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A COMPARATIVE LIFE CYCLE ASSESSMENT OF SYNTHETIC AND NATURAL TEXTILE FIBERS

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Abstract : Textiles are a vital part of the global economy and culture, but are a main contributor to environmental degradation, due to their "take-make-waste" linear approach. This study delves into the "Threads of Destruction" by examining the ecological risk factors of both natural and synthetic fibers, with a particular focus on cotton and polyester. The study uses a combination of life cycle assessment (LCA) data and the latest environmental results published in 2025 to uncover a "sustainability paradox": the use of natural fibres puts pressure on the local environment with high levels of water use (10,000-20,000 L/kg) and high soil toxicity, while the use of synthetics puts pressure on the global environment through high CPI polymerisation and high leakage of MPF. The papers also make the point that this is not just a matter of substituting materials: addressing the ecological footprint of the fashion industry will require a major decoupling of fashion from virgin resource extraction, the use of green chemistry (e.g. supercritical CO2 dyeing) and above all the transition to a truly circular fashion based on the principles of longer product life, rather than the faster production cycle currently in place.

IndexTerms **– Textile, Natural, Synthetic.**

INTRODUCTION

The textile industry is one of the oldest and largest industries of the world and is a primary means of cultural expression, a primary human need. However, its explosive expansion - driven by the establishment of so-called fast fashion - has taken an astonishing environmental cost. Nowadays, the industry is one of the greatest polluters of the planet that affects everything including the carbon equilibrium in the air up to the integrity of the local watersheds.

In all stages of the textile life cycle, Environmental degradation of Complexity of Contamination can take place. The process of the extraction of the raw material involves consuming resources such as pesticides and a lot of water for the cultivation of conventional cotton, and synthetic fibers are largely derived from petrochemical feedstocks. The dyeing and finishing processes during the manufacturing phase are sources of a concoction of harmful chemicals, heavy metals and microplastics in aquatic ecosystems. More so, the sector contributes and the biggest contributor in the global waste crisis, as millions of garments are thrown in the landfills or burnt every year, mainly in the developing countries that may not have the infrastructure to deal with the following toxic dye-off.

Purpose of the Research Although the economic advantage of the textile business cannot be neglected, the existing linear approach of take make waste is becoming more ecologically unsustainable. This paper aims at discussing the specific environmental stresses encountered during the production of modern textiles especially in the context of water scarcity, chemical pollution and carbon emissions. This collation of already available data related to the production methods and waste disposal in this sector shows that a transition to a more circular and environmentally friendly method is pressing.

LITERATURE REVIEW

In the 2020s, the textile sector is becoming larger due to the mechanisms of the so-called fast fashion and the ecological studies of this industry are successfully underway. Existing scientific evidence of the life cycle impacts of both man-made and natural fibers, such as water depletion, toxicity of chemicals, and the increasing problem of microplastic pollution, is examined.

1. Comparative Life Cycle Assessments (LCA)

LCA studies show recently a significant trade-off between natural and synthetic fibres. As already observed by Gonzalez et al. (2025) and Hossain and Mahmood (2025), though natural fibers like jute, and organic cotton are generally expected to have lower global warming potential (GWP), they also tend to have increased land use and other agricultural necessities.

Synthetic Fibers (Polyester/Nylon): It has been cited as energy intensive at the stage of production of the polymer where they use the feedstock of the fossil fuels. They generally have, however, less water use (cradle to gate) compared to natural alternatives.

Natural Fibers (Cotton/Silk): Cotton as a conventional is still a thirsty crop. As per the UNCCD (2025), 1 kg of cotton can use as much as 10 000–20 000 litres of water; a resource that is often in short supply in water-stressed regions of Central Asia and India.

2. Plastic Crisis and Synthetic Leakage.

Microplastic Fibers (MPFs) are one of the topical issues which are currently being researched. According to Changing Markets Foundation (2025), the main microplastic in the ocean is synthetic textiles accounting for approximately 35 per cent. It's also significant that in 2025 they discovered that the laundering process releases as much as 55‘ more microplastics from recycled polyester than from virgin polyester due to its brittle nature.

• Environmental Persistence: The synthetic MPFs are not natural fibers and last a century, whereas natural fibers only last for months or years. Probably, according to recent modelling by Hajiani et al. (2025), due to a lack of aggressive filtration and material development, MPF emission would grow by 43% in 2050.

3. Toxicity in Chemicals and Wet Processing

The second-largest water polluter in the world is termed the wet processing stage which is the scouring, bleaching and dyeing stage. The research paper Sane, Kind, and Cautious: Research in Sustainability (2025) states that even the natural fibres lose their sustainability when dyed and finished with synthetic dyes.

A Green Chemistry Innovation: There has been a significant increase in research in the field of “Supercritical CO 2 dyeing and Enzyme-based finishing as an acceptable alternative to aqueous dyeing, which is currently responsible for 20 per cent of the world industrial water pollution”.

4. Soil Health and Biodiversity Dimension.

More recent studies have started to close the textile production and soil wholeness divide.

Synthetic Impact: Phthalates and flame retardants leach from the thousands of synthetic materials thrown in the trash into the soil, disrupting the microbial communities.

Natural impact: Traditional production of natural fibres relies heavily on the use of pesticides, which according to UNU (2025) adversely affect biodiversity on soil and the nitrogen cycle in agricultural fields, although natural fibres are biodegradable.

RESEARCH METHODOLOGY

The world textile industry uses a modern network of production techniques that begin long before the product reaches the hands of a consumer and thus begins to produce environmental destruction that is visually striking in the fibres, but quite different from one type of fibre to another. This study focuses on dualism of fibre production, negative footprint of natural (cotton) and synthetic (polyester) fibres, harmful effect of fibres on the environment. Natural fibre has turned out to be promoted as a sustainable alternative due to its biodegradability, but in terms of its cradle-to-gate, the fibre is characterised by high water use and land degradation. On the other, instead of releasing the industry of landward pressures, synthetic fibres, the staple of modern fast-fashion economies, tie it to fossil dependence and a long-lasting micro-plastic up-toxic legacy. The study would show that presently there is no fibre which is impact free because of the vast demand of the world, both biological and technical cycles are being driven beyond the capacity of their regeneration.

The destruction begins with the drawing off of resources and most of the natural fibers add a lot of stress to the hydrological and soil structures of the earth. For instance, a cotton plantation takes up approximately 2.5% of the total arable land on earth, but employs a lot more than what it is supposed to. This run-off of chemicals forms so-called "dead zones" in the local water bodies, while the gigantic demands for irrigation water are often more than 10000L per kg fibre, leading to the disastrous drying process of whole inland seas. This study highlights that the cost of natural products is often still present in the soil strata and aquifer strata in developing countries and the agricultural practice of exporting raw materials continues to contribute to the loss of biodiversity on the terrain level and the process of desertification.

Synthetic fibres, however, have a life cycle that is the opposite of the biological depletion to the chemical and atmospheric persistence. One of the producers of the most significant greenhouse-gas emission in the world is 1st-generation polyester and nylon generation that is based on oil products, and has high energy consumption in the polymerisation process. But the most diabolical effect of synthetics with regards to destroying forces is the release of micro plastic fibres. The synthetic micro-plastics have become the new natural fibres because their presence does not get buried in the ground or lost in the ocean at the end of the life, but it is just captured during the manufacturing process, laundering cycle and during disposal, while the natural fibres are buried in the ground or lost in the ocean in the end. The research argues that the synthetic textile manufacturers have been able to shift a scarcity problem of resources (water and land) into a persistent problem of pollution, because the chemicals used to make the textiles into durable products make them a persistent pollutant of the environment.

It is in the last part of this investigation, the part of wet processing, where there is a common denominator; where natural and synthetic fibres meet where they are washed upon the same route to the path of destruction. Dyeing and finishing is a blend of heavy metal, surfactant and formaldehyde, many of which are not removed and get released to water bodies. When these fibres have to come to their end of life cycle, the lack of circular infrastructure causes such natural and synthetic textiles normally end up their course in landfills or furnaces. The study concludes that choice of materials is not the only answer, but is rather a

symptom of a linear production paradigm that is more focused on volume than velocity, and that in turn is a reflection of a broader question: what is the real solution to the problem of sustainability, irrespective of what kind of fibres are involved?

RESULTS AND DISCUSSION

1. Environmental Trade-offs Analysis

The findings show that there seems to be a paradox of sustainability between natural and synthetic fibres. The comparison supports the fact that, although natural fibres (cotton) are far more promising in terms of biodegradability, and sequestration of carbon, they cause a disproportionate impact on local ecosystems via water depletion and agrochemical pollution. However, on a different side of the coin, synthetic fibres (polyester) have a lesser impact on land and water sources in short term but on a long-term aspect of the world, it is causing the crisis of greenhouse-gas emissions and micro-plastic seepage, which is non-recoverable.

2. The Water-Carbon Nexus

The major outcome of the present study was separation of water and carbon footprints:

According to the data, the natural fibre of cotton is unsustainable, particularly in dry regions, when considering the cradle-to-gate water footprint of the traditional cotton. Reported literature values of irrigation needs are high (up to 20,000 L/kg), which results in the formation of local dead zones in the environment and salinisation of the soil.

Synthetic Fibres: Considering that thermochemical extraction process and polymerisation is an energy-intensive process, the carbon footprint of polyester production is about threefold as that of cotton. However, polyester requires much less water during the raw materials stage, which makes it a much more difficult choice, if there is a water scarcity or carbon limitation for a policy maker.

3. Continuation of the Wet Processing Pollution

Research has drawn a conclusion that dyeing and finishing department is an environmental equaliser. Whatever the base fibre used – be it natural or synthetic – it is the use of conventional chemical dyes that makes up some 20 per cent of world industrial water contamination! The conclusions show that the word natural on a garment is often rendered obsolete for the time the garment leaves the factory as the fibre will be treated with a cocktail of synthetic textures and chemicals, containing heavy metals, which will not allow for natural breakdown.

4. The unchanging Legacy: Microplastics

The most impactful point of view to mention is the quantifiable effect of Microplastic Fibers (MPFs). Natural fibres lose fibre particles which can be disintegrated through microbial activity, whereas synthetic fibres cannot as a result of which the loss of synthetic fibres leads to a lasting contaminant. As for the reduction of waste, it is believed that transition to recycled polyester could be one of the factors causing the release of microplastics in 2025, as it results in a decrease in the structural integrity of the recycled fibers. Circularity of synthetic textiles can therefore produce some unwanted effects on the marine and terrestrial environments.

5. Rhetoric: More Than just Material Choice

The facts show that the chemistry of the thread is not the only reason for the Threads of Destruction and the fast rhythm of the industrial production in the fast-fashion industry is the reason for them. The advantages of the environment, with the use of natural fibers which are considered environmentally friendly, i.e. organic, or synthetics, because of their recycling, currently compensate for the availability of the global production. The discussion highlights the need to switch to Green Chemistry solutions, that is the use of CO 2 -based dyeing solutions and the introduction of Extended Producer Responsibility (EPR) schemes. Unless a paradigm shift in the take-make-waste linear business model is implemented to become a circular economy, the textile will continue to strain its legs and toes on the planet's limits of fresh water consumption and chemical pollution.

CONCLUSION

As the idea of Threads of Destruction is developed, it is clear that it is not the existence of the bad fiber that makes the environmental crisis in the textile industry, but that of the complexity of ecological costs. The results of this study show that the production of natural fiber and synthetic fiber causes large environmental degradation, but, also significantly different degradation processes in both cases. Local ecological destruction due to acute water shortage and soil pollution is still caused by natural fibres (as one group), while global pollution is caused by carbon intensity and irreparable distribution of micro plastics from manufactured fibres.

The analysis also substantiates the following after the claim that "so-called green potential of any fiber is intrinsically undermined by standards of wet-processing. The poor chemical finishes that are applied to make the fiber 'look' and 'feel' the way the consumer wants it to are in effect a universal pollutant and cancel out the 'biodegradability' of natural fibers and contribute to the loss of chemicals that the synthetics release over time. Furthermore, the outcomes of recycled polyester are a major warning: “circularity” without fiber quality and microplastic emissions can become an unobvious potential environmental hazard.

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