VTT Technical Research Centre of Finland

Textile production water use and textile wastewaters

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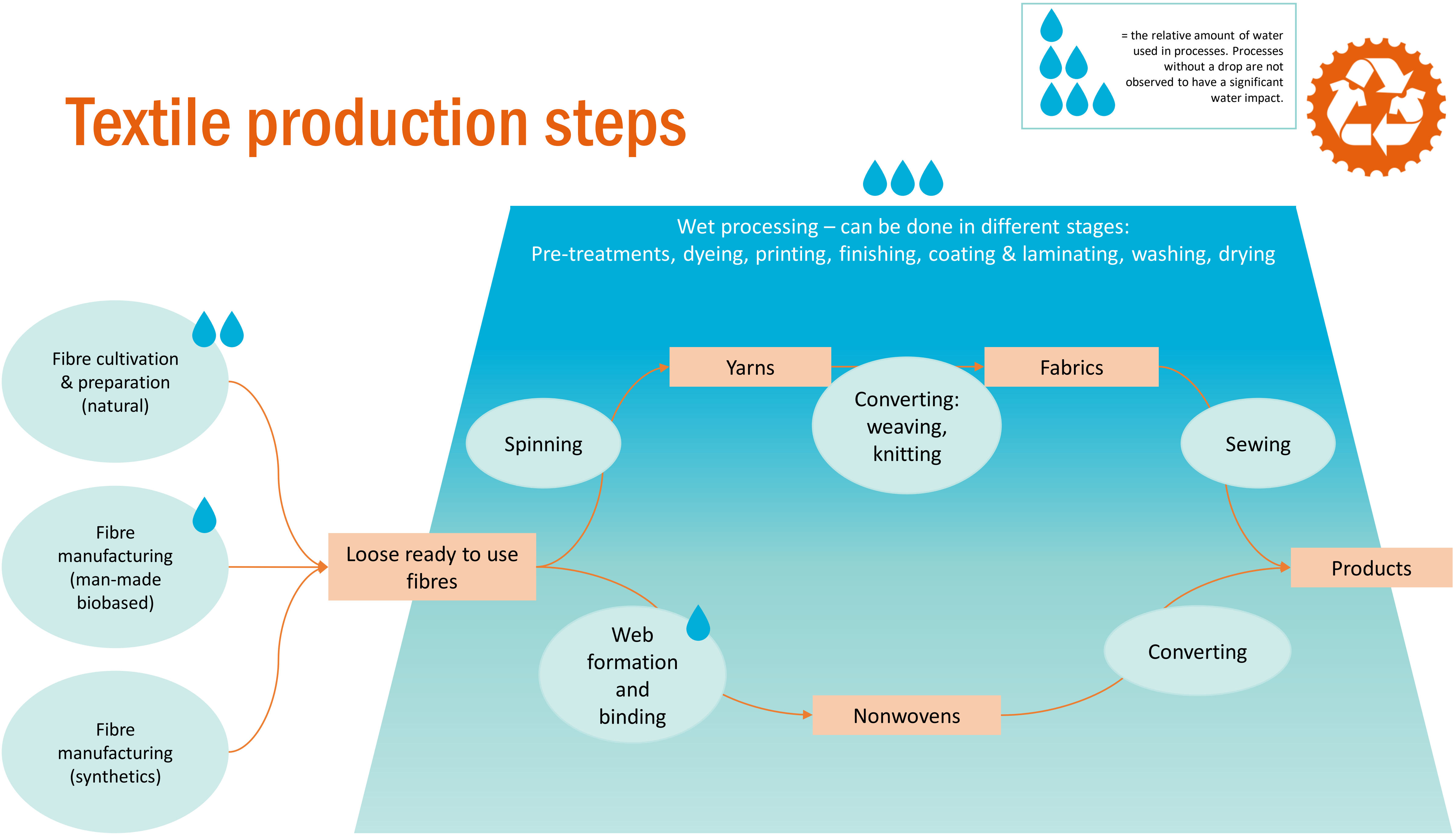
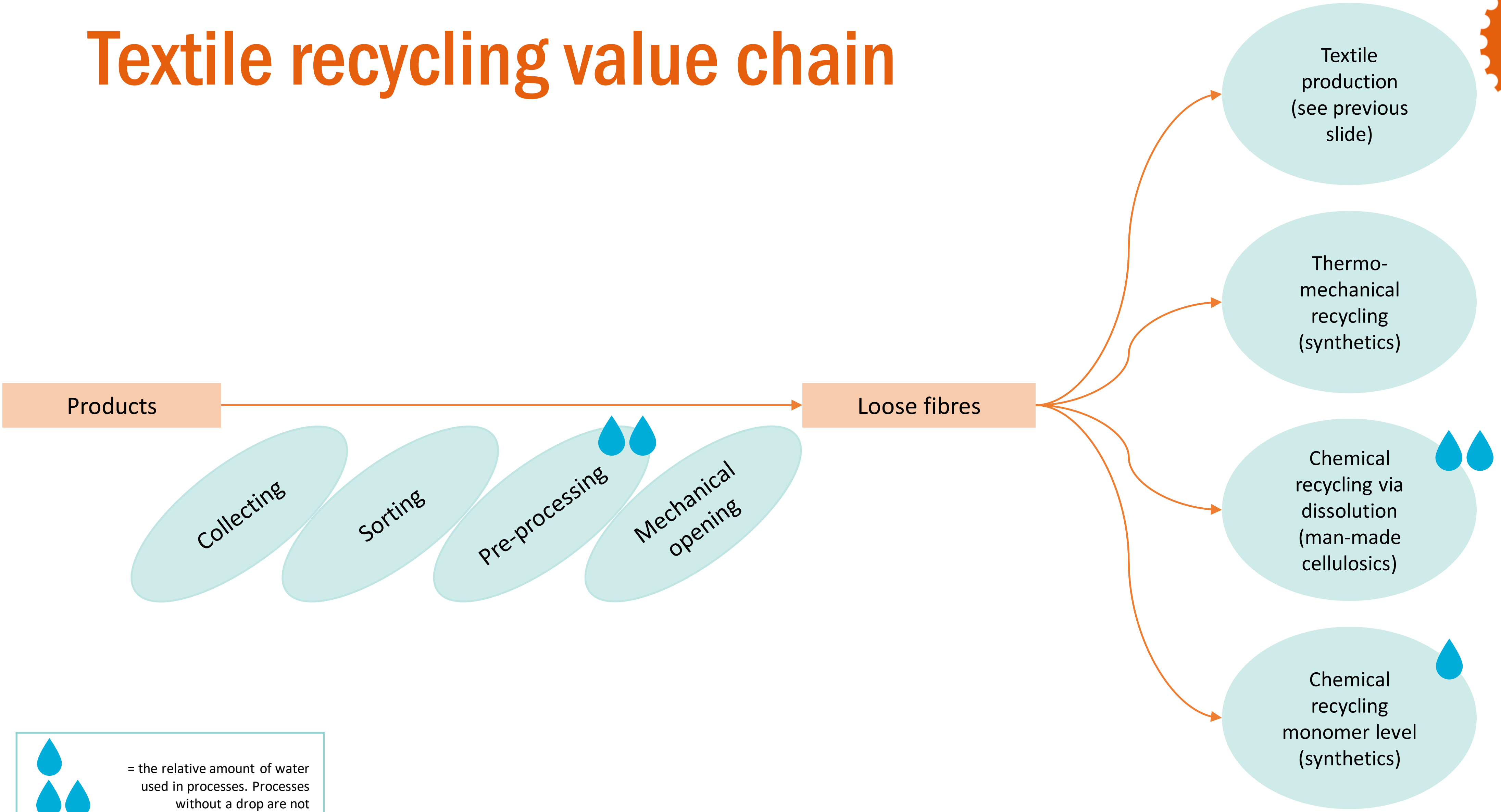
Contents

Textile production steps



Textile recycling value chain



= the relative amount of water used in processes. Processes without a drop are not observed to have a significant water impact.

Water use in textile industry

- The textile industry is estimated to consume **79 billion cubic metres fresh water** along the whole value chain (House of Commons UK 2019, p. 29)
    - It is said that the production of a cotton t-shirt consumes 2700 litres of water (The Conscious Challenge 2019)
    - The production of a pair of jeans consumes on average 10 000 litres of water (BBC 2023)
- The production of clothing, footwear and household textiles that a European citizen (EU-27) buys annually requires **9 cubic metres of blue water**
    - Additionally**, cotton production for the EU-27 market requires 20 billion cubic metres of green water** annually (European Environmental Agency 2023)

Blue water: Water in lakes, surface and groundwater reservoirs. Used for artificial irrigation.

Green water: Water in plants, roots, etc and rainwater. Used by plants.

Grey water: Used, possibly contaminated water. For treating of wastewater.

Fig. 1: Blue, green and grey water definitions.

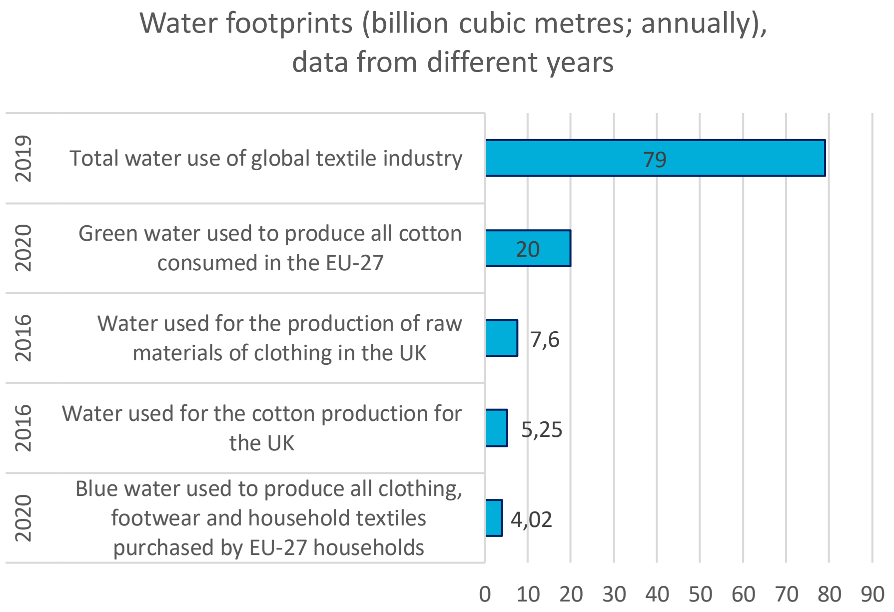


Fig. 2: Water footprints in different scenarios. Numbers from European Environmental Agency (2023), House of Commons UK (2019) and Wrap (2017).

Fresh water use and wastewater concerns in specific production stages

- In general, **most water is used in the textile dyeing and finishing** in the textile industry (Körlü 2019) but there are differences between the different fibres. It is also estimated that **fibre production, followed by dyeing & finishing and yarn preparation** withdraw the most freshwater in the apparel industry (Quantis 2018).
- **Water is used as a medium in e.g., dyeing and finishing, as a washing-off agent, and as generation of heat and steam for the process baths in the textile industry** (Saxena et al. 2017)
- **Fashion industry produces 20 % of the global wastewater** (UN News 2019), and the annual clothing production is estimated to increase from 109 million tons (2020) to 145 millions in 2030 (European Parliament 2023).

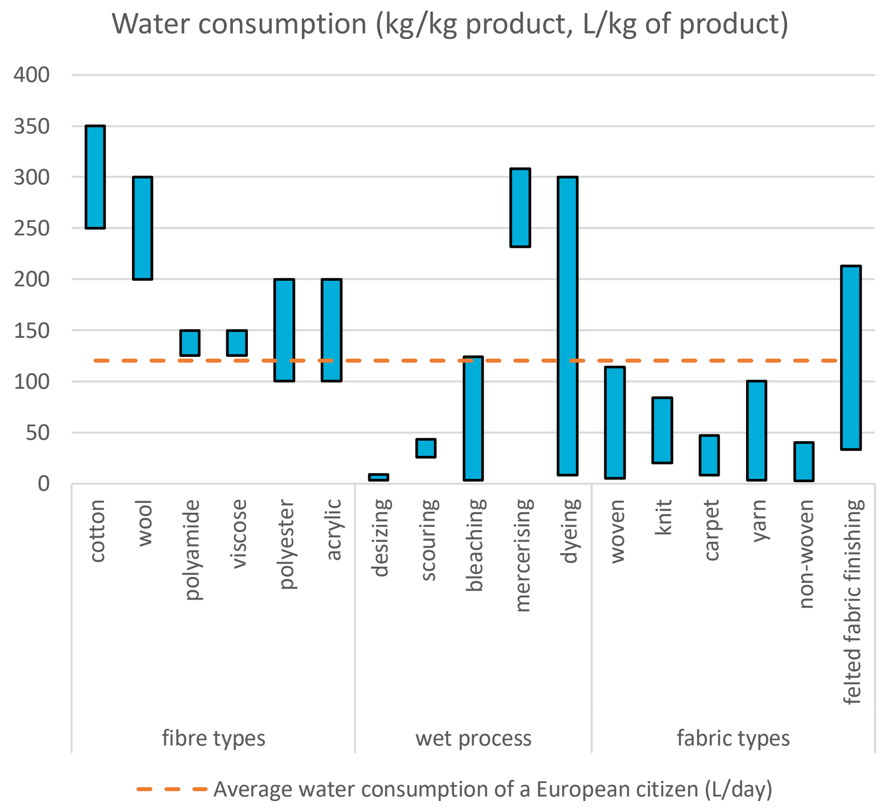


Fig. 3: Water consumption for different fibre types, wet processes and fabric types compared to the daily consumption of water of an average European citizen. (Karthik & Gopalakrishnan 2014, Zaharia & Suteu 2012, Kiron 2014, European Parliament 2018)

Fresh water use and wastewater concerns in recycling processes

- **For mechanical recycling; the water consumption during the recycling processes is low**, although it is expected that the waste textiles coming to the recycling factory so that the recycling process can run smoothly.
    - Water may be used for lubrication, anti-static treatment etc.
- **The greatest freshwater use and wastewater issues are identified for chemical recycling**
    - For cellulosic materials: for a successful chemical recycling, water is necessary in multiple steps. Pre-treatments, baths and washing between stages are the most water consuming stages of chemical recycling
    - For synthetics: synthetics are made of petrochemicals, and they produce microfibres. The most water is used in washing of the recycled PET.
- It has been reported **cellulose carbamate (CCA) production using discarded textiles consumes only 2 % of the water needed for cotton production, or 25 % of the water needed for viscose production**. The same mills may be used for CCA processing as for viscose processes (Paunonen et al. 2019)
    - The CCA regeneration can use up to **86 litres of water per produced kg** of fibre. If the CCA spinning mill is integrated into the pulp mill, water use may be decreased to 31 litres (Paunonen et al. 2019)

Chemical concerns of textile industry

- While it takes 2700L of water to produce one cotton t-shirt, it takes approximately **3 kg of chemicals to produce 1 kg of cotton shirts** (Swedish Chemicals Agency 2014)
- The footwear and apparel industry is estimated to use **8000 different chemicals and 10 000 different dyes** (Chequer et al. 2013, van Dulmen et al. 2023)
    - There are at least 281 hazardous agents and chemicals used in the textile fibre and fabric manufacturing (Haz-Map 2023a) and 562 in wet processes (Haz-Map 2023b).
- The chemicals used in textiles can be divided into three main groups; **the functional chemical substances, the auxiliary chemical substances and the unintended chemical substances** (Swedish Chemicals Agency 2014).
- The textile industry uses detergents, sizing agents, oils, latex, glues, dyes, fixing agents, and other special chemicals used as softeners, wetting agents, etc. (Zaharia & Suteu 2012)
    - **The problems are often associated with the hazardous, unnecessary, and persistent chemicals**

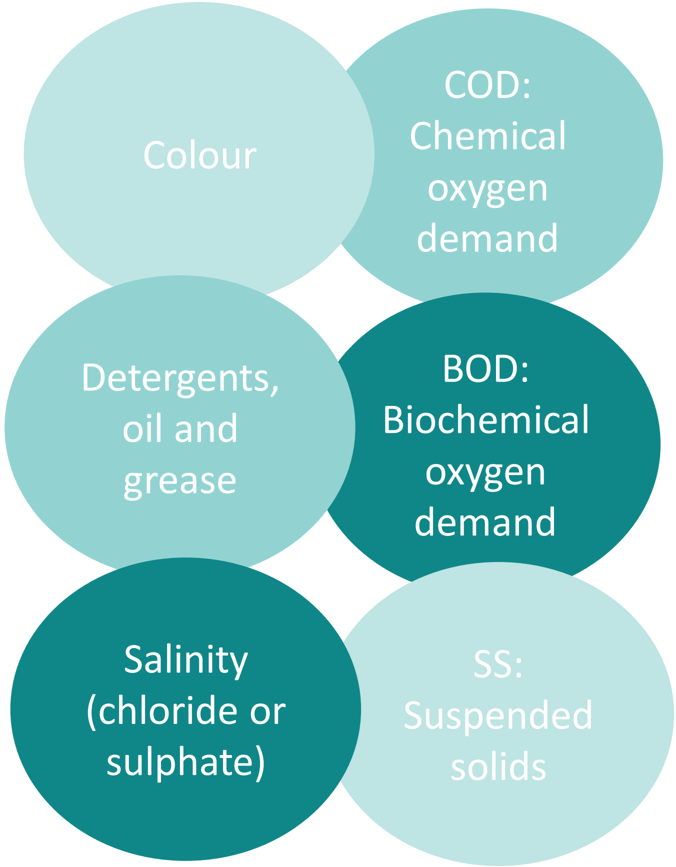


Fig. 4: The most important wastewater purity parameters in textile industry (Hessel et al. 2007)

Fibre production in general

- **On average, a produced kilogram of cotton fabric requires 5961.7 kg water,** with the range of 0 kg to 29 tonnes. 73% of global cotton fields are irrigated. (Picoli et al. 2023). Water consumption in cotton cultivation and in the cultivation of any natural fibres is greatly impacted by the geographic area and its rainfall, and the desired fibre (Chapagain et al. 2006).
    - Cotton has a greater water footprint than many of the other natural fibre crops. For example, the hemp crop water footprint is estimated to be at 2002 litres of water per produced kilogram (Wise et al. 2023) and no irrigation is necessary if rainfall is adequate (Rissanen et al. 2022)
- Synthetics are produced by three main methods: melt spinning, dry spinning and wet spinning
    - A wastewater contaminant directly related to synthetic textiles are microplastics (ECHA 2023)
    - **Wet spinning** is used for the fibres/polymers that cannot be melted or which are not soluble in solvents that can be evaporated (dry spinning). Wet spinning involves a coagulation bath in which the polymer solution comes out as a gel-like filaments. (Mather & Wardman 2015)
- The viscose process is a chemically loaded process with the greatest ecotoxicity impact coming from the sulfuric acid and zinc sulfate used in the coagulation bath (Guo et al. 2021) The main water consumption of MMCF derives from the cooling water (90-95%). The process water only accounts for 5-10%.
    - In lyocell process, the dissolvent (NMMO) can be recycled within the process up to 99.5 % (Mather and Wardman 2015). Guo *et al.* (2021) found that **the process of producing 1 ton of viscose results in 61 tons of wastewater, while lyocell process leaves 20 tons of wastewater**.
    - The exhaust gases of viscose processes include steam, carbon disulfide and hydrogen sulfide. For lyocell process, the exhaust gases comprise mostly of water steam (Guo et al. 2021)

Textiles wet processing

Table 2: The main textile wet process stages, their respective steps and/or most used agents (Maigari 2022, Kumar et al. 2021, Tanchis 2008)

Wet processing can be divided into three main categories or stages:		
Pre-treatments	Dyeing	Finishing
Sizing De-sizing (Thermal drying) Scouring Bleaching Mercerising	• Direct dyes • Vat dyes • Sulphur • Organic pigments • Reactive dyes • Dispersed dyes • Acid dyes • Azoic dyes • Basic dyes • Oxidation dyes • Developed dyes • Mordant dyes • Optical brighteners • Solvent dyes	Wet finishes Mechanical finishes Chemical finishes • Antistatic agents • Antimicrobial • Lubricants • Flame retardant • Water-repellent • Softeners • Stiffeners • UV stabilization

The water used in wet processing should be mild or soft, free of bicarbonate metals, free of ammonia, free of dissolved compounds, free of insoluble or floating matter, free of hydrogen sulfide, carbon dioxide and other dissolved gases, colourless, odorless, at normal temperature and have normal physical properties, such as boiling point, freezing point and density. (Kiron 2022)

Textiles wet processing

- **Textile wet processes consume approximately 60 to 90 % of the total water used in textile processes**. This is due to the effective rinsing of chemical agents between the different stages (Jovančić & Radetić 2008)
- **De-sizing and scouring are estimated to be the most chemical polluting wastewater stages** of textile wet processes (Jovančić & Radetić 2008)
- **Different surfactants are used in wet processes to make the production and manufacturing of textiles more efficient. Alkylphenol ethoxylates (APEO's) are a common type of surfactants**, that can be used in many pre-treatments, e.g. scouring, in lubrication, dyeing and printing, and finishing treatments (PCC Group 2023, Khan et al. 2023)
    - APEO's pose potential health risks and environmental risks. **Nonylphenol ethoxylates (NPEs/NPEOs)** are one of the most widely used APEOs. The use of NPE's has been restricted in EU since 2006 by REACH. (Chem-MAP 2019). **NPE's degrade into nonylphenols, that are toxic, bio-accumulative and persistent** (Greenpeace 2012, Hong et al. 2020).

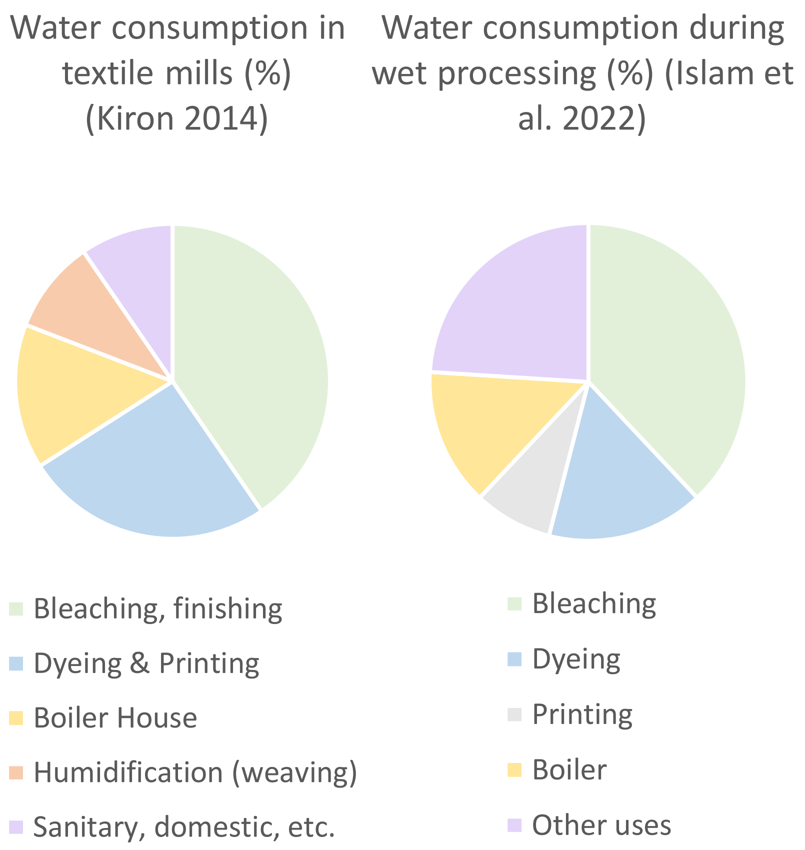


Fig. 7: The water consumption share of different textile processes.

Pre-treatments

Table 4: The chemicals used in the pre-treatments, the pollutants in the processes and the wastewater characterisation (Liu et al. 2022, Saxena et al. 2017, Le Marechal et al. 2012, Kiron 2014, Zaharia & Suteu 2012).

	Added substances	Possible wastewater contaminants and pollutants from the process	Wastewater characterisation	Water consumption (references are estimated so that 1 kg equals 1 liter)
De-sizing	De-sizing agents	Starch (used as a sizing agent), dilute acids, caustic soda, hydrogen peroxide, persulphate, carboxymethyl cellulose (CMC), enzymes, fats, oils, waxes, gelatine, polyvinyl alcohol (silk, acetates and other synthetics, hemicelluloses (cellulosic fibres)	**High BOD**, high COD, high TS, neutral pH	Low • Estimations between 3-9 litres of up to 23 liters including the washing after
Scouring	Wetting agents, emulsifiers, sequestering agents,	Anionic surfactants, non-ionic surfactants, waxes, fats, oils, soaps, sizes, glycerol (cotton), hemicelluloses (cotton), petroleum spirit (synthetics), glycol (wool), mineral oils (wool), acetate (wool), formate (wool), nitrogenous matter (wool)	High BOD, **high COD**, high TS, high alkalinity, high temperature	Low • Estimations between 23-43 litres. Washing of the scouring agents requires a major share of the amount
Bleaching	Oxidative or reducing bleaching agents, catalysts, stabilisers, neutralizers, surfactants, emulsifiers, dispersing and wetting agents	Heavy metals, radicals, metal complexes (the stabilisers inhibit the catalayst reactions), salts (from the neutralization of alkaline baths)	**Increased COD** due to the stabilizers, high BOD, high TS, high alkalinity	Medium • Anywhere from a few litres up to 124 litres of water. The bleach bath only requires approximately 2 l of water, washing off the rest • Bleaching with hydrogen peroxide requires large amounts of water
Mercerising	Alcohol sulphates, anionic surfactants, cyclohexanol, sodium hydroxide	Alcohols, phenols, benzaldehydes	High TS, high alkalinity	High • 232-308 litres per kg of product • Effluent can be re-used in scouring and bleaching

Dyeing

- First synthetic dye was discovered in 1856. From then, **most dyes used in the industry are synthetic. The dyes are often also toxic, mutagenic and carcinogenic, and the discoloured effluent causes problems in blocking the sunlight from reaching the aquatic life** (Zaharia & Suteu 2012, Zaharia et al. 2009, Hessel et al. 2007).
- Textile dyeing involves many chemicals**; the dyes and pigments and added organic and inorganic substances to facilitate the easier colouring**. Moreover, the wastewater of dyeing effluent must be controlled in terms of e.g., pH due to difficulties in conventional wastewater treatment processes. (Zaharia et al. 2009)
- **The dye effluents contain heavy metals**, such as cobalt (Co), copper (Cu), chromium (Cr), cadmium (Cd), iron (Fe), lead (Pb), manganese (Mn), nickel (Ni) and zinc (Zn) that facilitate the dying but pose risks to human and the environment (Khan et al. 2023, Uddin 2021).

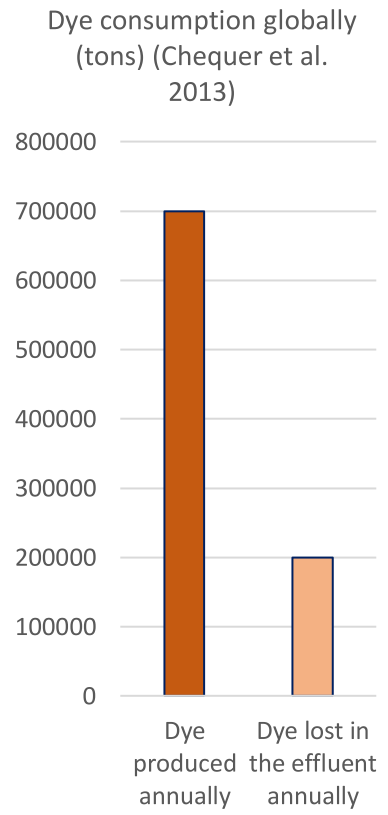


Fig. 9: The dye consumption and the unfixed dyes.

Heat-setting, dyeing, printing and finishing

Table 6: The chemicals used in following processes, the pollutants in the processes and the wastewater characterisation (Uddin 2021, Le Marechal et al. 2012, Kiron 2012, Zaharia & Suteu 2012, Jovančić & Radetić 2008).

	Added substances	Possible wastewater contaminants and pollutants from the process	Wastewater characterisation	Water consumption
Heat-setting	-	Scouring agents, dyes (less frequently)	Low BOD, low solids, high alkalinity	Low to medium • Hot water, steam (or air) • Short but energy consuming process
Dyeing	Acids, alkali, salts, fixing agents, carriers, dispersing agents, surfactants, soaps, reducing agents, stabilisers, pH controllers, leveling agents, etc.	Metals, non-biodegradable and persistent organics that include polyacrylates, phosphonates, sequestering agents (EDTA), synthetic sizes, anti-static, dispersing or fixing agents, preservatives,	Colour, High BOD, high COD, solids, neutral to alkaline pH	Low to high *depending* on the process • The cold pad-batch dyeing process is estimated to consume 15 m3 of water for ton of product, whereas paddly dying process may consume up to 290 m3 of water for ton of product (Ren 2000 se Kumar et al. 2017)
Printing	Thickeners, printing pastes, adhesives, reducing agents, binders	Printing paste and dye residues, volatile organic compounds (VOC's), urea, organic solvents,	Colour, High BOD, high COD, solids, neutral to alkaline pH	Low • Concentration of contaminants is high
Finishing	*Depends greatly on the desired property*; flame retardants, cross-linking easy care agents and softeners, antistatic agents, hydrophobic agents, biocides, etc.	Organic pollutants: cross-linking agents (easy-care) based on formaldehyde; organohalogens and phophorus compounds (FR agents); non-ionic, cationic surfactants, waxes (softeners); quaternary ammonium compounds (antistatic agents), waxes and fluorocarbons (water and soil repellency)	Colour, High BOD, high COD, solids, neutral to alkaline pH	*Depends greatly on the desired property*

Chemical recycling in general

- Water is used in pre-treatments, pre-washing, dissolution, depolymerisation, separation of catalysts, spinning and post-washing of chemically recycled fibres
- Cellulose recycling
  - Pre-treatment: Manipulation of DP, viscosity and metal and impurities removal. Haslinger *et al*. (2019) describe a pre-treatment process consisting of **alkali washing state, ozone and hydrogen peroxide baths, acid washing and disk refining**. Often used pre-treatment is an aqueous NaOH solution, washed off with distilled water (Ma et al. 2019)
  - Dissolution of cellulose can be done with NaOH, **NaOH with CS_2**, N_2O_4 with DMF, PF with DMSO, Cu with amine, LiCl with DMAc, NMMO, ionic liquid (IL), IL with DMSO, or alkali with urea (Li et al. 2021, Ma et al. 2019)
  - The cotton regeneration is most often done with wet spinning and dry-wet jet spinning (Asaadi et al. 2016). Coagulation baths can contain only water (Sun et al. 2021, Haslinger et al. 2019), or water with different concentrations of H_2SO_4 and Na_2SO_4 (Li et al. 2021),
- Polyester recycling
  - The chemical recycling of polyester (polyethylene terephthalate, PET) is carried through depolymerisation. It can be done with alcoholysis, **acid hydrolysis, alkaline hydrolysis (saponification, acidification), neutral hydrolysis (esterification),** aminolysis, ammonolysis and glycolysis

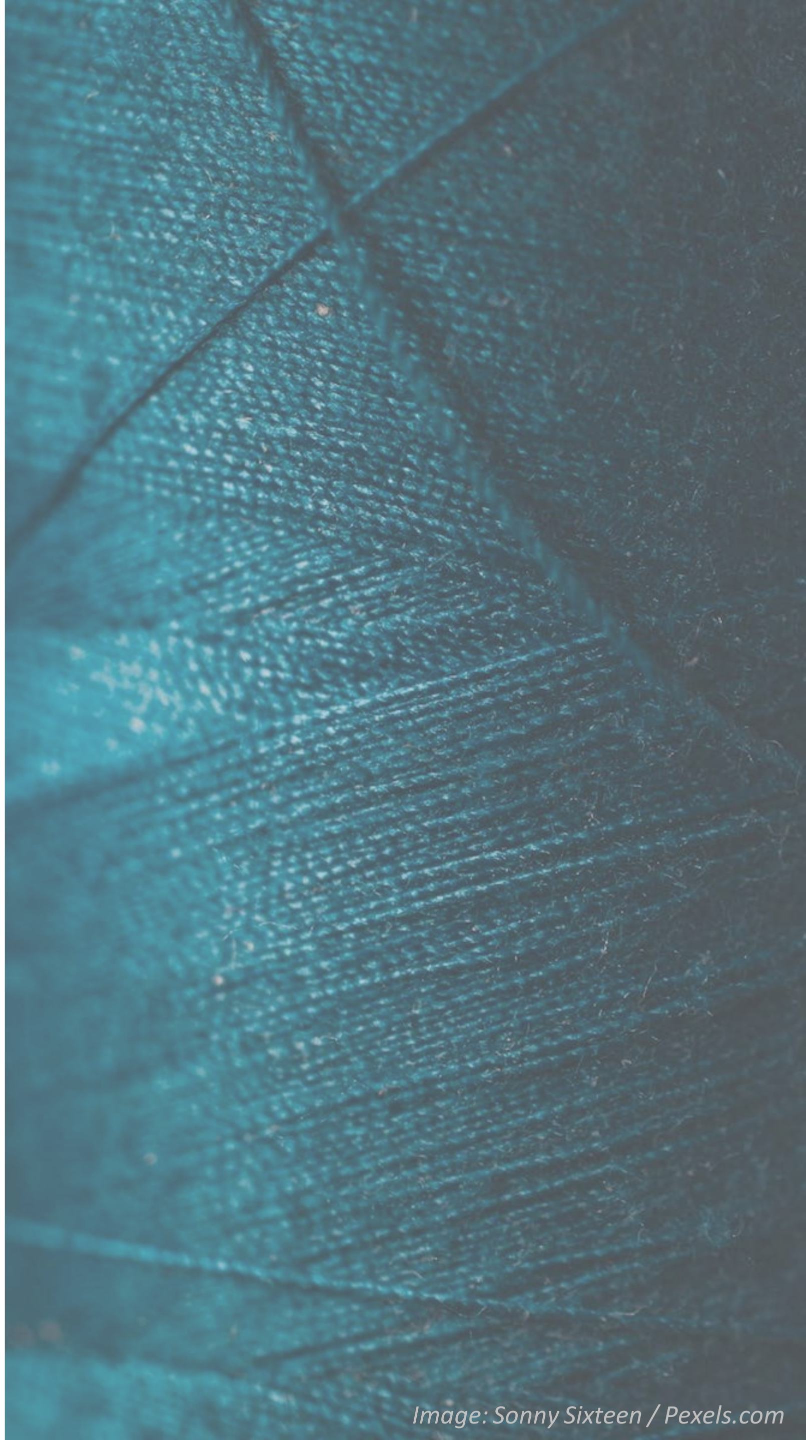


Image: Sonny Sixteen / Pexels.com

Wastewater treatments in textile industry

- The textile wastewater treatments consist of primary, secondary and tertiary treatments. **The primary treatment removes the solids, the secondary treatment decomposes the bacteria, and the tertiary treatment serves as an extra filtration** (LibreTexts 2023). Depending on the effluent, different treatments are used.
- The different technologies can be divided into 4 categories; **biological, physical, advanced chemical technologies, and their combinations.**

Biological treatments

- Aerobic biological treatments
- Anaerobic biological treatments
- Biosorption
- Enzyme degradation
- Algae culture

Physical treatments

- Membrane technologies; filtration
- Other filtration/coagulation techniques
- Activated carbon technologies
- Ion-exchange
- Irradiation
- Adsorption
- Reverse osmosis

Advanced chemical (oxidation) processes

- Electrochemical oxidation
- Electro-coagulation treatment
- Sono-catalytic process
- Photocatalytic treatment
- Photo-Fenton process
- Ozonation
- Ultraviolet irradiation

Combined technologies

- Anaerobic-ozonation process
- Fenton process as post-treatment and sequencing batch reactor
- Chemical + biological treatment
- Simultaneous chlorine photolysis treatment + photo-assisted electrochemical

Fig. 10: The textile wastewater treatment processes can be divided into four categories, with respective examples (Ahsan et al. 2023, Kumari et al. 2023).

Wastewater treatments in textile industry

- **The textile industry uses majority of its water in processing (90-96 %), and the rest (6-10 %) in cooling**. The amount of water used in processing is great compared to chemical industry, where approximately 20 % of the water is used in processing and the rest (80%) in cooling (Zaharia & Suteu 2012)
- The textile wastewater is characterised by the presence of **inorganic persistent pollutants** (European Environment Agency 2018), **high COD, BOD, and presence of matter, oil and grease** (Pensupa et al. 2017). **To be removed from/treated in textile wastewater include** (Zaharia & Suteu 2012):
  - **Colour**; this is done by de-colourization using biological and advanced non-biological methods. There is scarcity of data in how successful it is, and for example bright water-soluble reactive dyes are difficult to remove. Tertiary treatment is often necessary with organic dyes
  - **Differentiating pH values, salts, oxidants**; inorganic pollutants that are relatively easy to remove
  - **Starches, natural oils and waxes, biodegradable surfactants**; easily biodegradable
  - **Colourants, whitening agents**; difficult to biodegrade
  - **Polyvinyl alcohols, mineral oils**; difficult to biodegrade
  - **Retarders, heavy metals, formaldehyde, etc.**; cannot be removed by biological treatment

EU Regulation

- **Water Framework Directive (WFD)**, Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy
  - In force since 2000, the main law for water protection. **In 2022, it was proposed to revise the list of pollutants**
  - Supported by two daughter directives; one for the quality and quantity of groundwater and another one for the quality of surface water.
  - River basin management plans are mandatory for the Member states as described in Article 4, this means **protection and restoring of the water bodies, maintaining a good ecological and chemical status**
- **POPs Regulation**, Regulation (EU) 2019/1021 of the European Parliament and of the Council of 20 June 2019 on persistent organic pollutants
  - Amendment of Annex IV: care must be taken in disposal and management of waste containing or contaminated by added substances
  - **For textiles, the greatest concerns are with perfluorooctanoic acid (PFOA) and its salts and related compounds, polybrominated diphenyl ethers (PBDEs), hexabromocyclododecane (HBCDD) and perfluorohexanesulfonic acid (PFHxS) and its salts and related compounds**.
- **Drinking water directive**, Directive (EU) 2020/2184 of the European Parliament and of the Council of 16 December 2020 on the quality of water intended for human consumption
  - The main goals of the directive are to improve or maintain the quality of water, conclude a risk assessment/management and improve access to clean drinking water (European Commission 2024).
  - Article 25 states that **from 12th January 2026, the Member states must ensure the following substances do not exceed the limits in drinking water meant for human consumption:** Bisphenol A (2.5 µg/l), Chlorate (0.25 mg/l), Chlorite (0,25 mg/l), Haloacetic Acids (60 µg/l), Microcystin-LR (1.0 µg/l), PFAS Total (0.5 µg/l), Sum of PFAS (0.1 µg/) and Uranium (30 µg/l).
  - **Beta-estradiol and nonylphenol added to the first watch list** in January 2022 due to their endoctrine disruptance and the risk they pose to human health, as described in article 13 of Directive (EU) 2020/2184 and later in Decision (EU) 2022/679
  - The directive will also **follow up on the microplastics** by ”adopting a methodology to measure microplastics with a view to including them on the watch list” and follow the risks microplastics pose to human health through drinking water

UN Drinking water goal

- United Nations Sustainable Development Goal 6 aims to ensure clean drinking water and sanitation for all by 2030.
- **2 billion people lack safe drinking water**. While 44% of household wastewater is not safely treated, there is insufficient data regarding the safety of industrial wastewater treatment (United Nations 2021)
- **Global access to safe drinking water has been increasing** from 2015 to 2021, but the pace needs to be accelerated to reach the goal of safe drinking water by 2030 (WHO 2021)

6 CLEAN WATER AND SANITATION

Image: Seçil Sarı / Pexels.com

Conclusions

- Most water in textile production is used in processing, 90-96 %, and approximately 65 % of that is used in textile dyeing, printing and finishing
- Textile effluent is described by high alkali or acidic pH, vibrant colour, high COD, high BOD and presence of metals and other impurities
- Wastewater treatments include physical, chemical and biological methods, as well as their combinations
  - Primary, secondary, and tertiary treatments are used when necessary
- Legislation and restricted substance lists aim at eliminating or limiting certain chemicals from ending up in drinking water or in groundwater

Table 7: Recommendations for more knowledge on the matter.

Chemical burden of the textile industry	**Wastewater purification, water depletion impact**
Khan et al. 2023	Ahsan et al. 2023
Uddin 2021	Islam et al. 2022
Pensupa et al. 2017	Zaharia & Suteu 2012
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