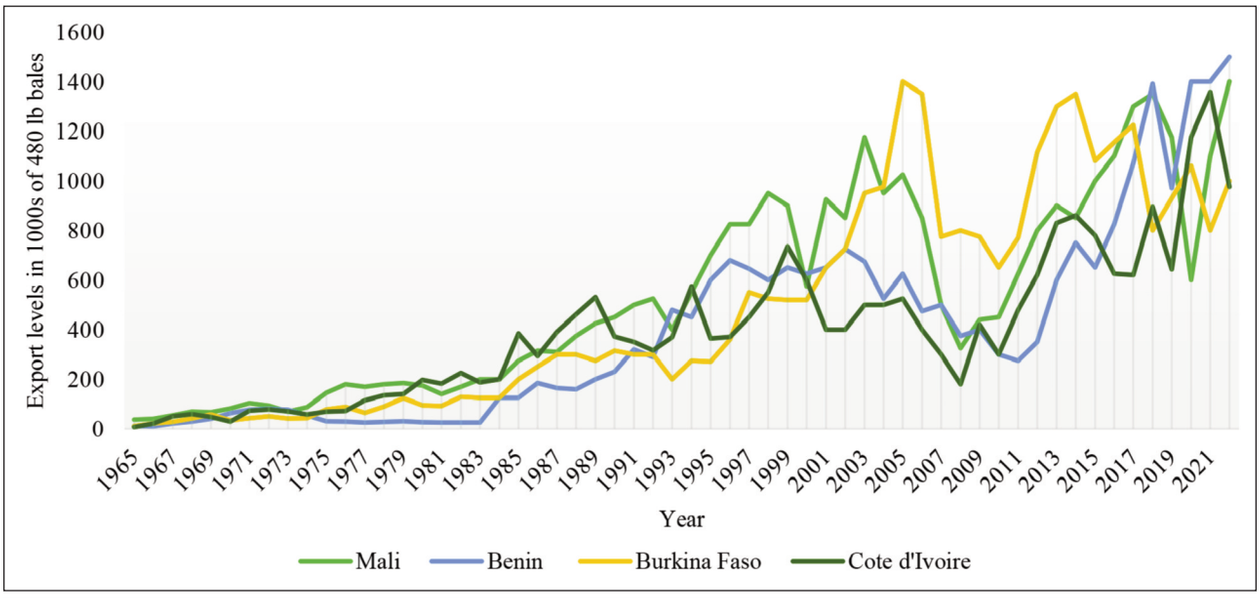


Fig. 2. Cotton exports of selected West African countries
(*Source: https://www.indexmundi.com/agriculture/?country=ci&commodity=cotton&graph=exports*)

negative footprint on water resources. Cotton is a crop that can benefit greatly from this approach. In one study conducted in rural Tanzania, water was harvested and stored in underground pits and water pans and then redirected to farms during the dry season. The result was a much higher maize yield, reaching up to 400% of normally cultivated farms [11]. Similar results can be expected by smallholder cotton farmers who are dependent on highly erratic rainfall to water their cotton crops.

These low-tech methods are highly suited to organic cotton growth but their implementation is reliant on the presence of bodies that provide incentives, without which farmers would have to take on great losses in revenue. GM cotton on the other hand is resource-intensive and is best suited to farmers who have access to funds and sophisticated equipment. While it is highly effective in increasing yield in North America and parts of Asia, genetically modified cotton has been implemented through high rates of mechanization, automation and complex monitoring tools. GM cotton is designed to optimize the uptake of resources such as fertilizer, therefore improvement in yield is contingent on the maximum provision of these resources. In India for example, there has been a very high cost associated with switching to GM cotton. The costs rose by 78%, 245%, and 158% for seeds, fertilizer and insecticide respectively. Overall, the production cost of Bt cotton rose by 143% [7]. A similar survey conducted in Mexico showed comparable increases in the cost of inputs with a concurrent 80% increase in cotton production since GM cotton was introduced in the country in 1996 [26]. At the same time, 40% of farmers who were surveyed indicated that they would be willing to return to conventional cotton if the option was available to them. This method is therefore not suitable for smallholder farmers in sub-Saharan Africa.

Ultimately, the solution for sub-Saharan Africa's cotton farming intensification efforts will require that government and private stakeholders invest in the more technological aspects of the crop while smallholders gravitate towards organic crops. Even then, large-scale cultivation projects will be operating in a highly constrained environment because of the scarcity of water resources. As such, any increases in irrigated land for cotton will have to operate within these constraints through several methods such as locating irrigation projects in areas with underutilized water resources. The Zambezi Basin in Southern Africa, the Congo Basin in the DRC and the Tana and Athi Basins in Kenya are some of the areas that have underutilized water resources that can support the expansion of high-tech and irrigation-dependent cotton growth without putting excessive pressure on water resources.

Mali has been one of the adopters of organic cotton in Sub-Saharan Africa. However, adoption has been negligible, accounting for only 200 tons out of the country's total annual yield. According to Westerberg et al. [27] some of the additional low-tech solutions that farmers in Mali have adopted include agroforestry practices, rotation with legumes and grazing of cotton residues to livestock. Mali exports more than 95% of its cotton, with China, India and Bangladesh being the main destinations. The country currently aims to increase the local consumption of cotton, with the government looking to process 10 to 25% of locally-grown cotton. What this indicates is that more of the crop's water footprint will be felt within the country, a problem that many of the other countries in sub-Saharan Africa will also face (figure 3).

### Dealing with wastewater

In the processing phase, one of the most harmful effects is the release of effluents from dyeing and other cotton fibre treatment processes. Samsami et al. [28] explore several viable processes for treating wastewater from dyeing. These include membrane technology, nano-filtration, adsorption and biological methods. A variety of these methods are used in different regions outside Africa but none of them are

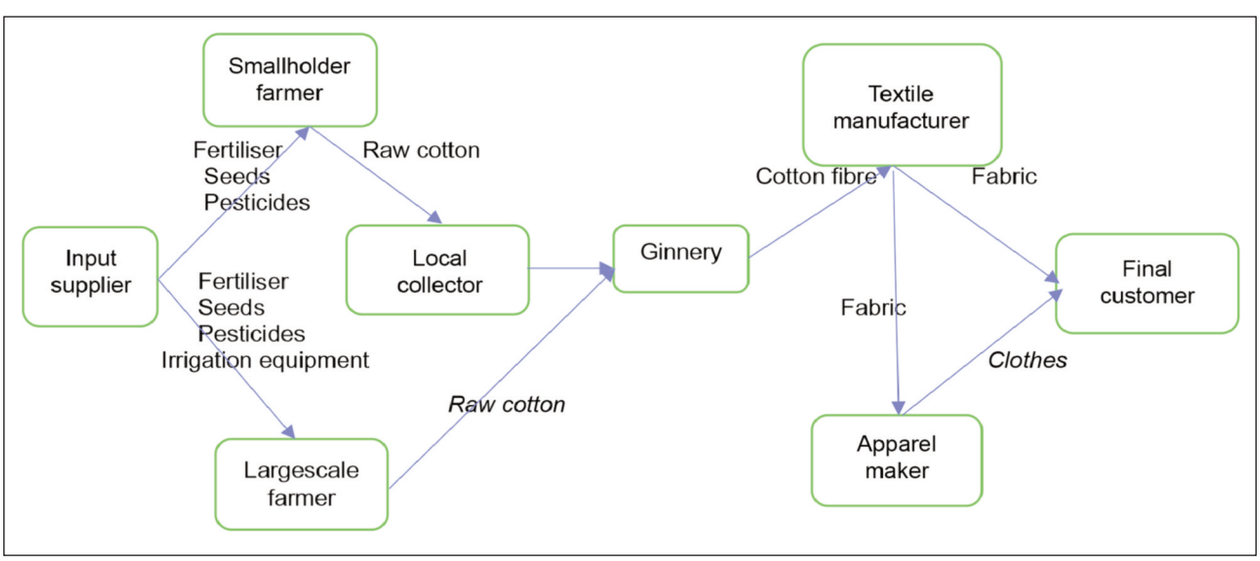


Fig. 3. Cotton industry value chain in West Africa

wholly effective in eliminating chemicals, particulate matter and biological agents. Instead, a hybrid method combining two or more methods has been shown to create be much more effective at decontamination. Therefore, such methods should be explored by sub-Saharan African countries more intently to provide sustainable solutions to the inevitably rising industrial activity surrounding cotton. A similar review conducted by Georgiou and Aivasidis [29] found cost-effectiveness to be a major obstacle to implementing many of these processes. On their own, each of these methods was not able to completely decontaminate water or remove discolouration, therefore there is a need to combine different methods as well as for further research and innovation surrounding the problem of water contamination by the cotton industry.

In a comparative study, Babu et al. [30] found a combination that started with electrochemical oxidation before performing biological treatment was effective at removing dyes and organic compounds. In addition, the process could also incorporate a photochemical treatment at the end to remove microbial life, though, with cotton processing, this is not a big priority. Babu et al. [30] also found that this chain presented the most cost-effective method since it does not involve a lot of complicated technology. As Awomeso et al. [31] assert, the government has a role in closing the loopholes that exist through the lax application of environmental laws that allow companies to pollute at will. This is an area of the cotton sustainability effort in that the government has a power monopoly and farmers have very little sway. At the same time, water recycling can help reduce water use by minimising the amount of water that is directed from rivers and other freshwater bodies. Overall, there is a need for sub-Saharan cotton projects, both small-scale and large scale to close loopholes that lead to inefficient water use. This effort encompasses solutions ranging from efficient irrigation methods to water recycling.

## CONCLUSION AND RECOMMENDATIONS

As a region that is hungry for economic development, sub-Saharan Africa's priorities require a tough balancing act between increased resource exploitation and environmental sustainability. This reality faces the cotton industry. Increased cotton production is a vehicle for lifting people out of poverty but at the same time jeopardizes clean water resources that are already ravaged by unsustainable exploitation and the growing threat of climate change. Pegging economic development to activities that further the depletion of important basic resources poses a paradoxical scenario for countries in the region. Essentially, the dual challenge of climate change and rising water demand raises a dire challenge for sub-Saharan Africa's sustainable future. Cotton cultivation and processing as a pillar of economic empowerment for rural economic sustenance and transformation cannot be disputed. Therefore, upending the crop from existing farms is not a prudent direction to take. Instead, there is a need for greater adoption of technology including mechanized farming methods, and improved seeds that increase yield without necessarily increasing pressure on the water resources that are already used today.

This essay recommends a multipronged approach to preempting the damage that cotton could precipitate in future for sub-Saharan Africa. In summary, the solutions include:

- Encouraging organic cotton among smallholders: organic cotton is cheaper to grow and is less impactful on water resources. While producing a lower yield, it fetches higher prices in some markets and the net result is higher income for farmers. The key to the successful implementation of organic cotton farming lies in the utilization of sustainable raw materials in the entire production lifecycle. Continuing projects in various countries have shown positive impacts in both environmental aspects as well as improving quality of life. In Turkey, some researchers showed that organic cotton reduced the leaching of fertilizer residue into freshwater resources. Equally, a pilot study in Meatu, Tanzania found great improvement in cotton yields, while also facilitating extensive positive socioeconomic reforms.
- Strategically placed irrigation projects: because modernization of cotton farming is still highly relevant, government and large private entities need to invest in irrigation but in a sustainable way that only utilizes water resources in areas where they are not at immediate risk of depletion. Currently, many cotton irrigation projects are placed in suboptimal locations where their activities are highly disruptive of local livelihoods through their impacts on water resources.
- GM Cotton: the use of GM cotton can help increase yield without the need for increased acreage that would threaten wetlands. The use of GM cotton has consistently shown neutral to strongly positive increases in yield in areas where it has been implemented. In Mexico for example, Rocha-Munive et al. [26] switching to Bt cotton yielded up to 80% increases in yield per hectare without any additional strain on water resources.
- Waste water management: ending the practice of water contamination by cotton factories releasing effluents into rivers could ease the destruction of water resources. Developed countries like the USA have put into place stringent water use laws that have significantly arrested pollution and water wastage from cotton cultivation and processing.

Currently, sub-Saharan Africa's contribution to greenhouse gas emissions through the region's cotton-related activities including cultivation, transportation and processing is negligible and this will remain the case at least for the foreseeable future. However, governments need to start looking at possible models of minimising that tenet of environmental impact because it also has a bearing on the availability of water resources.

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**Authors:**

DIADIE SACKO, HUA CHENG

Zhejiang Sci-Tech University School of Economic and Management,
310018, 5 second Avenue Xiasha Higher Education Zone, Hangzhou, China
e-mail: ssacko97@outlook.com

**Corresponding authors:**

HUA CHENG
e-mail: chenhua@zstu.edu.cn