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GLOBAL ASSESSMENT OF PRIVATE SECTOR IMPACTS ON WATER

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Acknowledgments

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Executive Summary

Figure 3. Key sectors and industries within those sectors with the most severe and systemic impacts on freshwater resources.

Key Sectors and Industries

Consumer Staples	Consumer Discretionary	Energy	Health Care	Materials	Information Technology	Utilities
Food products Beverage	Textiles, Apparel, and Luxury Goods	Oil and Gas	Pharmaceuticals	Chemicals Metals and Mining Paper and Forest Products	High-tech and Electronics Semiconductor and Circuit board Battery Manufacturing	Renewable Electricity (hydroelectric power)

Industry – from food production to mining, apparel manufacturing to high-tech – is collectively the single largest user and influencer of freshwater resources globally. Therefore, it has much to lose from critical water risks as population pressures and climate risks grow. How industry responds to intensifying water scarcity and water quality risks globally will be critical to its long-term future and society at large.

Against this backdrop, Ceres, in partnership with the Valuing Water Finance Initiative, commissioned the Global Institute of Water Security at the University of Saskatchewan for a first-of-its-kind comprehensive scientific review and analysis of industry impacts on freshwater resources around the world. This report analyzes the global role and impacts that industries are having on water systems, including their impact on water use, pollution, water flow alterations, and broader hydrologic system disruption. It also examines the long-term exposure that different industry sectors are facing from escalating water risks and the actions that companies can take to mitigate those risks.

Through this comprehensive analysis of the scientific literature, the report identifies five critical threats to global freshwater systems - **groundwater depletion, metals contamination, plastic pollution, diversion and transfer of water,** and **eutrophication** – threats driven primarily by industry practices.

The analysis makes clear that key industries, including **Food Products, Textiles, and High Tech and Electronics**, are the biggest contributors to these problems, which are undermining the functioning of global freshwater systems that underpin economic and societal stability.

This analysis demonstrates that these threats are not only locally severe, but are widespread, posing broader systemic risks to the global economy and to investment portfolios than have been commonly acknowledged. The degree to which corporate practices are triggering these severe and systemic impacts exposes companies and their investors to far-reaching financial risks, as several studies reviewed in the report show. A recent Barclays' research note warned that the Consumer Staples sector alone, which includes food and beverage production, is facing a potential $200 billion impact from water scarcity risks – roughly three times higher than carbon-related risks.

This report outlines the important role investors can play in engaging with companies and the industries that they invest in to halt the systemic harm these sectors are causing.

Given that climate change is accelerating these risks, time is running out to protect the Earth's most precious natural resource. The report concludes that it will be impossible to advance global water security without far stronger private sector leadership – both from companies and the investors owning them. Concerted and focused efforts of investors, companies, and governments to drive change in these unsustainable practices would make a significant positive impact to protect global water security, economic development, and the lives of millions.

Figure 4. Threats to freshwater from industrial practices deemed Very High (VH) or High (H) in terms of its severity, systemic nature, and overall impact. (see Appendix D).

Top 5 Critical Threats to Freshwater from Industry					
Water Impact	**Description**	**Severity**	**Systemic nature**	**Overall impact**	**Relevant GICS Industries**
Eutrophication	Excessive nutrient loading to water, usually nitrogen and phosphorus, which in turn stimulates excessive growth of algae and other aquatic plants that consume oxygen in the water.	VH	VH	VH	• Food products • Beverage • Household products • Textiles
Groundwater Depletion	An escalating global threat that has led to groundwater wells drying up due to excessive water extraction that exceeds natural recharge capacity.	VH	VH	VH	• Food products • Oil and gas • Metals and mining
Metals Contamination	Damages natural ecosystems and pollutes drinking water, threatening human health.	H	H	VH	• Metals and mining • Semiconductor and circuit board • Battery • High-tech and electronics
Plastic Pollution	A major pollutant that impacts aquatic species through entanglement and ingestion of plastics.	H	VH	VH	• Personal products • Food products • Beverage • Textiles • Automobiles • Chemicals
Diversion and Transfer of Water	Includes transferring water from one river basin to another and artificially concentrating water in large quantities using man-made channels and reservoirs.	H	H	VH	• Food products • Metals and mining • Renewable power (hydroelectric power)

KEY REPORT FINDINGS

These wide-ranging critical threats are not being caused by one industry alone. The biggest player is the **Consumer Staples sector**, including food, beverage, and livestock production. This sector is the largest driver of groundwater depletion and water pollution globally, much of it from nutrient-laden fertilizers and manure that overflow into streams, rivers, and coastal estuaries, causing low-oxygen, eutrophic 'dead zones' that are spreading worldwide. Agricultural supply chains within this sector account for 70% of global water withdrawals.

Other industries are also contributing to water scarcity threats. The **Textile, Apparel, and Luxury Goods industry**, mostly due to thirsty cotton production, is a significant driver of groundwater depletion in India, Brazil, Central Asia, and parts of the U.S. The **Metals and Mining industry** and **Oil and Gas industry**, especially from hydraulic fracturing and oil sands extraction, are also causing severe groundwater depletion and pollution.

On the pollution front, the **Metals and Mining industry** is the largest source of metal pollution, but the **Information Technology sector** also plays a significant role due to production of semiconductors, circuit boards, and batteries. The **Textile, Apparel, and Luxury Goods industry** also has a significant impact on water pollution, particularly in Asia, through the direct discharges of untreated or insufficiently treated wastewater from dyeing and finishing textiles directly into rivers and streams. In addition, textile plants release an estimated half-billion tons of microfibers from textile washing each year.

The report's analysis reveals broad shortcomings in how water is being managed and governed globally, notably:

Lax regulations

Weak or nonexistent policies and regulations governing water use and water quality impacts are an all-too-common problem globally. The dearth of policies is especially pervasive in Asia, Africa, and other developing countries where chemicals, heavy metals, and micro-plastics are discharged untreated into rivers, streams, and coastal estuaries. In particular, food production practices have tended to be less regulated globally.

Undervalued resource

Water is broadly undervalued globally. With rare exceptions, global economic systems continue to treat water as an infinite resource that has little monetary value, resulting in poorly managed and inefficient water use by industries in most parts of the world.

Water management gaps

Water management practices vary widely in scale and effectiveness across many industries – an indicator of the enormous challenge, but also the potential, for scaling up water management best practices worldwide, including the joint management of surface and groundwater resources.

Social responsibility gaps

Private sector water activities are triggering damaging social impacts across the globe, with vulnerable communities, including Indigenous and fenceline communities, being disproportionately impacted. Activities such as water diversions are displacing communities, the disproportionate use of water resources and overdraft of groundwater are leading to conflicts between frontline communities and industries, and the discharge of polluted water and inadequate wastewater management is impairing drinking water quality and jeopardizing human health.

The report cites several studies showing that stronger water management measures from industries will be far less costly than 'business as usual' approaches that have been broadly insufficient so far. A Barclays' report, for example, estimates that proactive water management will cost the Consumer Staples industry 18 times less than the cost of inaction. A 2019 CDP report reached a similar conclusion for other industry sectors.

Table 2. Table 2 provides a relative assessment of water impacts caused by industries within areas of the value chain, whether from direct operations, global supply chains, or end-product use. Industries with the most severe (very high) impacts throughout the value chain include Food Products, Beverage, Textiles, Apparel, and Luxury Goods, Oil and Gas, Pharmaceuticals, Chemicals, Metals and Mining, Paper and Forest Products, and Renewable Electricity.

Industry-Level Water Risk Overview

Very High Risk | High Risk | Medium Risk | Not enough information found

GICS Industry	Supply Chain		Direct Operations		Product Use/End of Life	
	Water Quantity	Water Quality	Water Quantity	Water Quality	Water Quantity	Water Quality
Food Products	Very High Risk	Very High Risk	High Risk	High Risk		
Beverage	Very High Risk	Very High Risk	High Risk	High Risk		Very High Risk
Household Products		Medium Risk		Medium Risk		High Risk
Personal Products				Medium Risk		High Risk
Textiles, Apparel, and Luxury Goods	High Risk	High Risk	Medium Risk	Very High Risk		High Risk
Automobiles and Components		Medium Risk		Medium Risk		Medium Risk
Hotels, Restaurants, and Leisure			Medium Risk			
Oil and Gas	High Risk	Very High Risk	High Risk	Very High Risk		Medium Risk
Consumable Fuels	Medium Risk		Medium Risk			
Construction and Building	Medium Risk	Medium Risk	Medium Risk	Medium Risk		
Electroplating				High Risk		
Pharmaceuticals				Very High Risk		Very High Risk
Chemicals	High Risk	High Risk	Medium Risk	Very High Risk		
Construction Materials			Medium Risk			
Metals and Mining	High Risk	High Risk	High Risk	Very High Risk		
Paper and Forest Products	High Risk	High Risk	High Risk	Very High Risk		
High-tech and Electronics	High Risk	High Risk	High Risk	High Risk		
Semiconductor and Circuit Board			Medium Risk	High Risk		High Risk
Battery	High Risk	High Risk		High Risk		High Risk
Renewable Electricity			Very High Risk	Medium Risk		
Electric Utilities				Medium Risk		

KEY IMPACTS IDENTIFIED

The report identifies the five most critical threats – largely attributable to industry – that are causing systemic impacts on water quantity, water quality, and broader environmental changes.

Eutrophication

Eutrophication, a complex process that results from excessive nutrient loading caused mostly by livestock- and fertilizer-related runoff and detergent discharges into wastewater, is increasing exponentially worldwide, causing billions of dollars in damages. Eutrophic "dead zones" in water cause fish die-offs, human health impacts, and declining water quality. Eutrophication affects an estimated 54% of the lakes and reservoirs in Asia, 53% in Europe, 48% in North America, 41% in South America, and 28% in Africa. In the U.S. alone, the United States Environmental Protection Agency has identified more than 166 dead zones across the country, including in the Great Lakes, Chesapeake Bay, and the Gulf of Mexico, much of it from agriculture-related nitrogen runoff. While some voluntary industry-led initiatives are underway in the U.S. to reduce nutrient pollution, these efforts are mostly small-scale in nature. And even as progress is being made in some parts of the world to reduce run-off of certain kinds of nutrients, the impacts from industry continue to grow in other regions. For example, nutrient levels in municipal wastewater are expected to increase 4- to 8-fold in sub-Saharan Africa and 3- to 5-fold in South Asia by 2050.

Groundwater Depletion

Groundwater depletion is an escalating global threat that has resulted in underground aquifers and groundwater wells drying up faster than their natural recharge capacity. Groundwater aquifer depletion, mostly due to crop-related irrigation, increased 22% from 2000 to 2010 globally. A 2019 study estimated that by 2050, 42% to 79% of watersheds that pump groundwater globally could surpass ecological tipping points without better management. Declining water tables are already causing financial impacts, including higher pumping costs and reduced crop yields and crop acreage. In India, cropping intensity, or the number of crops that farmers can grow in a given year, decreased by 68% in northern regions due to groundwater depletion. Devastating droughts and groundwater depletion in California have forced farmers to leave millions of acres unplanted in recent years. While water policy instruments have been strengthened in recent years by the 38 countries that are members of the Organization for Economic Co-operation and Development (OECD), these instruments are less commonly used to protect groundwater than surface water. Still, in places like California, nearly half of the state's crops are being produced with extremely inefficient flood irrigation practices.

Diversion/Transfer of Water

Water diversion and transfer projects are critical for many industries, particularly to support food crop irrigation and power generation. However, dams and other large-scale water diversions cause major disruptions to global water systems and critical habitats. Dams damage rivers in many ways, including through ecosystem impacts, high evaporation losses, leakage due to poor maintenance, increased salinization, and reduced sediment loading. They also cause societal upheaval and dislocation. More than 48% of global river basins are severely affected by existing water diversion projects, many of them in North America. Global river fragmentation will likely double if nearly 4,000 planned hydroelectric dams are built, most of them in China, India, South America, and Africa.

Metals Contamination

Metals, which can be toxic in even relatively low concentrations, are a threat to human health and wildlife worldwide. The human health threat is especially large in developing countries lacking environmental regulations and adequate wastewater treatment to address metals. Heavy metals have been found in rivers and lakes globally, with the highest concentrations in Africa, Asia, and South America, and lower levels in Europe and North America. Most metal pollution comes from the Metals and Mining industry, which releases contaminants during raw material extraction and processing. Another source is IT companies, which produce semiconductors, circuit boards, and batteries, leading to contaminated wastewater, including with mercury, copper, chromium, lead, and lithium. As water is increasingly polluted with metals, this also creates water scarcity risk for companies, especially IT firms that need ultrapure water. According to a 2019 CDP report, 91% of metals and mining companies reported water risk exposure, with an estimated combined financial impact of $24.9 billion.

Plastic Pollution

The world produces more than 368 million tons of plastic each year for packaging and other industrial uses, and, if managed or disposed of improperly, plastic waste can easily end up in water bodies, polluting water, entangling and poisoning aquatic species, and entering the food chain. Up to 80% of plastics in the world's oceans are carried there by rivers. The growing presence of plastics in water has major implications on the efficacy of water and wastewater treatment processes, impacting all water users. Microplastics (plastics less than 5 millimeters in size) are of particular concern because of their persistence in the environment and bioaccumulation in food chains. Poor waste management practices in many Asian countries have contributed to the continent being identified as generating the greatest volumes of plastic pollution globally. Asian rivers account for an estimated 86% of total plastic releases to ocean waters globally.

Climate Change -A Threat Multiplier

Climate change is directly impacting the global water cycle and the distribution and availability of freshwater around the world. Increasing temperatures, melting ice sheets and glaciers, changes in the distribution of water, and uncertainty associated with climate change all intensify the impact and development of critical threats to freshwater. These impacts on freshwater will also increase risks to industries that rely on freshwater resources. The private sector's response to these critical threats will require more focused consideration of climate change's role as a threat multiplier.

Emerging Threats

Recent research highlights additional evolving threats to global freshwater resources that will require heightened attention from industry and policymakers. These threats are intrinsically linked with industry activities that are proliferating and have only recently been identified as threats. For example, even as thousands of pharmaceutical drugs are polluting water resources across the U.S., most of them are not subject to federal safety limits and are currently not being measured in drinking water supplies or being removed during wastewater treatment. Per- and polyfluoroalkyl substances (PFAS), a widely used group of artificial toxic chemicals known as "forever chemicals," are also largely unregulated.

Pharmaceuticals

Escalating releases of pharmaceuticals, such as prescriptions and over-the-counter drugs, in water resources will have long-term damaging impacts on human and environmental health. Many wastewater treatment plants are not equipped to remove these complex chemical compounds, which, as a result, are being continuously released into water bodies. Between 1995 and 2015, research has found that pharmaceutical-related risks to global aquatic ecosystems rose 10- to 20-fold. Studies show that pharmaceuticals in water can impact antimicrobial and antibiotic resistance, create toxicity and endocrine disruptors in organisms, and impact human reproductive health.

PFAS

PFAS, commonly referred to as "forever chemicals," are a group of artificial chemicals widely used by industry to create non-stick coatings on cookware, carpets, and food packaging. PFAS are highly persistent and bioaccumulate, becoming a critical toxin in surface and drinking water. Discharged mostly in domestic wastewater, PFAS have been found in drinking and coastal marine waters, primarily in Europe, China, Korea, Japan, and North America. A recent study found nearly 120,00 facilities in the U.S. that may be handling PFAS and could be a source of contamination. PFAS have many human health implications, including cancer, thyroid disease, low birth weight, and immune suppression. The Stockholm Convention on Persistent Organic Pollutants added PFAS in 2015 as a compound that needs to be phased out eventually through use of safe alternatives.

INDUSTRY ACTIONS TO MITIGATE GLOBAL WATER RISKS

The report makes clear that current industry practices are leading to systemic water risks that jeopardize their business future and society at large. But it doesn't have to be this way. The private sector and investors are positioned to lead the world in adaptation and innovation in response to pressing global water threats. They can go beyond their direct operations and value chains to help solve these profound challenges. By acting quickly, companies can substantially reduce financial risks and bottom-line losses down the road.

Drawing on the available body of scientific literature and our own vision of sustainable business leadership, we offer seven core actions that companies should be focusing on:

1. Water Quantity

Companies should ensure their practices are not negatively impacting water availability, with particular attention to water scarce basins across their value chains.

2. Water Quality

Companies should ensure that their activities are not polluting local and regional water bodies.

3. Ecosystem Protection

Companies should ensure that natural ecosystems are not degraded from their business activities and help restore ecosystems that their businesses depend on.

4. Access to Water and Sanitation

Companies should collaborate on efforts to support access to clean water and sanitation in the communities they interact with and impact.

5. Business Integration

Companies should ensure that water related risks and opportunities are systematically integrated into corporate governance and decision-making from the board room to senior management to employees at all levels of the workforce. Companies should transparently disclose comprehensive water use across their supply chains.

6. Public Policy Engagement and Water Governance

Companies should proactively support public policies and water governance structures that further sustainable water resource management.

7. Multi-Stakeholder Collaboration

Since water is a shared resource, companies should be boosting multi-stakeholder collaborations to ensure sustainable water resources. They should be building, engaging and investing in industry and cross-industry efforts that challenge traditional business practices, that encourage research, and enable system-level changes that are needed.

CHAPTER 1

HOW INDUSTRY AFFECTS AND IS IMPACTED BY FRESHWATER RESOURCES

Stressed global water resources and escalating demands on those resources are creating unprecedented risks that threaten economic activity and human well-being. Population growth and mounting climate change impacts are compounding these threats.

Industry—from food production to mining, apparel manufacturing to high-tech—collectively is the single largest user and influencer of water resources globally. It has much to lose from the critical risks arising from water scarcity, pollution, and broader hydrological disruptions. It is also uniquely positioned to mitigate these challenges through adopting a range of better water management practices.

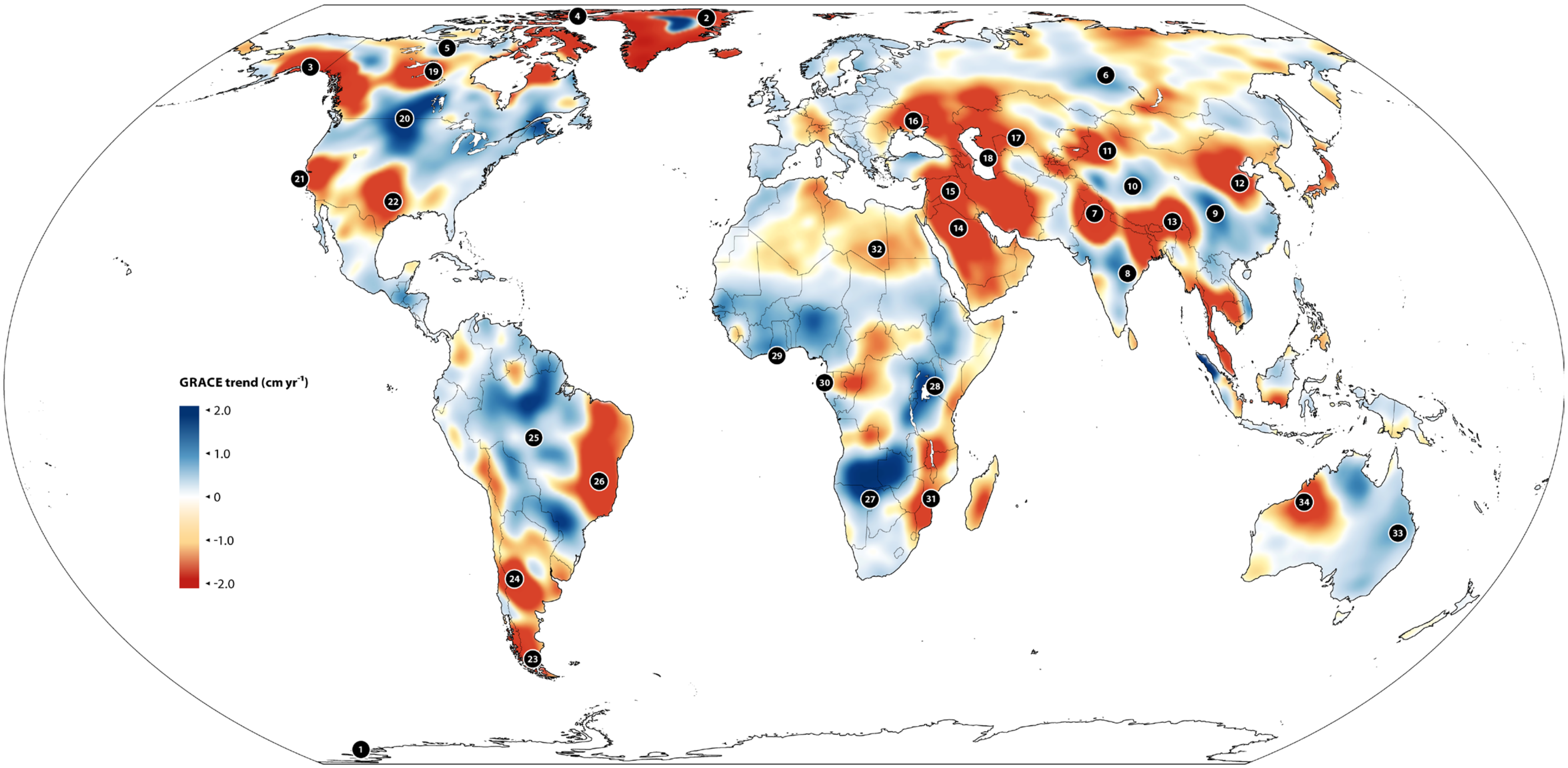
Food and agricultural production accounts for 70% of water withdrawals globally, while other industries such as energy, mining, and manufacturing account for another 19%. Given this, it will be impossible to significantly advance global water security without stronger private sector leadership, both from companies and the institutional investors that own them [1]. The risks of inaction are extremely high—not just for the long-term sustainability of businesses, industries, and entire economies—but critically for the millions of people globally whose health and livelihoods are threatened by irresponsible water management.

All industries need water to operate, and many companies have taken important steps in recent years, oftentimes voluntarily, to improve their water stewardship – an encouraging indicator of the enormous potential for scaling up water management best practices [2]. Still, the overall responses to date have been broadly insufficient.

This report is a first-of-its-kind comprehensive scientific review and analysis of the perilous global water landscape – focusing specifically on how key industry practices are critically affecting global freshwater resources. Through an extensive literature review, the report also identifies the multiple chronic and systemic risks to surface and groundwater resources. It also explores what the private sector (both companies and the investors that own them) can do to strengthen water stewardship globally.

Global hot spots for changing freshwater availability

Figure 1. Data collected from NASA's Gravity Recovery and Climate Change (GRACE) satellites shows places where freshwater resources are rapidly increasing (e.g. due to increased flooding) in deep blue. Places where freshwater resources are rapidly decreasing (e.g. due to prolonged drought, groundwater depletion, or melting ice) are shown in deeper reds. These rapid changes are largely human driven and result from climate change and unsustainable water exploitation [3]. Visualization credit: Charles Gibbons/Ceres.



- *Probable climate change impact*
- *Possible climate change impact*
- *Probable direct human impact*
- *Possible or partial direct human impact*
- *Probable natural variability*

1. Ice-sheet loss
2. Ice-sheet loss
3. Glaciers retreating
4. Glacier and ice-cap loss
5. Precipitation increase
6. Precipitation increase
7. Groundwater depletion
8. Precipitation increase and groundwater policy change
9. Three Gorges and other reservoirs filling
10. Precipitation increase
11. Water depletion and precipitation decrease
12. Groundwater depletion
13. Water depletion and precipitation decrease
14. Groundwater depletion
15. Groundwater depletion and drought
16. Groundwater depletion and drought
17. Decline of the Aral Sea
18. Decline of the Caspian Sea
19. Surface water drying
20. Progression from dry to wet period
21. Groundwater depletion and drought
22. Drought
25. Recovery from early-period drought
26. Recent drought
27. Progression from dry to wet period
28. Increasing lake levels and groundwater
29. Precipitation increase
30. Precipitation decrease
31. Precipitation decrease
32. Groundwater depletion
33. Progression from dry to wet period
34. Return to normal after wet period

How Industry Affects Freshwater Resources

Decades of scientific and empirical evidence make clear that wide-ranging industrial activities, especially from agricultural supply chains and industries within the consumer staples sector, are putting considerable pressure on freshwater systems through changes in water availability, water quality, and ecosystem alterations, such as wetland destruction, river diversions, and irrigation (Figure 1). This evidence underscores that industry is a critical part of the global hydrologic system, along with natural processes and direct human use.

Water availability

Food products and other industries are threatening water availability globally, especially groundwater resources that are being drained faster than their natural recharge capacity. A 2019 study estimates that by 2050, 42% to 79% of watersheds that pump groundwater globally could surpass ecological tipping points without better water management [4]. Many of the worst hot spots are in heavily populated countries, such as India, which rely almost entirely on groundwater for food production. While crop-related irrigation is the biggest driver of water scarcity, resource extraction activities, such as mining and oil and gas production (especially hydraulic fracturing) can also cause severe localized water scarcity, particularly in regions with high water stress. The apparel industry, largely due to cotton production, has also triggered catastrophic localized water shortages.

Water pollution

Water contamination, whether from metals, plastics, pharmaceuticals, synthetic fertilizers, or manure, is another escalating threat that is being caused almost entirely by industrial activities and consumer waste. By nearly every measure, water pollution levels are rising in developed and developing countries alike.

Agriculture (fertilizers, manure, sediment, pesticides, and pharmaceuticals) and household products (soaps and detergents) are primary contributors to excessive nonpoint pollution into streams, rivers, and estuaries, resulting in toxicity and low-oxygen eutrophic 'dead' zones that are spreading worldwide. Metal pollution, mostly from metals, mining, and technology manufacturing, is another growing threat, especially in developing countries lacking environmental regulations and adequate wastewater treatment.

Plastic waste, especially microplastics, is another growing problem that is traceable to multiple industrial sectors, with the biggest footprint being in Asia. Poor waste management is a significant factor in plastic pollution. Much of this plastic ends up in surface waters and oceans, entangling and poisoning species and bioaccumulating in the human food chain. Pharmaceuticals and a group of artificial chemicals known as perfluoroalkyl and polyfluoroalkyl substances (PFAS) are additional evolving threats.

Water diversions/Ecosystem alterations

Industry's contribution to natural ecosystem destruction is also a critical factor in water stress and biodiversity loss, whether from the filling of wetlands for site operations or agricultural fields to the razing of forests for cattle raising. Water engineering and infrastructure projects designed to make freshwater available for industrial uses, such as agriculture, energy production, and other economic activities, are altering natural water flows and critical habitats globally. The dam-building frenzy that marked the 20th century in the U.S. is now happening on a far larger scale globally [5]. In addition to high evaporative losses, dam projects can also cause increased salinization, nutrient enrichment, and reduced sediment loads. They can also cause major negative socioeconomic impacts, including relocation of communities and increased probability of user conflicts.

How Freshwater Resources Affect Industry

The relationship between industries and freshwater systems should be broadly viewed as a two-way interaction, meaning that freshwater resources affect industry just as industry affects freshwater. It is important to realize that declining water availability and water degradation, as well as climate change impacts, such as increased flooding and drought, are profound financial risks that industries must recognize and respond to more affirmatively.

A recent Barclays' research note warned that the consumer staple sector alone, including agriculture, food, and beverage companies, is facing a potential $200 billion impact from water scarcity risks – roughly three times higher than carbon-related risks[6]. A 2020 CDP report, based on data from nearly 3,000 companies, warned of even larger business losses, potentially eclipsing $300 billion if water risks were not mitigated [7].

Water scarcity

Water conflicts between companies and local communities are becoming more commonplace in places like India and the U.S. and will likely worsen as populations swell and water becomes scarcer. Beverage companies have been in the spotlight due to such conflicts. In some instances, bottled water brands were forced to close groundwater wells due to water scarcity and pollution concerns from the community. Food and agriculture companies also face water availability risks. Declining water tables are already causing devastating financial impacts for farmers in India, including higher pumping costs and reduced crop yields. Droughts and groundwater depletion in California have forced farmers to leave millions of acres unplanted in recent years. The mining and energy sectors are also vulnerable to localized water shortages, whether from depleted groundwater aquifers that stop a mining project in its tracks or drought conditions that can throttle hydroelectric production.

Supply chain disruptions

Global supply chains for numerous industries are increasingly vulnerable to water-related risks, many of them tied to climate-driven extreme weather events, such as flooding and drought. The total cost of damages (direct physical damages across numerous industries and residential properties, as well as public infrastructure) from water disasters (droughts and floods) in the U.S. is estimated to be nearly $1 trillion since 1980 [8]. In just the first eight months of 2021, extreme flooding in central China shut down coal deliveries, which led to widespread power shortages; flooding and landslides in western Europe disrupted rail traffic for steelmakers and other producers that were unable to get raw materials; the worst drought in half a century in Taiwan in the summer of 2021 deepened the shortage in semiconductors, which use large amounts of water to produce [8]. In the last quarter of 2021, a once-in-a-century flood in British Columbia disrupted supply chains both in Canada and the U.S. for months. Industries that have limited supply chains geographically can be especially vulnerable to these kinds of disruptions. Heavy rare earth metals, which are critical to aerospace, electric vehicle, medical appliances, and other electronic industries, are geographically concentrated in southeastern China, which is especially prone to climate hazards, including extreme rainfall events. It is estimated that each extreme rainfall event or a series of such events causes at least a 20% decrease in heavy rare earth production in this region due to flooding, mine site damages and disrupted logistics [9].

Climate change – a threat multiplier

Human-caused climate change is disrupting global water cycles that drive precipitation and weather patterns in every corner of the planet – disruptions that are already cascading across major industries and their supply chains. The November 2021 report from the International Panel on Climate Change (IPCC) found that "global warming is projected to further intensify the global water cycle," from more extreme floods and droughts to changing rainfall patterns [10]. Warming global temperatures are already causing detectable changes that are throwing our delicate global climate system off balance. Melting polar ice caps are causing rising sea levels, threatening major population centers and critical agriculture zones. Melting glaciers and continental ice sheets are also changing streamflow patterns in the headwaters of the world's rivers and are jeopardizing aquatic ecosystems and freshwater supplies for one sixth of the world's population.

Added together, these cumulative risks are already having profound financial and social consequences, known as economic externalities, that are not reflected in day-to-day business costs. This is largely the result of global economic systems continuing to treat water as an infinite resource with little value, leading to widespread waste and misuse. The 'true cost' of water is estimated to be at least three times higher than what companies currently pay, once direct and indirect costs of water shortages and other risks are incorporated[11]. The urgency for industries, institutional investors, and policymakers to address this misalignment – so that water is treated as a finite and precious resource – should be crystal clear.

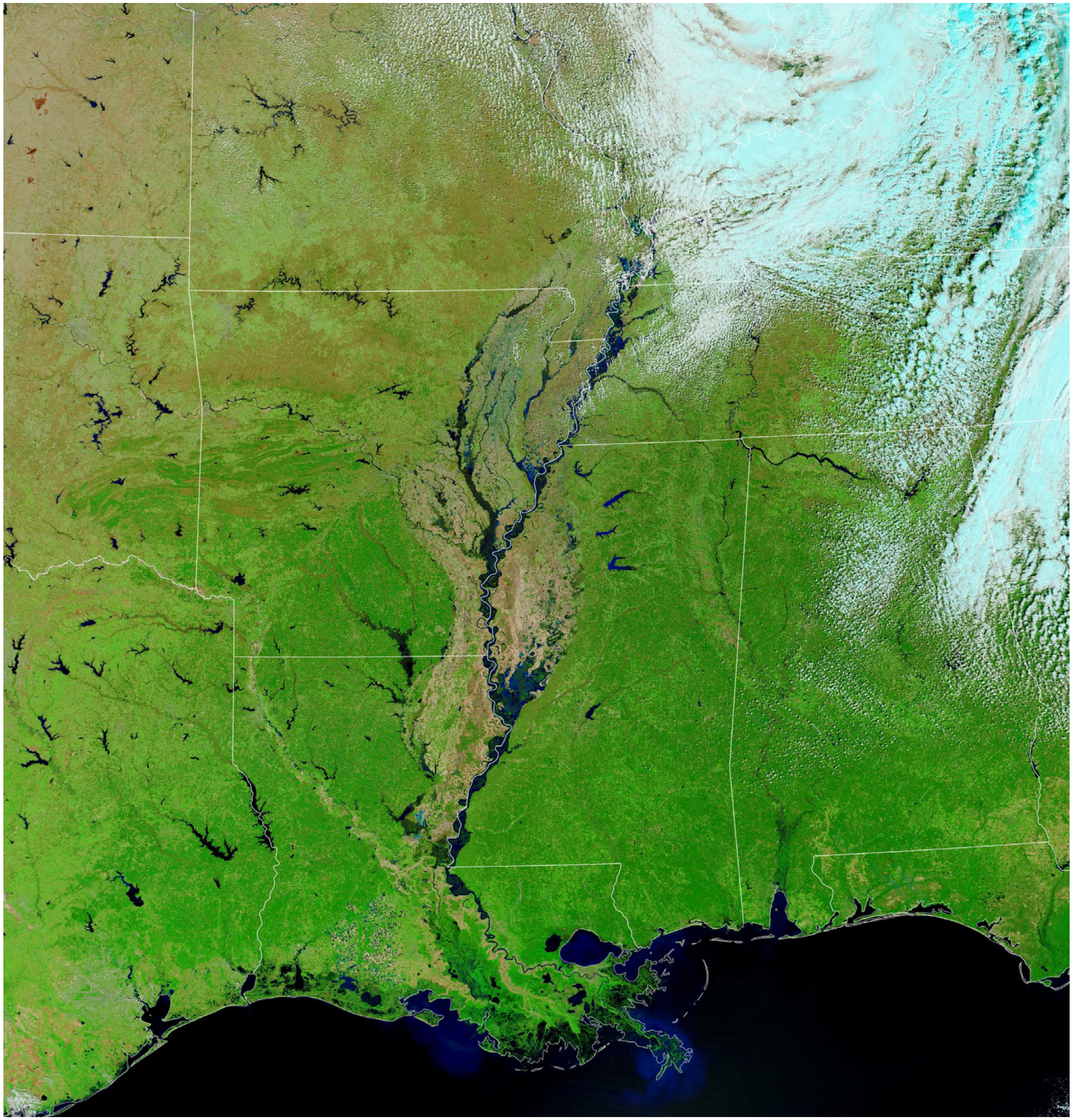


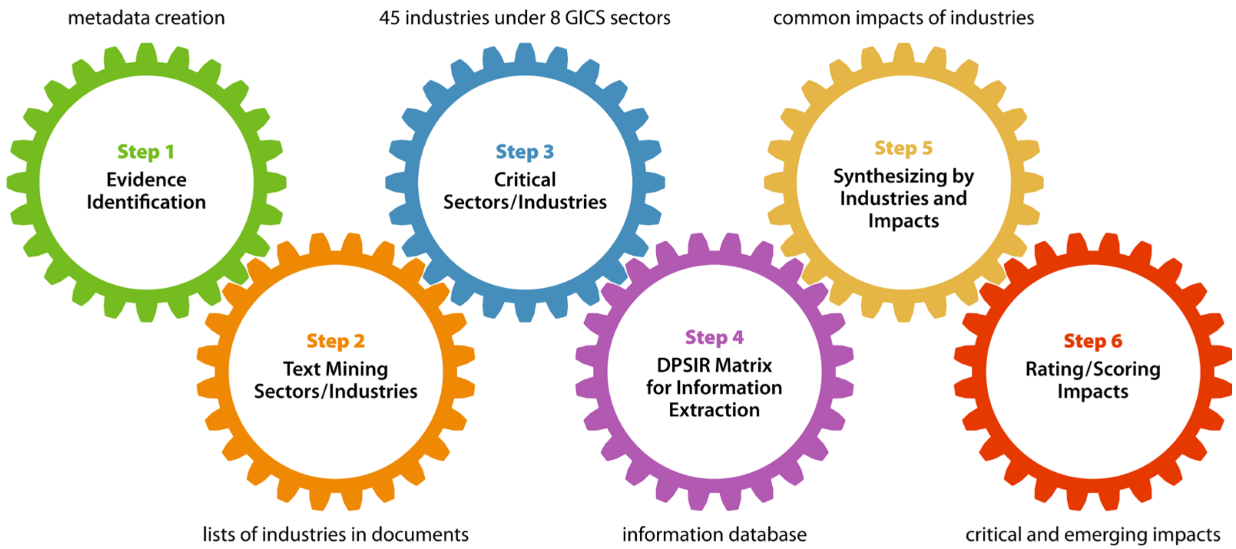
Image: NOAA

Scope, Goals, and Methodology

As summarized in Figure 2, this assessment reviews and synthesizes the scientific literature to identify the critical sectors and industries impacting freshwater and the industry practices leading to water impacts. Through the scientific evidence and literature review, the report also includes how these damaging impacts pose long-term financial risks, especially as population growth and climate change impacts ripple across the world.

The Driver-Pressure-State-Impact-Response (DPSIR) [12] model was applied as a conceptual framework to guide information extraction from selected literature. The model was then again used to synthesize evidence that describes the causal chain of how various industrial practices and activities affect freshwater systems and societal responses to these impacts, such as regulations, measurement, and laws. Based on the causal chain, critical impacts and associated practices were identified according to the intensity and severity that have been reported in the literature. The DPSIR framework was developed by the European Environment Agency as an extension of the previous Pressure-State-Response model from the Organization for Economic Co-operation and Development (OECD). The assessment used a four-tiered industrial classification system, known as the Global Industry Classification Standard (GICS), to classify companies based on their principal business activities. Finally, using a comprehensive systematic literature review process, the assessment identified critical sectors and industries and their impacts (Appendix B and C).

Figure 2. Overall approach to industrial water impacts identification.



Using this methodology, the following key GICS sectors (and associated industries) causing significant impacts to freshwater resources are identified: **Consumer Staples** (food, beverage, household and personal products), **Consumer Discretionary** (apparel, textiles, automobiles, household durables, and hotel, restaurants, and leisure), **Energy** (oil and gas and consumable fuels), **Industrials** (building/construction, electroplating, and marine), **Health Care** (pharmaceuticals, health care services, and providers), **Information Technology** (high-tech and electronic, semiconductor and circuit board, and battery), **Materials** (metal and mining, chemicals, paper and forest products, and construction materials), and **Utilities** (renewable electricity and electric utilities).

It should be noted that the industries included in this report were widely reported upon in the academic literature as having significant impacts on freshwater resources. This does not imply that those industries not mentioned in this report have less or no adverse impacts on water. Rather, it means that they were not well represented in academic literature. Many of these missing industries are also contributing to escalating water risks. The cumulative impacts of industry on water require comprehensive action by all sectors to address one of the biggest risks mankind has ever faced—the water crisis.

The Role of Investors - Understanding Water Risk as Financial Risk

Currently, many of the world's largest institutional investors have not integrated the widespread impacts of private sector activities on freshwater into their investment and engagement practices. There is a limited awareness of the degree to which certain corporate practices are both severe and systemic in nature, threatening the freshwater resources that economies and societies depend on and creating far-reaching financial risks for companies and investors themselves.

This analysis brings together scientific and financial research in a way that summarizes for the investor community the extent of these impacts and sectors and associated industries that are causing the most harm and have the most to lose if improvements are not made. Financial institutions can then apply this scientific evidence to their own investment process to understand how their investments are impacting water resources, how broadly they are exposed to water-related risks, and how they can engage with companies and industries that they invest in to halt the widespread systemic harm these sectors are causing. For instance, this research was recently used to inform two materiality briefs, published by Ceres in partnership with Bluerisk, DWS, and S&P Sustainable1, focused on the cost of action to address water impacts created by two high impacting industries, apparel and packaged meat (food products)[13],[14]. The analysis found that the impacts are so harmful they could cost up to $1.8 billion annually for some of the firms to address--though the cost of inaction could be five times higher [7].

Capital market players have a critical role to play in addressing the global water crisis. This report is part of the work of the Valuing Water Finance Initiative, a partnership between Ceres and the Government of the Netherlands and other stakeholders, to advance large-scale change in corporate water practices and water-related financial risks. To ensure the analysis is relevant to a capital markets audience, the Valuing Water Task Force, made up of major institutional investors and banks, provided input as part of the review process that included a scientific advisory committee, the Valuing Water Stakeholder Working Group, and other experts.

CHAPTER 2

CHARACTERIZATION OF GLOBAL IMPACTS OF INDUSTRIAL SECTORS ON WATER

This chapter presents the impacts of sectors and associated industries on freshwater systems and the related ecological, economic, and social issues. Key sectors and industries with the most severe and systemic impacts on water resources were identified through a systematic and comprehensive literature review and expert evaluation. As shown in Figure 3, the industries having "very high" impacts fall under six economic sectors of the GICS taxonomy [15]: **Consumer Staples**, **Consumer Discretionary**, **Energy**, **Health Care**, **Materials**, and **Utilities**. **Information Technology** was also included as a key industry due to its identified emerging impacts throughout the value chain. (Other GICS industries identified in the literature review are discussed in Appendix E.)

Figure 3. Key sectors and industries within those sectors with the most severe and systemic impacts on freshwater resources.

Key Sectors and Industries						
Consumer Staples	Consumer Discretionary	Energy	Health Care	Materials	Information Technology	Utilities
Food products Beverage	Textiles, Apparel, and Luxury Goods	Oil and Gas	Pharmaceuticals	Chemicals Metals and Mining Paper and Forest Products	High-tech and Electronics Semiconductor and Circuit board Battery Manufacturing	Renewable Electricity (hydroelectric power)

Using the DPSIR model (as explained in Chapter 1), all applicable data and information found in the literature on industry activities, its impacts on freshwater resources, and key geographical hotspots were organized following the value chains of each identified industry group. The water intensity and risk metrics used for the synthesis are drawn from trusted, independent sources, including peer-reviewed academic publications and literature.

This comprehensive modeling exercise to determine the degree of impact and industry specific impacts is novel and complementary to other tools, such as the CDP Water Impact Index and the SASB Materiality Map, which provide information on industrial sectors and companies and their water sustainability practices. This scientific assessment seeks to advance existing work on assessing water impacts created by industry in the following ways:

- Provides a comprehensive scoring and weightage of industry specific water impacts, based on DPSIR conceptual modeling and an extensive literature review starting from 1950 onwards.
- Factors in geographical context, based on evidence from scientific papers and grey literature, suggesting hotspots globally for freshwater impacts from industry practices.
- Provides insights on industry impacts from activities mapped across the value chain.
- Analyzes industry impacts on water quality and quantity.

Industrial Impacts on Freshwater: Assessment Criteria

The key industries and practices that were identified as having the most damaging impacts on freshwater systems are included in Table 1. Industry impacts were evaluated based on severity (damages being caused to water resources) and the systemic nature of those impacts (the extent to which damages are affecting accessibility of other water users regionally and are costly for restoration). Impacts evaluated include water scarcity, such as surface and groundwater depletion, water diversion, and water quality due to a variety of pollutants. An overall designation of “very high” (“VH”) severity indicates that the impact is at an unacceptable level and causes catastrophic and irreversible damage to freshwater. “Very high” impacts are systemic in nature and significantly affect access to clean freshwater supplies across a variety of regions.

Table 1. Relative assessment of industrial impacts on freshwater. The table depicts the qualitative matrix used to evaluate the industrial impacts on freshwater resources at different stages of the value chain based on literature review and expert assessments. The matrix was developed based on a risk assessment methodology outlined in [16] and [17], and full methodology are included in Appendix D.

Water Impact	Severity	Systemic nature	Overall impact	Identified Industry Practices	Relevant GICS Industries
Water scarcity (general)	VH	H	VH	• Irrigation and raising animals • Hydraulic fracturing • Mineral extraction	• Food Products • Oil and Gas • Metals and Mining • Paper and Forest Products
Metals contamination (e.g., heavy metals and rare earth elements)	H	H	VH	• Acid mine drainage and metal leaching • Electronics manufacturing wastewater	• Metals and Mining • Semiconductor and Circuit Board • Battery • High-tech and Electronics
Eutrophication	VH	VH	VH	• Farm use of fertilizer and manure (food, grains, cotton) • Consumer use of soaps and detergents	• Food Products • Beverage • Household Products • Textiles
Physicochemical stress-ors (e.g., organic matter, pH, salinity, suspended solids, thermal alteration)	M	H	H	• Industrial wastewater for food, beverage, paper products • Consumer use of soaps and detergents • Tilling • Industrial wastewater	• Food Products • Beverage • Household Products • Paper and Forest Products • Renewable Electricity
Groundwater depletion	VH	VH	VH	• Irrigation and raising animals • Hydraulic fracturing • Mineral extraction	• Food Products • Oil and Gas • Metals and Mining
Plastic, Microplastics, and Phthalates	H	VH	VH	• Consumer use of personal products • Laundry • Automobile tire wear • Plastic manufacturing wastewater	• Personal Products • Textiles • Automobiles • Chemicals
Pharmaceutical pollution	H	VH	VH	• Pharmaceutical consumer use • Veterinary pharmaceutical use	• Pharmaceuticals • Food Products
Direct ecosystem impacts	M	M	M	Habitat destruction to create mines and dams for hydropower	• Metals and Mining • Renewable Electricity • Paper and Forest Products
Social conflicts and justice	M	M	M	• Large amounts of water used for food and beverages • Building dams to control water for hydropower	• Food Products • Beverage • Renewable Electricity

Water Impact	Severity	Systemic nature	Overall impact	Identified Industry Practices	Relevant GICS Industries
PAH pollution	H	M	H	• Oil extraction • Industrial wastewater	• Oil and Gas • Chemicals • Paper and Forest Products
Pesticide pollution	VH	VH	VH	• Pesticide use on farms (food, cotton) • Pesticide production	• Food Products • Textiles • Chemicals
Diversion of water	H	H	VH	• Irrigation (food, cotton) • Use of dams for hydropower	• Food Products • Textiles • Renewable power
PFAS and PFOA	H	VH	VH	• Industrial wastewater • E-waste leaching	• Chemicals • Semiconductor & Circuit Board
Streamflow alteration	M	H	H	• Canals and ditches for irrigation • Use of dams for hydropower • Hard rock quarrying	• Food Products • Renewable Electricity • Construction and Building
Bacteria and pathogens	M	M	M	• Animal raising and use of ma-nure as fertilizer • Slaughterhouses • Release of ship wastewater	Food Products
Erosion and sedimentation	M	M	M	• Tilling • Deforestation	• Food Products • Paper and Forest Products
Acidification	H	M	H	• Acid mine drainage • Consumer use of soaps and detergents	• Metals and Mining • Household Products
Oil spills	M	M	M	Accidental spills during oil and marine transport	Oil and Gas
Personal care chemicals	M	H	H	Consumer use of personal care products	Personal Products
Nanomaterials	L	L	L	Manufacturing wastewater	Battery
Radioactive pollution	L	M	M	Operation of nuclear power plants	Electric Utilities
Dyes	H	H	VH	Textile wastewater	Textiles

Exploring the key industries further, Table 2 provides a relative assessment of water impacts by industries within areas of the value chain, whether from direct operations, global supply chains, or end-product use. Industries with the most severe ("very high") impacts throughout the value chain includes Food Products, Beverage, Textiles, Apparel, and Luxury Goods, Oil and Gas, Pharmaceuticals, Chemicals, Metals and Mining, Paper and Forest Products, and Renewable Electricity.

Table 2. Overall relative assessment of water quantity and water quality impacts across the value chains.

Industry-Level Water Risk Overview

Very High Risk | High Risk | Medium Risk | Not enough information found

GICS Industry	Supply Chain		Direct Operations		Product Use/End of Life	
	Water Quantity	Water Quality	Water Quantity	Water Quality	Water Quantity	Water Quality
Food Products	Very High Risk	Very High Risk	High Risk	High Risk		
Beverage	Very High Risk	Very High Risk	High Risk	High Risk		Very High Risk
Household Products		Medium Risk		Medium Risk		High Risk
Personal Products				Medium Risk		High Risk
Textiles, Apparel, and Luxury Goods	High Risk	High Risk	Medium Risk	Very High Risk		High Risk
Automobiles and Components		Medium Risk		Medium Risk		Medium Risk
Hotels, Restaurants, and Leisure			Medium Risk			
Oil and Gas	High Risk	Very High Risk	High Risk	Very High Risk		Medium Risk
Consumable Fuels	Medium Risk		Medium Risk			
Construction and Building	Medium Risk	Medium Risk	Medium Risk	Medium Risk		
Electroplating				High Risk		
Pharmaceuticals				Very High Risk		Very High Risk
Chemicals	High Risk	High Risk	Medium Risk	Very High Risk		
Construction Materials			Medium Risk			
Metals and Mining	High Risk	High Risk	High Risk	Very High Risk		
Paper and Forest Products	High Risk	High Risk	High Risk	Very High Risk		
High-tech and Electronics	High Risk	High Risk	High Risk	High Risk		
Semiconductor and Circuit Board			Medium Risk	High Risk		High Risk
Battery	High Risk	High Risk		High Risk		High Risk
Renewable Electricity			Very High Risk	Medium Risk		
Electric Utilities				Medium Risk		

INDUSTRIAL SECTORS Value Chain Analysis of Practices, Externalities, and Water Impacts Globally

The following sections provide further detail from the literature review and expert assessment of the different industries and practices that are contributing to "very high" impacts on water resources and key emerging industries as identified in the assessment as reflected in Tables 1 and 2. (Other GICS industries identified in the literature review are discussed in Appendix E.)

For each industry within the sector, a schematic is provided to depict the practices along the value chain and their associated externalities and water quantity and quality impacts. Each section also includes the associated geographies where impacts were observed that were frequently cited in the literature.

Figure 4. Summary of Food Products industry freshwater impacts along the value chain, including on-farm and off-farm. Selected hotpots are the regions frequently cited in the literature.

Value Chain	Practices	Externalities	Freshwater Impact	Selected Hotspots
On-farm production	Irrigation	Water consumption, extraction	Water stress, groundwater depletion, social conflict	India, China, Bangladesh, USA, Middle-East, Kyrgyz Republic, Indonesia
		Canalization	Streamflow alteration, water diversion	Europe, North America
	Tilling and land use	Sediment erosion, salinity	Suspended solids, ecotoxicity	Western Spain, Iran, USA, Australia, Argentina
	Fertilizer use	Nutrient runoff	Eutrophication, human health impacts	USA, China, India, Southeast Asia, Spain
	Pesticide use	Pesticide runoff	Ecotoxicity, human health impacts	USA, Ecuador, Argentina, Australia
	Animal raising	Water consumption, extraction	Eutrophication	Australia, India, Iran
		Nutrient, organic matter, pathogen runoff	Eutrophication	
		Runoff of pharmaceuticals and hormones	Bioaccumulation in aquatic organisms, endocrine disruption	Taiwan, Switzerland, South Korea
		Fish feeding	Non-ingested fish feed including metals and nutrients	Mediterranean, Philippines
		Use of plastic cages and netting	Plastic pollution	
Off-farm production	Packaging and processing	Water consumption, extraction	Water stress	Australia, New Zealand, Brazil
		Wastewater discharged	Eutrophication, ecotoxicity, human health impacts	Canada, Romania, Ethopia
		Plastic pollution	Ecotoxicity, bioaccumulation	

1. Consumer Staples Sector

The Consumer Staples sector includes industries that produce products that are essential for consumers, whether for food or day-to-day living. The key industries within the sector identified as causing significant impacts to freshwater resources include Food Products, Beverages, Household Products, and Personal Products. Food Products and Beverages were identified as having the most severe and systemic impacts. Others are included in Appendix E.

Food Products

The Food Products industry is the largest driver by far of water consumption, water pollution, and other water-related impacts globally. The industry, which includes growing crops, raising livestock and food for livestock, and processing ingredients for packaged foods, uses large amounts of the world's freshwater [18], [19]. It is also a major contributor of point and nonpoint sources of water pollution (including nutrients, suspended solids, pesticides, herbicides, plastics, organic matter, pathogens, pharmaceuticals, and hormones). Agriculture is the leading driver of water degradation globally, and industries that rely extensively on agricultural supply chains are at higher risk than others.

Practices and associated externalities

Figure 5 depicts the water foot print of key crops and animal products. Raising beef cattle consumes the most water, using an estimated 15,000 liters of water per kilogram of beef. Since 1961, cattle and meat (beef and buffalo) production has more than doubled globally. Poultry production has grown more than 12-fold, with the U.S., Brazil, and China being the largest producers.

Nutrients, including nitrogen, phosphorus, potash, and manure, are the largest pollution source from the Food Products industry. This is primarily from on-farm fertilizer use and off-farm food and slaughterhouse processing wastewater discharges. Global use of fertilizer nutrients rose significantly over the past 50 years to around 209 million tons of nitrogen, phosphorus, and potassium in 2019 [23], [24]. Manure use as a fertilizer on cropland, which

Figure 5. The water footprint of selected crop and animal products: (a) water footprint in a liter of water per kilogram of product (L/kg), (b) water footprint in a liter of water per kilocalorie (L/kcal) of nutritional energy contained in the product. Data source [20]–[22].

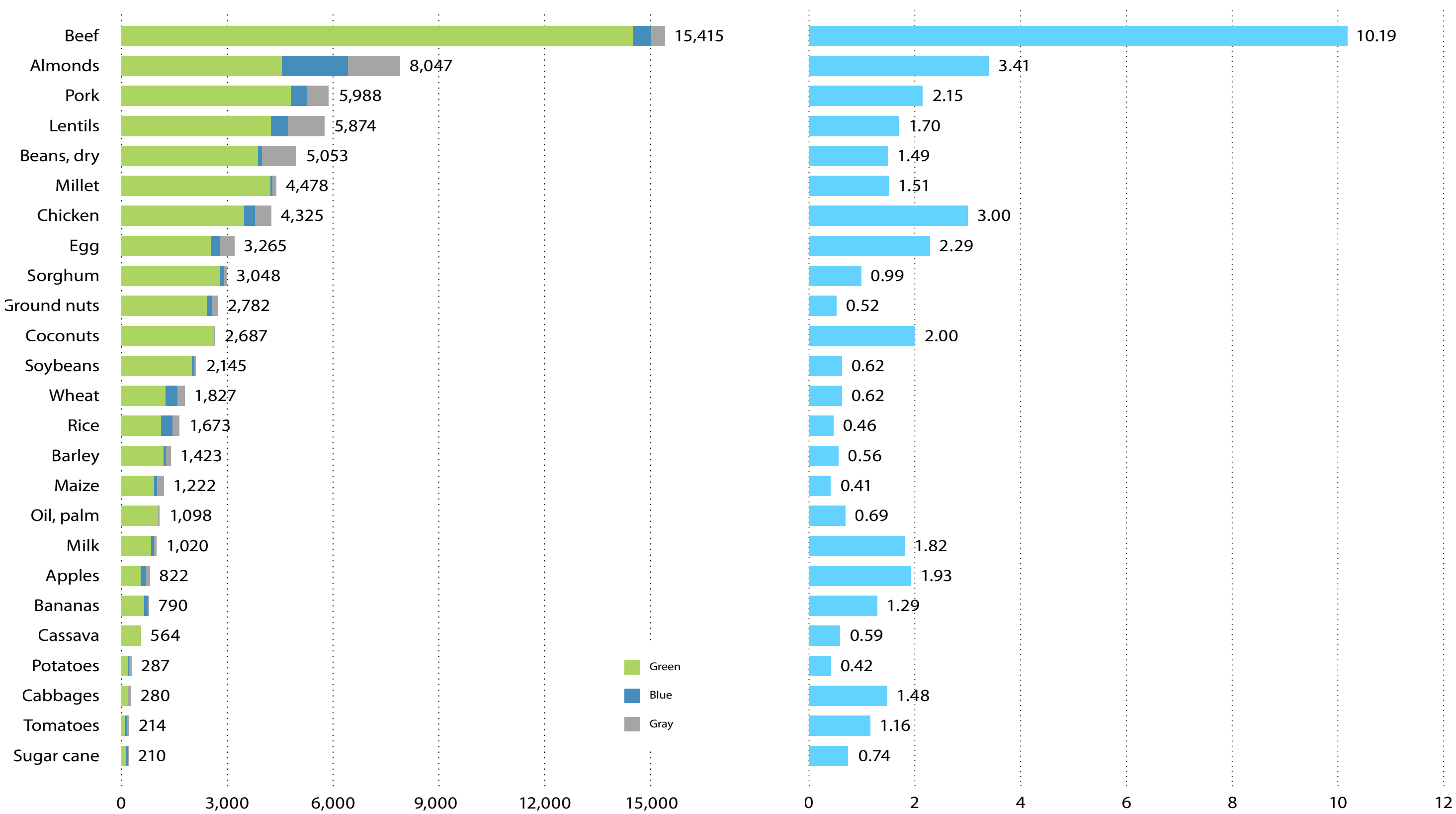


Figure 5a · Water footprint in liters of water per kilogram of product (L/kg)

Figure 5b · Water footprint in liters of water per kilo-calorie (L/kcal) increases nitrogen and phosphate runoff into water bodies, has also grown significantly. Manure nitrogen production from livestock increased about fivefold from 1860 to 2014.

Globally, pesticide use grew over 30% from 2000 to 2018, reaching 4.45 million tons in 2018 [25]. Agricultural runoff from crops increases the pesticide concentration in water bodies, while the runoff from livestock waste increases pathogens, organic matter, pharmaceuticals, and hormones (given to livestock to prevent disease and optimize growth).

Tillage and other farming land-use activities worsen soil erosion and salinity, polluting water bodies. Global annual cropland related soil erosion is estimated at about 11.57 tons per hectare, while pasture erosion is about 1.87 tons per hectare. Severe water-salinity issues due to irrigation have been reported in major food producing countries, negatively affecting water quality for about 1.1 billion people [26]. Food production is also a critical driver of deforestation worldwide throughout its supply chain, which further increases soil erosion in many regions, such as in the Amazon. In the Brazilian Amazon, 65% of deforestation can be attributed to cattle ranching [27], [28].

Freshwater impacts

Irrigation for agricultural food production is the dominant force driving global groundwater depletion. India uses the most water per day for agricultural irrigation, followed by China and the U.S [1], [21]. Among primary crops, nuts, rice, and sugarcane are the top three water consumers on a per unit basis. Although water abstraction trends for irrigation have decreased in most countries since 2005, crop-related irrigation continues to play a major role in causing water stress in many countries, including Turkey, Mexico, India, China, and the U.S. In India, which is more dependent on water pumped from groundwater aquifers than any other country, excessive pumping compounded by droughts is draining major aquifers that sustain more than 30 million wells [29]. In the U.S., the federal government declared a first-ever Tier 1 water shortage in 2021 for the Colorado River, where agriculture accounts for about 80% of water use primarily from the irrigation of over 5 million acres of farmland [30]. The declaration reduces the amount of water that Arizona, Nevada, and Mexico can claim.

Water pollution from phosphorus has become a severe issue in many river basins around the world, highlighted in yellow and red in Figure 6. Agriculture is the second largest source of phosphorus water pollution globally. The processing and packaging of food and meat are major contributors to water toxicity and eutrophication, especially from meat, which has seen a tripling in global production during the past 50 years. About 80 billion animals are slaughtered each year [32]. In China, manure and fertilizer runoff from meat producers caused widespread water pollution of major lakes, rivers, and coastal waters between 1980 and 2010, according to a 2018 study [33]. In the U.S., river basins have repeatedly suffered harmful algal blooms and massive fish kills from poultry and hog farm waste lagoons that overflow following extreme rain events.

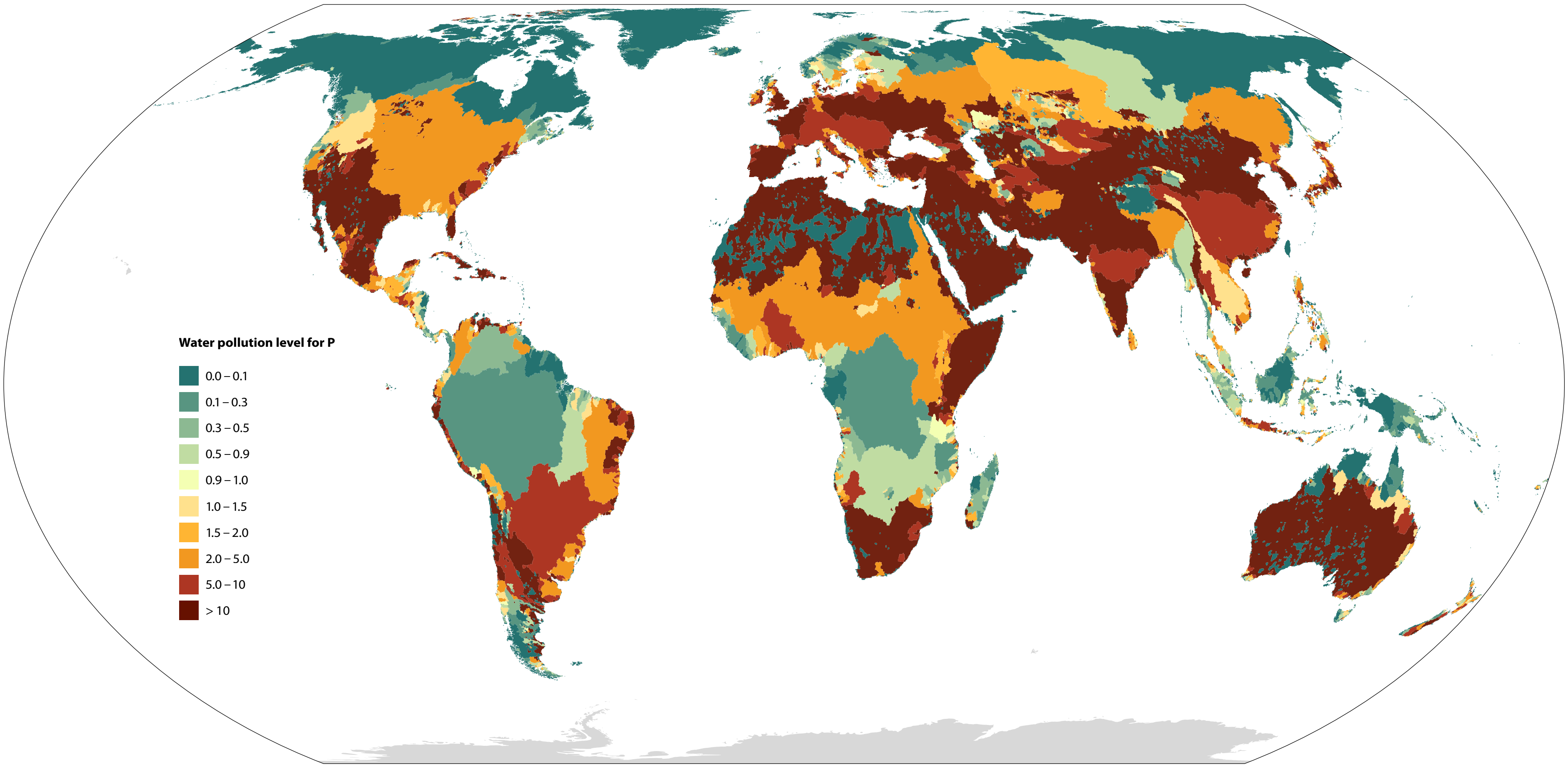
Geographical hotspots

Global hotspots of water scarcity and pollution intensified by agricultural irrigation include the U.S. (especially the Great Plains and California), India (northern regions), Mexico (Central), and Northern China. Figure 7 below shows the total water footprint (WF) related to crop production for human consumption. The pie chart shows the major countries with a large share of the total global water footprint.

The largest fertilizer users are mostly in eastern Asia and Brazil. The main use of fertilizer in Brazil is for growing coffee beans, sugarcane, citrus, and soybeans. China is the largest user of fertilizer and pesticides in the world, with most of it used inefficiently [34]. Other hotspots for major fertilizer use are India and Indonesia, primarily for rice, groundnuts, wheat, sugarcane, maize, and palm oil production. The production of palm oil, a commodity used in nearly half of packaged products globally, has grown more than 25-fold in Indonesia in the past half-century, with excessive amounts of fertilizer being applied to the plantations.

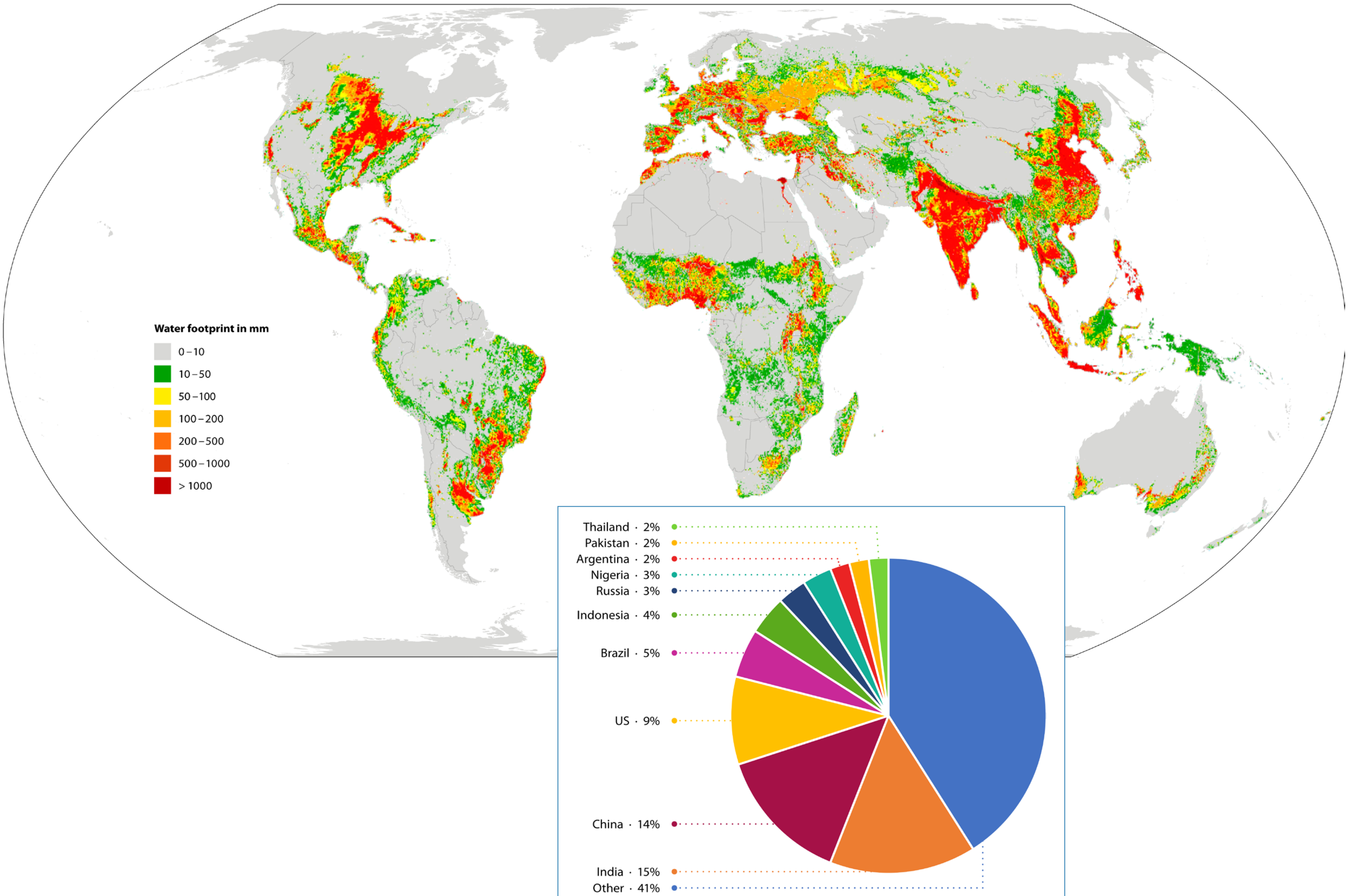
Global hotspots of water pollution from phosphorus loads

Figure 6. The map shows the phosphorus loads from agriculture (37.9%), domestic (54.2%), and other industries (7.9%) during 2002-2010 [31]. Note: water pollution level for P over 1 means the phosphorus concentration exceeds standard. Visualization credit: Charles Gibbons/Ceres.



Global hotspots of total water footprint from food crop production

Figure 7. The map shows the total water footprint from crop production between 1996-2015. The pie chart (inset) shows the contribution of countries to total water footprint, with India, China, and the U.S. accounting for 38% of the total footprint [22]. Visualization credit: Charles Gibbons/Ceres.



Beverage

The Beverage industry includes the production of soft drinks, bottled water, wine, beer, and distilled alcohols. Beverage manufacturing and the related supply chains consume water and discharge pesticides, herbicides, fungicides, and solid wastes into water bodies, while also negatively impacting oxygen levels, odor, and color.

Practices and associated externalities

Water is required for nearly every aspect of beverage production, from growing ingredient crops, such as sugarcane, barley, grapes, and coffee beans, to packaging and bottling in factories. According to the Water Footprint Network, it takes at least 70 liters of water to produce 0.5 liters of soda, 74 liters for a glass of 0.25 liters of beer, and 132 liters for a cup (0.125 liters) of coffee. Around 18,900 liters of water are needed to produce 1 kilogram of coffee beans [35].

Ingredient cultivation is the most water-intensive practice within the industry. Nevertheless, the industry's water footprint for manufacturing processes, such as wet milling, mashing, filtering, bottling, pasteurization, and cleaning, is significant, as water is a main ingredient of beverage products. Beer, for instance, is composed of 90% to 95% of water in mass [36]. These manufacturing processes are highly water intensive, especially wet milling. For example, corn wet milling generally requires approximately 1.5 m3 of freshwater per ton of corn [37].

The Beverage industry also generates a variety of pollutants in its agricultural supply chain and manufacturing processes. Pesticides used within the on-farm section of the value chain, and solid waste released from off-farm manufacturing are the main activities in the Beverage industry that contribute to pollution. The manufacturing processes also generate pollutants, such as total suspended solids (TSS), total dissolved solids (TDS), metals, and nutrients, which lead to high concentrations of biochemical oxygen demand (BOD) and chemical oxygen demand (COD), and plastics and salts that compromise water quality. If left untreated, wastewater discharges containing these pollutants can have a variety of water quality, ecological, and health-related impacts, such as surface water acidification, eutrophication, ecotoxicity, and groundwater contamination.

Figure 8. Summary of Beverage industry freshwater impacts along its value chain, including on-farm production, manufacturing and processing, and consumer use. Selected hotspots are the regions frequently cited in the literature.

Value Chain	Practices	Externalities	Freshwater Impact	Selected Hotspots
On-farm production	Pesticide use	Pesticide runoff	Ecotoxicity, human health impacts	Spain
Manufacturing and processing	Hard and soft drink processing and bottling	Water consumption, extraction	Water stress, groundwater depletion, social conflict	India
		Wastewater discharged	Ecotoxicity, human health impacts, eutrophication	South Africa, Jordan, USA
	Bottling water	Water consumption	Water stress, groundwater depletion, social conflict	USA
Consumer Use	Consumption of beverages, pollution	Plastic pollution	Ecotoxicity, bioaccumulation	

Freshwater impacts

The Beverage industry uses large amounts of water to produce ingredients and products, but water consumption can significantly differ among companies and varies geographically. The water consumed along the value chain of the industry depends on water availability in the location in which ingredients are produced and the technology companies deploy in their factories. For instance, to produce 1 liter of beer it takes 180 liters of water in Tanzania, 155 liters in South Africa, 61 liters in Peru, and 62 liters in Ukraine. Growing crops, including wheat and barley, account for about 90% or more of the respective water footprints. Growing these crops in water-stressed regions can trigger stress and competition between the company and local communities. These conflicts have led to bottling plant closures in India and U.S.

Pesticide and fertilizer use for growing ingredients contributes to high concentrations of toxic chemicals and eutrophication of water bodies. Many regions in the world, including in South Africa and Jordan, have reported that COD and BOD concentrations from beverage plant wastewater far exceed standard discharge limits. In South Africa, for instance, a brewery's effluent had concentrations of COD (5,340.97 mg/L) and BOD (3,215.27 mg/L) that were both well over European Union discharge limits (125 mg/L, and 25 mg/L respectively) [38].

Geographical hotspots

Water overuse and pollution impacts related to this industry were found globally, especially in Africa (South Africa, Nigeria, Benin, Tanzania, Burundi, and Malawi), North America (U.S., Mexico, Canada, Cuba, El Salvador, and Haiti), Asia (Jordan, Thailand, India, Cambodia, China, Indonesia, and Laos), Europe (Spain, Italy, Portugal, Romania, Germany, and Ukraine), South America (Costa Rica, Brazil, Puerto Rico, Bolivia, Colombia, and Peru), and Oceania (Australia and New Zealand). As the Beverage industry continues to widen its offerings and overall demand continues to grow, the impacts on water availability and pollution from the industry will likely keep escalating, threatening the industry considerably.

2. Consumer Discretionary Sector

Key industries within the sector identified as causing significant impacts to freshwater resources include Textiles, Apparel, and Luxury Goods, Automobiles and Components, and Hotels, Restaurants, and Leisure. The Textiles, Apparel, and Luxury Goods industry was identified as having the most severe and systemic impacts. Others are included in Appendix E.

Textiles, Apparel, and Luxury Goods

The Textiles, Apparel, and Luxury Goods industry includes apparel, textiles, accessories, and footwear. Large volumes of water are needed for growing natural fibers and industrial manufacturing processes. Pollution from pesticide and fertilizer use during fiber cultivation contaminates freshwater bodies and is a significant water risk globally.

Practices and associated externalities

Across the entire value chain, clothes and textile production is enormously water intensive, withdrawing more than 215 billion m3 of water annually [39], equal to the total amount of water withdrawn by Indonesia [40].

Based on the life cycle analysis, on-farm cotton production is the largest consumer of freshwater for many apparel companies. On average, about 9.36 million liters of water is needed to produce one ton of cotton textile, and the production of one cotton T-shirt and a pair of jeans can require as much as 2,720 and 10,850 liters of water, respectively [41]. Organic cotton, which is primarily grown on small farms, uses 91% less water, according to a 2017 Textiles Exchange report. Within apparel companies' manufacturing process, spinning uses the most water in viscose textile manufacturing, followed by pulping and presoaking [42].

The footwear industry requires more water for industrial manufacturing processes than for the production of raw materials. Water is critical for tannery and leather factories, particularly tanning, which accounts for up to 70% of total water use during manufacturing. Roughly 1 to 3 m3 of water is needed for every ton of hide produced, 4 to 8 m3 per ton for post-tanning, and 0 to 1 m3 per ton for finishing processes [43].

Pollution concentrations vary widely across the industry, depending on the raw materials and technologies used for production and on

Figure 9. Summary of Textiles, Apparel, and Luxury Goods freshwater industry impacts along its value chain, including on-farm production, manufacturing, and consumer use. Selected hotspots are the regions frequently cited in the literature.

Value Chain	Practices	Externalities	Freshwater Impact	Selected Hotspots
On-farm production	Irrigation	Water consumption	Water stress, groundwater depletion	India, China, Pakistan, USA, Uzbekistan, Brazil
	Irrigation	Pesticide runoff	Ecotocity	
	Fertilizer use	Nutrient runoff	Eutrophication	
Manufacturing	Wet processing	Water consumption	Water stress	India, Palestine, Bangladesh
	Wastewater	Wastewater release including dyes, metals, organic matter, etc.	Ecotoxicity	
Consumer Use	Washing clothes	Release of microfibers	Ecotoxicity, bioaccumulation	

wastewater treatment. Pesticide and fertilizer use for on-farm ingredients generates many contaminants, including nutrients, pesticides, and pharmaceuticals. Contaminants are especially pervasive in cotton cultivation, which uses 16% to 24% of the insecticides and up to 40% of the pesticides applied globally [44].

Textile plants release numerous contaminants, including an estimated half-billion tons of microfibers from textile washing each year. Wet processing, such as dyeing, washing, printing, and fabric finishing in textile and tannery production, produces the most chemical pollutants [45].

Freshwater impacts

Cotton production for the apparel and footwear industries is water intensive and is accelerating water scarcity of groundwater and surface waters in water-stressed regions. Once the world's fourth largest lake, the Aral Sea in Central Asia is now largely dried up due to widespread water extraction for cotton monoculture and cotton-related river diversion for irrigation. The United Nations has called it one of the world's worst environmental disasters. According to WRI's Aqueduct Water Risk Atlas in 2013, more than half of cotton production globally was in high to extremely high water-stressed irrigated regions, and the recent data on water and food security shows that the percentage could increase to over 70% by 2030[46],[47].

The production of ingredients, especially cotton, causes pesticide and nutrient pollution that is harmful to aquatic organisms and causes eutrophication. Pesticides have been found in many water bodies, including rivers and drinking water reservoirs, that are close to cotton cultivation areas[45]. Fertilizer runoff from cotton fields can result in 1,296-62,554 tons of nitrogen discharges into water bodies annually in a variety of countries [41][45],[48].

Untreated or insufficiently treated wastewater from textile plants can have wide-ranging ecological and health related impacts. Microfibers and colorants from textile wastewater discharges can cause diseases and conditions that include hemorrhages, skin ulcerations, nausea, severe skin irritation, and dermatitis. Dyes also contain high levels of trace metals that pollute water bodies.

Geographical hotspots

Countries that use large amounts of water for cotton production include India, Brazil, China, and the U.S., where it is a significant driver of groundwater depletion. The countries with the largest impact on external virtual water resources (the water embedded in cotton that is produced in and imported from other countries) are China, the U.S., Mexico, Germany, the U.K., France, and Japan. Roughly half of China's water footprint for cotton is within the country, while the other half is sourced from other countries, primarily India and Pakistan. Water pollution from textile plants has been documented in India, Palestine, and Bangladesh. Many textile and tannery factories in these countries release untreated wastewater into rivers, streams, or embankments.

The global apparel market is expected to grow from $1.5 trillion in 2020 to $2.25 trillion by 2025, indicating that impacts on water will continue to grow across many geographies[49].

3. Energy Sector

The Energy sector includes oil and gas operations and fuels for energy generation. Drilling and hydraulic fracturing and integrated oil and gas production are practices that significantly contribute to water risks, especially water quality and availability. Key industries within the sector identified as causing significant impacts on freshwater resources include Oil and Gas and Consumable Fuels. The Oil and Gas industry has been identified as having the most severe and systemic impacts. The Consumable Fuels industry is included in Appendix E.

Oil and Gas

The Oil and Gas industry's impact on water resources is pervasive across exploration, production, and delivery activities, including extraction (drilling and hydraulic fracturing, as well as produced water), processing, transportation of crude materials, refining, and retail.

Practices and associated externalities

While impacts vary by geography, oil and gas shale extraction practices, including wastewater discharges, are the industry's most intensive water impact by far. If left untreated and exposed to the environment, the industry's wastewater will have various water quality, ecological, and health-related impacts, including surface water acidification, eutrophication, ecotoxicity, and groundwater contamination.

Hydraulic fracturing, a $35 billion global industry in 2019, can significantly pollute waterbodies[50]. Hydraulic fracturing involves injecting water, sand, and chemicals under high pressure into drilling wells and then reinjecting the process wastewater back into the ground after the extraction. Drilling and hydraulic fracturing lead to water contamination by introducing metals into groundwater, rivers, streams, and oceans. This process can also result in large volumes of fracturing fluid flowback to the water source or nearby water bodies. In Canada, contaminants typically migrate 3-5 kilometers from the contamination point in streams and rivers[51].

Drilling, extraction, refining, and logistics from oil and gas industry extraction technologies can also trigger water stress. The processes require large amounts of water -- an average of 15,141.65 m3 of water per well, according to the American Petroleum Institute – and can reduce the availability of freshwater resources near operating sites. Much of this activity is in water-stressed areas such as the Permian Basin, the most prolific oil field in the U.S. in West Texas.

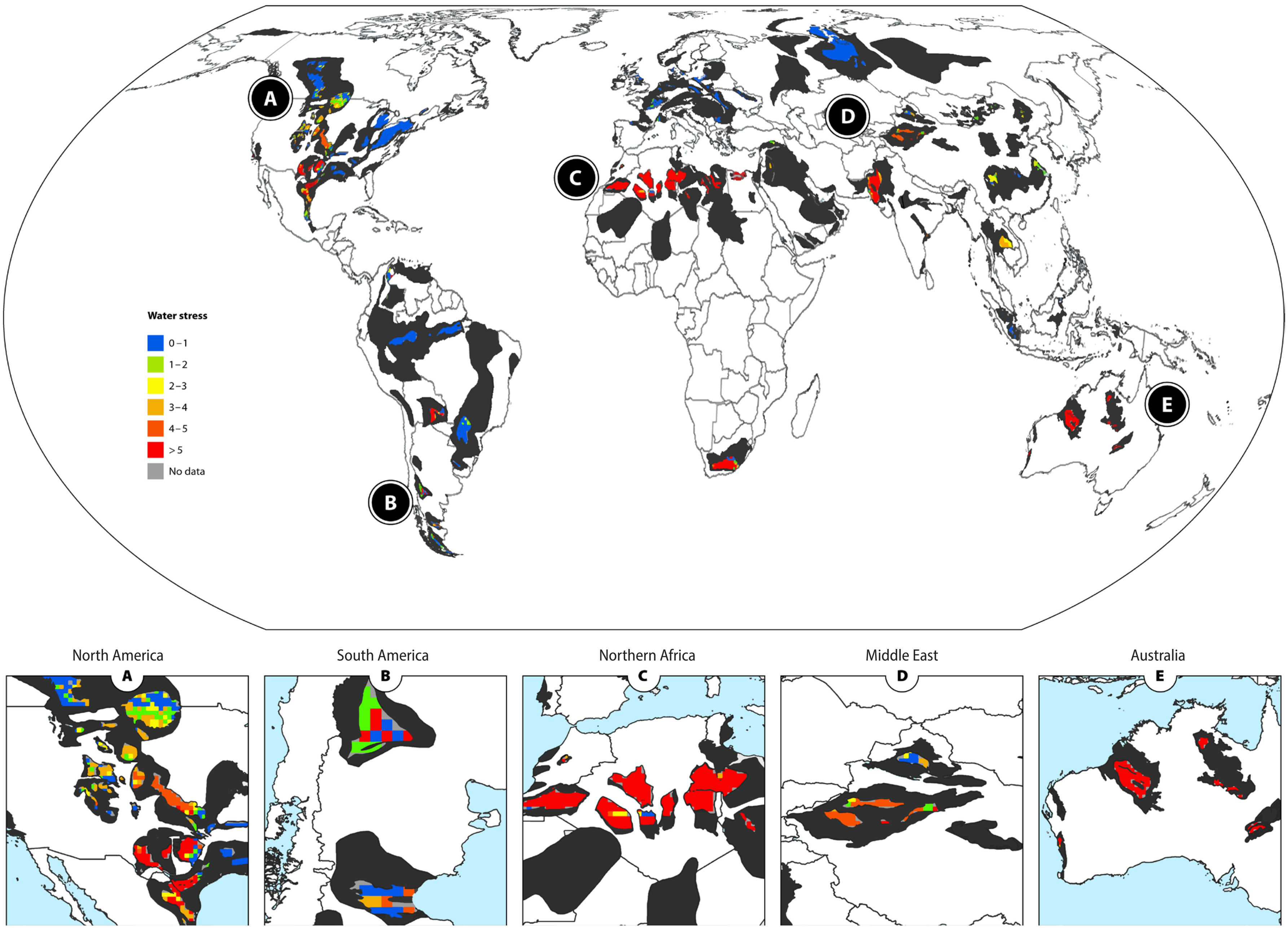
Hydraulic fracturing affects groundwater aquifers more severely than surface water, although both are at risk. According to a 2016 Ceres report, 57% of the 106,000 wells that were hydraulically fractured over a five-year period were in regions with high or extremely high wa

Figure 10. Summary of Oil and Gas industry freshwater impacts along its value chain, including upstream and midstream activities. Selected hotspots are the regions frequently cited in the literature.

Value Chain	Practices	Externalities	Freshwater Impact	Selected Hotspots
Upstream	Drilling and hydraulic fracturing	Water consumption	Water stress, groundwater depletion	Canada, South Central USA, Argentina, South Africa, China, India, Australia, Northern Africa
		Release of contaminated fluids (metals, PAHs, PACs, naphthenic acids)	Ecotoxicity	
Midstream	Transportation	Oil spills	Ecotoxicity	

Global map of water stress within shale deposits

Figure 11. Map shows regions where shale deposits overlap with high water stress aquifers. Values with water stress indexes greater than one are subjected to unsustainable water consumption [53].



ter stress, including basins in Colorado, Texas, Oklahoma, and California[52]. Globally, 59% of shale deposits are in the footprint of major freshwater aquifers and 20% of shale deposits are in regions affected by groundwater depletion. Figure 11 shows the regions globally where shale deposits overlap with high water stress aquifers.

The oil sands industry also compromises the natural hydrology of streams, rivers, and lakes due to site clearing, water diversions, and draining wetlands. Massive toxic tailings ponds, which are commonly used in oil sands mining operations to store tailings materials that are recycled back into the extraction process, contain salts, suspended solids, and chemical compounds that are yet another risk for water pollution. These ponds pose threats to surrounding water bodies because they have the potential to fail and discharge contaminated water. The oil sand industry's water footprint in Canada is significant, accounting for an estimated 9.6% of the country's overall water use, based on multiple year averages.

Production, storage, and transportation of fossil fuels can also lead to oil spills, which have had enormous impacts on water quality, ecosystem health, and regional economies. In 2010, a pipeline transporting heavy crude oil broke in Marshall, Michigan and caused a spill of 4,200 m3 that polluted the Kalamazoo River[54]. Overall, in the U.S., from 2001 to 2020, there have been 5,750 significant pipeline incidents onshore and offshore, resulting in over $10 billion in damages[54]. The Niger Delta has experienced 7,940 oil spill incidents, of which 67% occurred onshore [55]. While the number of major accidents has dropped significantly since the 1970s, aging infrastructure and more pronounced extreme weather due to climate change will likely mean more accidents in the future as oil and gas production continues to surge globally.

Freshwater impacts

Hydraulic fracturing production has grown significantly in the past two decades, and affects groundwater aquifers more severely than surface water, although both are at risk. Drilling and hydraulic fracturing use large amounts of water that can reduce the availability of freshwater resources near operating sites. In the shale gas industry, large volumes of water are required to enhance the production of gas from the wells. In China, shale gas wells use an average of 26,580 m3 of water per well for drilling, completion, and processing, and the volume can go as high as 34,756 m3 of water per well in some fields[56]. In the U.S., shale gas wells use anywhere between 10,000-30,000 m3 of water per well for the same processes[57], [58].

The process of drilling also introduces metals, such as barium, cadmium, chromium, copper, mercury, lead, zinc, and titanium, into groundwater, rivers, streams, and oceans. Oil sands extraction generates toxic elements, including naphthenic acids, Polycyclic Aromatic Hydrocarbons (PAHs), and Polycyclic Aromatic Compounds (PACs). High concentrations of these elements in wastewater have contributed to water contamination in surface and groundwater systems.

Geographical hotspots

Shale oil and gas deposits in current water-stressed regions are mostly centered in the U.S., Canada, Argentina, South Africa, northern Africa, China, India, and Australia. In some arid regions, more than half of their regional water will likely be required for shale extraction in the future, including Cambay shale in India, Etel shale in Libya, Frasnian shale in Algeria, Tunisia/Gacheta shale in Colombia, Lower Silurian shale in Morocco, and Goowood/Cherwell shale in Australia. Locations worldwide are impacted by drilling and hydraulic fracturing, including in the U.S., Canada, and Norway. These activities in already depleted regions, such as in the south central U.S., northern India, and Pakistan, will accelerate the depletion of groundwater.

4. Health Care Sector

The Health Care sector is made up of industries that provide significant value to individuals in the global economy by maintaining human health and well-being. The industry within the sector identified as having the most severe and systemic impacts is Pharmaceuticals, which generates many chemical pollutants, including a wide range of emerging pharmaceutical compounds that affect water quality more than many other sectors.

Pharmaceuticals

The Pharmaceuticals industry includes companies that research, develop, or produce pharmaceutical drugs, including veterinary drugs, used to prevent and treat diseases in humans and animals. Pollutants traced back to pharmaceutical use are increasingly being detected in surface waters, groundwater, and soils globally. These pollutants bioaccumulate and are toxic to aquatic ecosystems and humans. When released in drinking water supplies, they also promote antimicrobial resistance (AMR), which can increase the potential of the spread of AMR diseases, threatening public health and creating associated societal costs. It is estimated that waterborne AMR costs between $1 billion to $5 billion annually in additional healthcare expenditures globally, with the Global South suffering the most [59].

Practices and associated externalities

Pharmaceuticals, including over-the-counter and prescription drugs, are mostly being detected in surface waters, although they also pose a threat to groundwater, brackish water, sediment, and soil. A comprehensive estimate has pinpointed the presence of more than 600 pharmaceuticals in the environment globally, most of which are residues detected in surface water bodies [60].

Wastewater treatment plant discharges, originating from pharmaceutical manufacturing plants and households, are the main entry points for pharmaceuticals to get into water sources. Some 559 substances have been detected in treatment plant influent, effluent, and sludge [60].

Antibiotics are the most common pharmaceuticals detected in waters in many countries, with the highest concentrations found in surface waters near pharmaceutical production sites [61]. Other commonly found pharmaceutical groups include analgesics, anti-cancer, antidiabetics, anticonvulsants, antifungals, antihistamines, antiparasitics, beta blockers, endocrine disrupting pharmaceuticals, and psychiatric drugs.

Figure 12. Summary of the Pharmaceuticals industry freshwater impacts along its value chain, including ingredients production, manufacturing, and consumer use. Selected hotspots are the regions frequently cited in the literature.

Value Chain	Practices	Externalities	Freshwater Impact	Selected Hotspots
Manufacturing	Cooling and production	Water consumption, extraction	Water stress, groundwater depletion	Africa, Asia, South America
Manufacturing	Wastewater discharge	Pharmaceuticals in industrial wastewater	Ecotoxicity, bioaccumulation, human health impacts	China, India, Israel, South Korea, USA
Consumer use	End products use and disposal	Pharmaceuticals in municipal wastewater	Ecotoxicity, bioaccumulation, human health impacts	Western Europe, Asia, Latin America
On-farm agriculture	Veterinary pharmaceuticals for animal raising	Runoff of pharmaceuticals	Ecotoxicity, bioaccumulation, human health impacts	

Medicines used to raise animals are another growing source of pharmaceutical pollution worldwide. The use of antibiotics in livestock, which is already widespread, is expected to increase by 67% by 2030 across the globe, particularly in emerging economies [62].

While pharmaceutical manufacturing does not use water as intensively as other industries, it does use a considerable amount of ultrapure water (water of extremely high quality) for cooling and production, which potentially increases the risk of groundwater depletion. For example, from 2018-2019, the pharmaceutical company Pfizer used 5.32 billion liters of water per year for production at all Pfizer-owned and operated manufacturing sites [63].

Freshwater impacts

Drinking water sources polluted by pharmaceuticals can create potentially high risks for public health, including antimicrobial resistance. Absent action to address these risks, including by curtailing the overuse of antibiotics and increasing wastewater treatment capabilities, the number of people who die annually from drug-resistant infections is expected to jump from 700,000 during the past few years to 10 million by 2050 [64].

However, because non-effect concentrations (or the limit below which no adverse effects of exposure in an ecosystem are measured) haven't been established for most detected pharmaceutical substances in freshwater, and potential synergistic effects from the combination of various chemicals are not fully understood, it is difficult to monitor and assess the risks of these pharmaceuticals enough to address or regulate their production and uses. There are tens of thousands of pharmaceutical substances, making these risks extremely difficult and costly to measure. Further, conventional wastewater treatment plants are not designed to fully remove pharmaceuticals from wastewater, creating additional challenges for mitigation [62].

Geographical hotspots

The top producers of pharmaceuticals include China, India, Israel, South Korea, and the U.S. Pharmaceutical production and use of ultrapure water in the production process can heighten the risk of groundwater depletion, particularly in areas of Africa, Asia, and South America.

Pharmaceutical pollution is contaminating water on all continents, with strong correlations between socioeconomic status of a country and higher pollution of pharmaceuticals in its rivers. The world's most severely polluted countries and regions are those in sub-Saharan Africa, South America and parts of southern Asia [65]. High concentrations of pharmaceuticals in water that exceed national standards were found in several European countries and the U.S. Most of these were found in western Europe, where more than 30 different pharmaceuticals have been detected in tap or drinking water sources. Between 11 and 30 pharmaceutical substances have been found in drinking water in Canada, China, France, Sweden, and the U.S [60]. Given that over 75% of all pharmaceuticals have not yet been measured for in water, more comprehensive investigation is clearly needed in both developed and developing nations.

5. Materials Sector

The Materials sector is made up of industries that provide resources or raw materials for other industries. Key industries within the sector identified as causing significant impacts to freshwater resources include Chemicals, Metals and Mining, Paper and Forest Products, and Construction Materials. Among those, Chemicals, Metals and Mining, and Paper and Forest Products were identified as having the most severe and systemic impacts. The Construction Materials industry is included in Appendix E.

Chemicals

The Chemicals industry involves products used in other industries, including agriculture, consumer products, and textiles. It also includes companies or producers of commodity chemicals, diversified chemicals, fertilizers and agricultural chemicals, industrial gases, and specialty chemicals.

Practices and associated externalities

While chemical production requires significant water use, the Chemical industry's main threat to freshwater is from the pollutants that are discharged into the environment. Pollution from the chemical supply chain enters water sources from many different avenues, including production of chemicals by the chemical industry itself, production by other industries of products using chemicals, and direct use of those chemicals across a variety of industries. The primary chemical contaminants released in water are heavy metals, polycyclic aromatic hydrocarbons (PAHs), microplastics, phthalates (PAEs), pesticides, and fertilizers.

- Heavy metals (mercury, cadmium, nickel, lead, zinc, copper, arsenic, chromium) are released in industrial wastewater from gold mining, coal burning, chlor-alkali processes, cement manufacturing, and textile dyes and tanneries, with mercury being the most prominent due to its persistence in the environment.
- Polycyclic aromatic hydrocarbons are toxic, known to bioaccumulate, and some are carcinogenic (to humans and animals), teratogenic, and mutagenic [66]. They are largely attributed to the oil and gas, chemical manufacturing, and electronic industries. PAHs are a main water contaminant in China and Mexico due to the drilling processes for industrial gases and minerals. PAHs can be ingested by humans through the intake of contaminated fish and shellfish and can be associated with poor fetal growth and cardiovascular disease.
- Microplastics end up in water bodies from numerous industries, practices, and products, including plastic manufacturing, paints, chemical additives, aging and lost shipping containers, and aquaculture products. This also includes waste resulting from consumer use of everyday products like soaps and makeup. Up to 14 million tons of plastic waste are transported in rivers to the oceans each year, globally [67].
- Phthalates, used for making furniture, food packaging, drug coatings, and other everyday products, are released into water sources from plastic manufacturing discharges and municipal waste runoff.
- Herbicides, insecticides, and fungicides are widely used around the globe as agricultural inputs. Atrazine, Dimethoate, and Carbendazim are the most commonly detected pesticides in water. Fertilizers are widely used for crop production, releasing nitrogen and phosphorus into water bodies through runoff. Estimates show that 50% to 70% of all nitrogen applied to crops is lost from the soil-plant system through soil leaching and erosion [68].

Freshwater impacts

Heavy metals, which are acutely toxic and bioaccumulate, can cause nervous system damage and impair cognitive and physical development. PAHs can be carcinogenic, bioaccumulate, and have potential mutagenic and genotoxic effects. Phthalates are endocrine disrupting chemicals with potential teratogenic, mutagenic, and carcinogenic properties. Pesticides are persistent, acutely toxic, and carcinogenic, cause endocrine disruption, and impact photosynthesis and other physiological properties. Fertilizers cause eutrophication, hypoxic and anoxic conditions, and reduced light penetration in water bodies, significantly impacting fish and organisms and drinking water quality.

Figure 13. Summary of chemicals industry freshwater impacts along its value chain. Selected hotspots are the regions frequently cited in the literature.

Value Chain	Practices	Externalities	Freshwater Impact	Selected Hotspots
Full Value Chain	Chemical Production	Water consumption, extraction	Water stress	India, China
Chemical Production	Metals mining exploitation	Wastewater release including metals	Human health impacts, ecotoxicity	
	Coal burning			
	Chlor-Alkali processes			
	Cement manufacturing			
	Textile dyeing and tanneries			
	Coal and oil consumption	PAHs	Ecotoxicity, bioaccumulation, human health impacts	
	Plastic manufacturing	Phthlates in wastewater	Ecotoxicity, human health impacts	
	Fertilizer manufacturing	Nutrients in wastewater	Eutrophication	
	Pesticide manufacturing	Pesticides in wastewater	Ecotoxicity, human health impacts	
Consumer Use	Laundry, personal products use, vehicle tire wear	Microplastics	Ecotoxicity, bioaccumulation	
	Disposal of food packaging, furniture, etc	Phthlates leaching from landfills	Eutrophication, ecotoxicity, human health impacts	
	Agricultural fertilizer use	Nutrients	Eutrophication	
	Agricultural pesticide use	Pesticides	Ecotoxicity, human health impacts	China

Geographical hotspots

The Chemicals industry has ubiquitous impacts on water environment. Countries throughout Asia, particularly India and China, use extensive amounts of water directly and indirectly throughout the chemical value chain. On the pollution side, China uses the greatest amount of coal and petroleum in the world, contributing to PAHs contamination of surface waters. Sixteen PAHs compounds detected in China's surface water bodies surpass the EPA's acceptable drinking water limit [69]. According to a comparative review of studies on major pesticide consuming countries, high concentrations of pesticides were found in drinking water sourced from many major rivers in China, Japan, Malaysia, and India [70].

Metals and Mining

The Metals and Mining industry includes the extraction and processing of aluminum, copper, gold, silver, steel, and other precious metals and minerals.

Practices and associated externalities

Raw mineral extraction has many impacts on water bodies, especially on water quality. Core pollution impacts include acid mine drainage, heavy metal contamination, and leaching. Acid mine drainage, largely associated with gold and coal mining, occurs when the mineral pyrite contacts oxygenated water, such as in rainfall. Heavy metals contamination for arsenic, cobalt, copper, cadmium, lead, silver, and zinc is especially common at mining sites. Gold and arsenic mining also cause arsenic contamination of groundwater. Metal processing and smelting release metal contaminants through industrial wastewater.

Mining activities also require considerable freshwater resources. In Chile, the world's largest copper producer, the mining industry withdraws an average of 70 m3 of fresh water to produce one metric ton of copper.

Freshwater impacts

The impacts from the mining industry on freshwater supplies are widespread. Mining-related pollution, caused primarily by mineral extraction, is toxic to wildlife and can cause biodiversity losses through multiple pathways, both locally and globally. Mining pollution also impacts human health and communities' well-being, including some indigenous communities. One indigenous community living near an abandoned mercury mine in the U.S. had an average blood mercury level of 15.6 mg/L (where normal levels are between 10-20 micrograms/L), heavily tied to the consumption of contaminated fish [71]. In the Brazilian Amazon, Tribal and Nahua People have long been exposed to mercury poisoning due to intensive mining activities in the area [72].

Mining activities are causing a decrease in surface and groundwater availability in many parts of the world, with more severe impacts in water-stressed regions. Mining activities have caused severe groundwater depletion

Figure 14. Summary of metals and mining industry freshwater impacts along its value chain. Selected hotspots are the regions frequently cited in the literature.

Value Chain	Practices	Externalities	Freshwater Impact	Selected Hotspots
Extraction	Mining of gold, coal, and other metals	Acid mine drainage, metal leaching	Ecotoxicity, human health impacts, ecosystem impacts	Portugal, Iran, Canada
		Water consumption, extraction	Water stress, groundwater depletion, social conflict	USA
Processing	Smelting	Metal pollution	Ecotoxicity	

in western Australia, South Africa, and Peru [73],[74]. Extensive mining activities in the Canning Basin in western Australia caused the world's third highest rate of groundwater depletion [74]. The declining freshwater availability in many regions has caused increased competition between mining companies and local communities. The struggle between the largest mining companies and communities is evident in many places globally, such as the conflict in Cajamarca in Latin America [75].

The development of mining sites can spur people to migrate from other regions, upending local communities, creating competition for water and land, and raising living costs. For example, booming bauxite mining in Guinea in western Africa, which turned the country into a top global exporter, attracted a throng of new residents outside the mining sites, leading to reduced water levels and water-related riots [76].

According to a 2019 CDP survey of the world's largest mining companies, 27% of production and up to $50 billion in revenues are likely to be exposed to high levels of water stress risk by 2030. More companies are resorting to using greater amounts of seawater desalination, which has its own environmental concerns, and water recycling to hedge against possible disruptions to operations. For example, copper mining in Chile consumes 15.4 m3/s of freshwater, 15% of which is from raw and desalinated seawater. Using seawater has increased from 1.3 in 2013 to 2.3 m3/s in 2015. The Las Luces copper-molybdenum plant in Chile has successfully operated using seawater as the sole source of water for over 20 years [77].

Geographical hotspots

Metals, which can be toxic in relatively low concentrations, are a growing threat to human health and wildlife, especially in developing countries lacking environmental regulations and proper wastewater treatment facilities. Mining impacts on freshwater availability are reported in many developing countries, including Peru, Chile, Saudi Arabia, Morocco, Western Sahara, Namibia, and South Africa. Mining companies in these regions face high water risks. Heavy metals, much of them released through mining extraction and processing, have been detected globally in rivers and lakes, with the highest concentrations in Africa, Asia, and South America, and lower levels in Europe and North America.

Paper and Forest Products

The Paper and Forest Products industry includes all sub-industries involved in paper manufacturing and other wood products, including the cork, forestry, cellulose, pulp and paper, wood, and timber sub-industries. These

Figure 15. Summary of paper and forest products industry freshwater impacts along its value chain. Selected hotspots are the regions frequently cited in the literature.

Value Chain	Practices	Externalities	Freshwater Impact	Selected Hotspots
Forestry	Logging	Deforestation	Change in hydro-climatic patterns, erosion	Borneo and Sumatra, Papua New Guinea, Chile, Brazil, Eastern Russia
Products processing	Pulp and paper milling	Water consumption, extraction	Water stress	USA, Canada, China, Japan
		Wastewater release (e.g., PAHs, PCBs, metais)	Ecotoxicity, eutrophication, social conflict, human health impacts, bioaccumulation	Europe
Consumer Use	Industrial biomass	Water consumption, extraction	Water stress	Europe

industries have a wide reach due to their usage in construction, paper, wood products, and fuel.

Practices and associated externalities

Global water consumption by the Paper and Forest Products industry has risen from 768 billion m3 per year in 1961-1970 to 961 billion m3 per year in 2001-2010 [78]. This industry consumes and pollutes large amounts of water in the production of lumber, pulp, paper, fuel, and firewood products, involving a wide range of practices from wood harvesting to end-product processing, such as cooling, sealing, lubrication, and heating. Pulp and paper mills consume a large volume of water to produce paper products. Based on available data, the consumptive water footprint of producing an A4 Sheet paper, used for printing and writing, ranges between 2-13 liters (300-2,600 m3/ton paper), depending on location and type of wood used [79]. In China, the production of tissue paper consumes more water than any other type of paper, followed by printing paper. Non-wood pulp-based papermaking consumes at least two times more water than wood and bamboo pulp-based papermaking [80].

Pulp and paper production is also one of the biggest contributors to freshwater pollution, especially from paper processing-related PAH discharges. Paper processing plants also release fluorene, anthracene, naphthalene, fluoranthene, phenanthrene, and pyrene in waste-water. Pulp mill effluent can cause excessive biological and chemical oxygen demand, and includes many contaminants, including PCBs, adsorbable organic halides (AOX), ammonium, phenol, sulfur, metals (iron, chromium, mercury), oil and grease, biocides, and resins [81].

Freshwater impacts

The Paper and Forest Products industry can have a wide range of negative impacts on freshwater systems. Sourcing wood materials results in forest degradation or deforestation, which further disrupts regional hydro-climatic patterns by altering movements of air, water, and heat through evaporation and transpiration. These disruptions can dramatically impact temperature and precipitation both locally and thousands of miles away [82]. For example, the average precipitation in the Amazon can decrease by -62 mm per year (-2.3%) in response to total deforestation [83].

Pulp and paper mills have a significant impact on water through intensive water consumption in the processes of producing the final products. The growing demand for paper products will intensify the pressures on freshwater globally, with some 85% of water use within the industry related to the production processes [84].

In addition, many organic pollutants produced during the paper making process are directly discharged into aquatic systems without proper treatment. The wastewater impact from paper mills has been linked to impacts in fish, including reproductive issues. Toxic pulp and paper effluent also contribute to eutrophication, oxygen depletion, and contaminated water supplies.

Geographical hotspots

Damaging freshwater impacts from the Paper and Forest Products industry take place predominantly in countries with large forestry industries, including North America, Asia, and Europe. The industry is intensifying water consumption in many large paper producing countries, including China, U.S., and Japan [80]. The paper industry in North America consumes more water than many other paper-producing regions in the world. U.S. paper mills use approximately four to 10 times the water volume than those in China and Germany. Even mills with recycled water systems in the U.S. use significantly more water than identical mills in the Europe or China [85].

The growing demand for paper products will also increase the need for wood materials, which will accelerate deforestation, impacting the hydrology in surrounding regions. The evidence of these impacts has been widely observed globally: the Amazon Basin, where 17% of rainforest has been destroyed since 1970 for harvesting of wood, among other reasons, is a well-known example. The remaining natural forests and their associated ecosystems in regions such as Borneo and Sumatra, Papua New Guinea, the Russian Far East, southern Chile, and the Atlantic Forest region in Brazil are at a high level of deforestation risk due to the growing demand for pulpwood [86]. Significant and moderate decreases in precipitation due to deforestation, as a result of wood harvesting and other activities, will likely happen in Northern Hemisphere monsoon regions (East Asia, North America, North Africa, and South Asia) and in the Southern Hemisphere monsoon regions (South Africa, South America, and Australia) [83].

6.Information Technology Sector

The Information Technology Sector (IT) refers to technological products and industries including the High-tech and Electronics, Semiconductors and Circuit Boards, and Battery industries. Semiconductor manufacturing and raw material extraction for batteries are water intensive processes, while electronic waste (e-waste) and battery recycling facilities leach contaminants into water bodies, such as PFAS, nanomaterials, ionic liquids, and metals.

Although the High-tech and Electronics, Semiconductors and Circuit Boards and the Battery industries were not flagged as having a "very high" impact based on the literature review, the emerging impacts from these industries should be further investigated, given the growing global demand for electronic devices and electric vehicles (EVs) and the potential for severe freshwater impacts. For instance, the Battery industry was designated as "high impact" for its direct operations, supply chain, and the product end use cycle, demonstrating that the impacts are consistently high throughout all stages of the value chain. For the High-tech and Electronics industry, both the water quality and water quantity impacts in supply chain and direct operations were high. The water –related impacts of these industries have drawn public attention more recently, so many aspects of freshwater and ecosystem impacts remain to be investigated in-depth.

High-tech and Electronics

The High-tech and Electronics industry is the aggregation of electronics industries using leading-edge technologies to integrate electronic devices and software and provide IT services. The industry also includes the electronic components, equipment, and data centers subindustries.

Practices and associated externalities

Highly reactive and toxic rare earth elements (REEs), such as europium and cerium, that are critical industry inputs are released into water bodies without proper treatment through multiple pathways throughout the value chain, including during material extraction. REEs are used to produce electronics products, such as display screens, optical fibers, medical imaging, and magnets. The often ineffective wastewater treatment processes used in factories make these elements a main source of pollution from product manufacturing [87].

Data centers consume water through both direct and indirect pathways. Water is used directly in some data centers for cooling servers and other equipment, while it is indirectly used through electricity (thermoelectric power) generation needed to run the data centers. In 2014, a total of 626 billion liters of water was used by U.S. data centers [88]. A medium-sized data center (15 megawatts) can use as much water annually as three average-sized hospitals or more than two 18-hole golf courses. In the U.S., efforts have been made since 2017 to use more non-potable sources of water, and potable water consumption has dropped from 64% in 2017 to 57% in 2019. Many data center operators in other parts of the world, however, are still drawing more than 50% of their water from potable sources [88].

E-waste is having increasing impacts on water sources globally, with pollutants leaching into water bodies, especially within the countries where tech products are bought and disposed of and those that receive e-waste through transportation and trading. About 8% of used electronic equipment was exported from North American countries in 2010 and 2011, while the total global flow of used equipment was 7% to

Figure 16. Summary of High-tech and Electronics industry freshwater impacts along its value chain. Selected hotspots are the regions frequently cited in the literature.

Value Chain	Practices	Externalities	Freshwater Impact	Selected Hotspots
Raw materials extraction	Raw material processing	Rare earth elements (REEs) release	Ecotoxicity, human health impacts	Most detected in Northern Hemisphere
Manufacturing	Cooling and production of ultrapure water	Water use	Water stress	
	Cooling and production of ultrapure water	Rare earth elements (REEs) release	Ecotoxicity, human health impacts, water disputes and conflict	Most detected in Northern Hemisphere
	Acid wastewater discharge	Metals released	Ecotoxicity, human health impacts, water disputes and conflict	
End-of-life disposal	E-waste recycling	Leaching of metals, PFBS, PFOS, PFOA, and PFAS from landfills	Ecotoxicity, human health impacts, water disputes and conflict, bioaccumulation	China, USA, India

20% [89]. Globally, the e-waste generated by the High-tech and Electronics industry contributes 8% of total municipal solid waste. E-waste has been found to leach "forever chemicals," including perfluorobutane sulfonic acid (PFBS), perfluorooctane sulfonate (PFOS), perfluorooctanoic acid (PFOA), perfluoroalkyl and polyfluoroalkyl substances (PFAS), and metals from landfills. Toxic metals released include chromium, lead, mercury, iron, zinc, copper, and cadmium. Given the growing demand for electronics, the annual quantity of e-waste is expected to increase to 81.57 million tons by 2030 from 59.52 million tons in 2019 [89].

Freshwater impacts

Wastewater released from manufacturing processes used by the High-tech and Electronics industry may include REEs, heavy metals, and organic chemicals, which are persistent and toxic, and, if ingested, can cause severe human health impacts, including nephrogenic systemic fibrosis, neurological disorders, and cytotoxicity.

Pollution from the industrial manufacturing process has triggered water disputes and conflicts between companies and local communities, as evidenced in the Siaoli River basin of Taiwan. In 2001, as several large-scale electronics facilities ramped up operations near the head of the Siaoli River, they began discharging approximately 40,000 tons of wastewater daily into the river, creating a toxic environment that led to fish kills and the closure of fisheries [90]. In 2011, Meiko Eletronics, Apple's key supplier in China, was identified as having failed to address severe water pollution caused by its manufacturing activities. The report of pollution caused a year-long dispute over water security between the company and local residents [91]. Many other conflicts over water between companies within this industry and local community have been reported globally, including a cross-sector conflict between Samsung Electronics and the water utilities sector in Giheung in South Korea [92].

While high-tech products have generated direct impacts on surface water, e-waste is one of the major sources of groundwater contamination due to leaching from landfills. Approximately 70% of heavy metals in U.S. landfills come from e-waste, and these contaminants can migrate into both surface water and aquifers through run-off and leaching [93]. The resulting water pollution can have toxic impacts on aquatic species, including fish, and drinking water sources for residents. If these heavy metal residues are not mitigated, many human health issues arise, including hypothyroidism, cardiovascular disorders, and cancer.

Water use by the electronics industry, including data centers, accelerates freshwater scarcity in water-stressed regions and can cause water competition with other local water users. Many data centers in the U.S. draw water from moderately to highly stressed watersheds, leading to conflicts with local communities, such as when conservation groups in South Carolina opposed Google's data center expansion plans that included withdrawing 5.68 million liters daily from the strained Charleston Aquifer [94]. As the global demand for internet and IT services increases, data centers are being built around the world to provide millions of servers to match the growing demand, so freshwater impacts are likely to accelerate as well.

Geographical hotspots

REEs from industrial wastewater have been most widely detected in the Northern Hemisphere and are starting to emerge in monitoring data in the Southern Hemisphere. China, the U.S., and India generate the most e-waste globally, accounting for approximately 38%. The Global South lacks e-waste regulations, which threatens the water quality in these regions in particular. In fact, over 50% of countries do not have regulations or policies in place to measure and monitor e-waste and related pollutants.

Semiconductor and Circuit Board

The Semiconductor and Circuit Board industry includes both fabless manufacturers and fabrication manufacturers of semiconductors, and related products, such as memory chips, sensors, and processors. Semiconductor production for fabrication manufacturers requires large volumes of water and releases toxic and persistent pollutants, including PFAS and metals.

Practices and associated externalities

Semiconductor and circuit board chip production are extremely water-intensive and require ultrapure water (water that is thousands of times purer than drinking water). Most of the water footprint in the semiconductor industry is from ultrapure water used in manufacturing at fabrication facilities. Other water uses include for cooling systems [95]. The average semiconductor factory uses up to 15 million liters of water per day, consuming more than 1,000 billion liters of water annually. Growing chip sales (a year-to-year increase over 12% from 2016-2018) are predicted to increase absolute water use [96]. For example, water use for chip manufacturing by TSMC in Taiwan, the biggest chip manufacturer in the world, increased fivefold from 43.4 million liters in 2009 to 197.9 million liters in 2019 [97].

Wastewater from the production of semiconductors includes a wide range of chemicals, including perfluorinated chemicals (PFCs) (e.g., perfluoroalkyl carboxylates-PFCAs and perfluoroalkyl sulfonates-PFASs). Wastewater from semiconductor and circuit board production also generates toxic metal pollutants, including barium, copper, manganese, and chromium.

Freshwater impacts

Semiconductor and chip manufacturing can add to water stress and conflict in water-scarce regions. Growing chip sales are expected to increase further demands on available water resources, as approximately 13% of semiconductor production is located in high water-stressed regions [96]. The demand for chips is increasing dramatically and, as a result, the absolute water use from the industry is predicted to increase globally. According to recent data, chip sales grew 29.7% between August 2020 and August 2021, driven by the build out of cloud computing and 5G wireless, along with the growing demand for products using chips, from cars to appliances [98].

Semiconductor fabrication can generate a wide range of toxic chemicals, including metals that have long been detected in water bodies, while some others are emerging in the monitoring data and require further investigation, such as PFCAs and PFAS. Metal contaminants can be toxic to aquatic ecosystems and humans who ingest contaminated water or fish containing the contaminants. PFAS, which are long-lived contaminants, can result in toxic pollution in water bodies and threaten human health for decades after their introduction into the environment.

Figure 17. Summary of Semiconductor and Circuit Board industry freshwater impacts along its value chain. Selected hotspots are the regions frequently cited in the literature.

Value Chain	Practices	Externalities	Freshwater Impact	Selected Hotspots
Manufacturing	Cooling and production of ultrapure water	Water withdrawals and consumption	Water stress, water disputes and conflict	South Korea, China, Taiwan, USA, Japan
	Manufacturing wastewater discharged	Wastewater including PFCAs, PFAs, and metals	Ecotoxicity, human health impacts, bioaccumulation	Taiwan

Geographical hotspots

Semiconductors are manufactured in the U.S., South Korea, Japan, Taiwan, and mainland China, which combined account for more than 80% of the semiconductor manufacturing capacity of the world and the bulk of the industry's water use. High levels of pollution have been detected in water bodies surrounding many semiconductor manufacturing facilities, particularly in eastern China, Taiwan, and South Korea. There have also been noted environmental violations levied by the local regulating agency in some of these areas due to their polluted discharges.

Battery (Technology Hardware and Equipment)

While the Battery industry is not technically a GICS "industry" (it is included within the Technology Hardware and Equipment industry), the value chain of batteries contributes significantly to freshwater impacts and is included as a separate industry in this assessment. Batteries play a key role in the Information Technology sector and are an important component of the Automobile industry for its electric vehicle (EV) production. The industry's primary products include lead-acid, lithium-ion (Li-ion), nickel-metal hydride, nickel-cadmium, and nickel-zinc batteries. Among all battery types, investment in Li-ion battery is growing the most, driven by demand for electric cars and the lower cost of Li-ion battery production. In general, the Li-ion battery is more environmentally friendly than traditional batteries, such as lead-acid batteries, because it contains fewer toxic metals. Many of the metals it does contain, including iron and cobalt, are considered safe for landfills [99]. In 2016, Li-ion batteries made up 70% of the rechargeable battery market [100]. The global Li-ion battery market is projected to grow from $41.1 billion in 2021 to $116.6 billion in 2030 [101].

Practices and associated externalities

Throughout the value chain, Li-ion battery-powered electric vehicles use less energy than fossil fuel powered vehicles, but they consume 56% more water than other types of batteries to produce [100]. The raw material extraction of lithium and copper mining is extremely water intensive. Wastewater produced during the manufacturing of batteries may

Figure 18. Summary of Battery industry freshwater impacts along its value chain. Selected hotspots are the regions frequently cited in the literature.

Value Chain	Practices	Externalities	Freshwater Impact	Selected Hotspots
Full Value Chain	Production and use of electric vehicles	Water use	Water stress	
Raw mineral extraction	Lithium and copper mining	Water use	Water stress, groundwater depletion	Chile, China
Manufacturing	Battery manufacturing wastewater	Wastewater released including nanomaterials, ionic liquids, and metals	Ecotoxicity, algae growth, bioaccumulation, human health impacts	
End of life disposal	Battery recycling	Leaching of nanomaterials, ionic liquids, and metals	Ecotoxicity, algae growth, bioaccumulation, human health impacts	Central and South America, South East Asia, Africa

include emerging contaminants, including nanomaterials, ionic liquids, metals, and metal oxide nanomaterials. Metals such as lead, arsenic, and cadmium are major pollutants due to leaching at battery recycling sites.

Freshwater impacts

The Battery industry impacts water resources through its raw material sourcing and manufacturing processes, as well as end-of-life battery recycling. Lithium mining for batteries is water intensive and can contribute to freshwater scarcity in lithium producing countries. For instance, in Chile's Salar de Atacama, lithium and related mining activities consume 65% of the region's water, leading to groundwater depletion.

Metal leaching from battery recycling sites has severe impacts on freshwater resources and on human health since it can increase toxicity in receiving water bodies and aquatic ecosystems and decrease the quality of drinking water. Ingestion of lead causes a variety of health-related effects, particularly in children, including neurotoxicity, developmental delays, hypertension, impaired hearing acuity, impaired hemoglobin synthesis, and male reproductive impairment. Emerging contaminants in wastewater from battery production, such as nanomaterials and PFAS, can impact soils by damaging their microbial diversity [102].

Geographical hotspots

Hotspots for lithium mining water use include Chile and China. Battery recycling and related freshwater impacts mostly occur in Southeast Asia, Africa, and Central and South America, putting almost 1 million people at high risk of lead pollution [103].

7. Utilities Sector

The Utilities sector includes industries that produce or distribute electricity, gas, and water to customers. Key industries within the sector identified as causing significant impacts to freshwater resources include Electric Utilities and Renewable Electricity. Among those, Renewable Electricity—specifically, hydropower—was identified as having the most severe and systemic impacts. The Electric Utilities industry is included in Appendix E.

Renewable Electricity

The Renewable Electricity industry generates electrical power using renewable energy sources, which include hydropower, wind power, solar, and geothermal systems. According to the International Energy Agency [104], the share of renewable energy as part of global electricity generation grew from 27% in 2017 to 29% in 2020, with hydroelectric power accounting for much of that generation. Renewable electricity generation in 2021 is set to expand by more than 8% to reach 8,300 TWh, the fastest year-on-year growth since the 1970s, with solar photovoltaic and wind contributing two-thirds of this growth. Electricity generation from wind is expected to notch the largest increase among renewables, growing by 275 TWh, or almost 17%, significantly greater than 2020 levels [105].

Practices and associated externalities

The Renewable Electricity industry uses significant amounts of water to produce electricity, the vast majority for hydropower plants. Hydropower plants use flowing water from surface water bodies to generate power before discharging the water in a different location. Their construction and operation can severely alter the temporal patterns of the natural streamflow of rivers and, as a result, natural habitats. From 2008-2012, the global consumptive water footprint of electricity and heat was estimated to be 378 billion m3 per year, with hydropower making up 49%. Geothermal, solar, and wind energy contribute very little to the global total consumptive water footprint, at just 0.06% [105].

Hydropower plants are the primary driver of streamflow alteration, water diversion, and river fragmentation. Globally, dam construction for hydropower is one of the main drivers of river fragmentation. Only 37% of the world's long rivers are still free flowing, with 23% flowing uninterrupted into the ocean [106].

Dam construction also impairs water quality, particularly through the release of heavy metals. In China's Manwan Reservoir, high heavy metal concentrations were observed in river sediment for seven years after the dam closed.

Figure 19. Summary of the Renewable Electricity industry impacts freshwater resources along its value chain. Selected hotspots are the regions frequently cited in the literature.

Value Chain	Practices	Externalities	Freshwater Impact	Selected Hotspots
Full Value Chain	Dam construction for hyroelectric power	Water extraction, water relocation	Evaporation, river fragmentation, streamflow alteration, water diversion, water disputes, ecosystems impacts	Europe, China, Latin America, USA, Canada, India
		Pollutant accumulation	Ecotoxicity	
	Geothermal power generation	Water extraction	Water stress	Europe, China, Latin America, USA, Canada, India
		Wastewater release	Ecotoxicity, salinity	USA, Philippines

Dams also collect contaminants, such as nutrients and sewage, which are often eventually released downriver.

Geothermal power plants have a fairly small water footprint. However, they release large quantities of waste heat relative to other types of power facilities, as well as geofluids. Water impacts from waste heat and geofluids include thermal pollution and the release of salts and metals into water bodies, such as hydrogen sulfide, boron, ammonia, mercury, and arsenic. The release of geofluids from the cooling systems of these plants can be highly saline, as evidenced in the Salton Sea field in the U.S. and in Iceland [107].

Freshwater impacts

Water is withdrawn from lakes and rivers as a free resource by thermal and hydropower plants. During droughts, however, obtaining water can become a financial burden on power companies. In 2021, a California hydropower plant on Lake Oroville shut down for the first time since it opened in 1967 due to low reservoir levels. Dams and reservoirs also lose large amounts of water to evaporation, especially in hotter climates [108],[109].

Hydro-related streamflow alteration and river fragmentation also affect the magnitude and seasonality of flows, floodplains, riparian and aquatic habitat, sediment transport, and fisheries. River fragmentation has been linked to sharp declines of terrestrial and aquatic species, contributing to the 83% decrease in freshwater populations since 1970 [110]. Streamflow alteration is reported to have higher impacts on river systems than water consumption. Hydroelectric power dams also create socioeconomic impacts and water conflicts. It is estimated that up to 80 million people have been displaced because of dam construction over the past 100 years [111]. On the other hand, the expansion of renewable energy, particularly solar and wind, can have a positive effect on reducing system-level water consumption because it displaces water-intensive fossil fuel generation.

Geographical hotspots

China, the U.S., Canada, and India, along with some countries in Europe and Latin America, rely on large amounts of freshwater for renewable electricity, specifically hydropower. The construction and operation of hydropower plants have altered streamflow in most of the world's rivers, and many large river basins have been heavily fragmented, except for those in remote areas, including the Arctic, the Amazon Basin, and the Congo Basin [105].

CHAPTER 3

CRITICAL AND EMERGING IMPACTS AND THREATS TO GLOBAL WATER SYSTEMS

The evaluation of the scientific evidence identified in Chapter 2 reveals the enormous water impacts of industrial sectors and their widespread systemic effects along industrial supply chains. In this chapter, critical and emerging freshwater impacts and threats that have been identified to be systemic in nature are discussed, along with resulting potential risks to industries. Systemic water impacts affect interrelated systems in pervasive ways and can be identified as ones that [112]:

- Jeopardize water quantity to the point that available water is insufficient to meet objectives over a specific period.
- Impact water quality so that the water is no longer adequate for a particular purpose.
- Create extreme conditions, including droughts and flooding, that lead to too little or too much water, preventing objectives from being met and imposing additional costs.
- Impede effective functioning of freshwater ecosystems, reducing environmental services for society and the environment.

Critical threats

From the collection of scientific evidence, we identified five critical systemic threats:
(1) **eutrophication**, (2) **groundwater depletion**, (3) **diversion and transfer of water**, (4) **metals contamination**, and (5) **plastic pollution**. As gleaned from the literature, these critical threats are:

- Causing systemic water impacts due to alteration of water quantity, water quality, and the broader physical environment.
- Attributable to practices, activities, and impacts associated with multiple sectors, industries, and their extended value chains.
- Geographically distributed, which create vulnerable hotspots globally.
- Producing chronic impacts that are larger in scale and over longer duration producing ever-deepening impacts.

Five critical and systemic threats identified

Figure 20. Chart of critical threats as identified through the literature review.

Critical Threat	Defined Threat	Identified Sector/ Industry	Geographic Distribution	Environmental Impacts	Human Health Impacts	Socioeconomic Impacts	Impacts to Industry
Eutrophication	Excessive enrichment of water by nutrients, usually nitrogen and phosphorus, contributing to algal growth	Consumer Staples (Food Products, Household Products, Beverage), Consumer Discretionary (Textile & Apparel)	Most impact in SE USA, Western Europe, East and Central Asia	Oxygen depletion, ocean acidification, blocked sunlight, fish die-off events, deterioration of water quality	Tainted water supply, "blue-baby" syndrome, rashes, stomach, liver illness, respiratory issues, neurological effects	Eutrophication cost USA $2.2 billion in 2009 (Dodds et al., 2009)	Maximum financial impact for Food, Beverage, and Agriculture industries is USD$19.59 billion (CDP, 2020)
Groundwater Depletion	Occurs when extractions exceed natural groundwater recharge	Eutrophication Consumer Staples (Food Products), Energy (Oil and Gas), Materials (Metals and Mining)	Hot spots include western USA, India, Saudi Arabia, China, Mexico, Northern Africa, Pakistan, and China	Permanent loss of aquifer storage capacity, land subsidence, groundwater salinization, sea-level rise, decreased streamflow, and wetland loss	Stress on drinking water resources	Deeper wells are more expensive, expected to increase social conflicts	Decreased cropping intensity and crop yields
Diversion and Transfer of Water	Movement away from natural channels, transferring water from one basin to another	Consumer Staples (Food Products), Consumer Discretionary (Textile & Apparel), Utilities (Renewable Power)	India, China, Middle East, Peru, Bolivia, USA	Increased evaporative loss, salinization, nutrient enrichment, spread of pollutants, reduced sediment load, and changes in species	Increase spread of pollutants and disease	Relocation of communities and destruction of livelihoods for construction	Reduced water allocations, competition can increase water prices, aging infrastructure is a risk
Metals Contamination	Metallic elements that can be toxic in relatively low concentrations	Materials (metals and mining), Information Technology (Semiconductor & Circuit board, Battery, High-tech and Electronics)	Higher concentrations found in Africa, Asia, and South America	Toxic to organisms and can bioaccumulate	Toxicity includes organ failure, impaired development, genetic disorders, cancer, and neurogenic properties		Maximum financial impact of USD$22.7 billion for Materials and USD$191 billion for Manufacturing (including electronics)
Plastic Pollution	Ubiquitous in the environment, microplastics are <5mm in length	Consumer Staples (Personal Products), Consumer Discretionary (Households products,Textile & Apparel, Automobiles), Materials (Chemicals)	China, India, Bangladesh, and Indonesia	Bioaccumulate in organisms, large pieces of plastic may entangle or kill animals	Microplastics accumulate in the food chain, absorb chemicals, and are a vector for biofilms	May impact coastal tourism, and beach clean-ups are costly	The presence of plastic has overwhelming effects on water and wastewater treatment

1. Eutrophication

Eutrophication is a complex process that results from excessive nutrient loading of water, usually nitrogen and phosphorus, which in turn stimulates excessive growth of algae and other aquatic plants that consume oxygen in the water. Eutrophication is strongly linked to oxygen depleted water known as hypoxic and anoxic "dead zones," which can cause catastrophic system stressors, such as fish die-off events, blocked sunlight, declining water quality, contaminated water supplies, and ocean acidification. The increasing concentration of nitrogen and phosphorus in the world's water systems is broadly recognized as one of the most pressing threats to global sustainability [26]. In the U.S. alone, the EPA has identified more than 166 dead zones across the country, including in the Great Lakes, the Chesapeake Bay, and the Gulf of Mexico [113].

Industrial practices

The Consumer Staples sector is the largest global source of human-driven nutrient loading, in particular the Food Products industry, which generates enormous amounts of nutrient pollution from livestock production, fertilizer application, and runoff. The estimated global annual nitrogen and phosphorus loss to water from manure and fertilizer use alone is 9.10 million and 1.65 million tons, respectively [114]. Other agricultural industries contributing to nutrient loading are Aquaculture, Food and Meat Processing and Packaging (slaughterhouses and dairy), Beverage, and Textiles (cotton and silk). Activities from these industries that contribute to nutrient loading include on-farm fertilizer use and the release of product manufacturing wastewater.

The Household Products industry, particularly from detergent use and resulting releases into municipal wastewater, is also strongly associated with phosphorus discharges, which have been directly tied to major eutrophication events in freshwater bodies around the world. For example, 24% of phosphorus loadings into the Black Sea were associated with detergent use [115].

Global trends

Globally, 415 coastal areas have been identified as eutrophic, of which 169 are hypoxic (dissolved oxygen concentrations of less than 2-3 mg/L) [26]. Hypoxic and eutrophic zones are prevalent along the coast of western Europe, the eastern and southern coast of the U.S., and around East Asia (Figure 21). In August 2021, the low oxygen 'dead zone' in the Gulf of Mexico covered about 6,334 square miles, which is roughly the size of Connecticut. A major contributor to this is nutrient pollution from agricultural activities along the Mississippi River watershed, which drains from the Midwest. Coastal hypoxia related to eutrophication in the U.S. has increased almost 30-fold since 1960 [116].

Eutrophication affects 54% of the lakes and reservoirs in Asia, 53% in Europe, 48% in North America, 41% in South America, and 28% in Africa [118]. Recent satellite data shows that the problem is worsening in many lakes around the world (Figure 22) [119]. Within North America, phosphorus inputs from tributaries into Lake Erie have increased from 11% to 24% since the mid-1990s, creating dangerous algal blooms [120]. Since the late 1980s, approximately 62% of water areas in 67 of China's main lakes have become severely eutrophic [121].

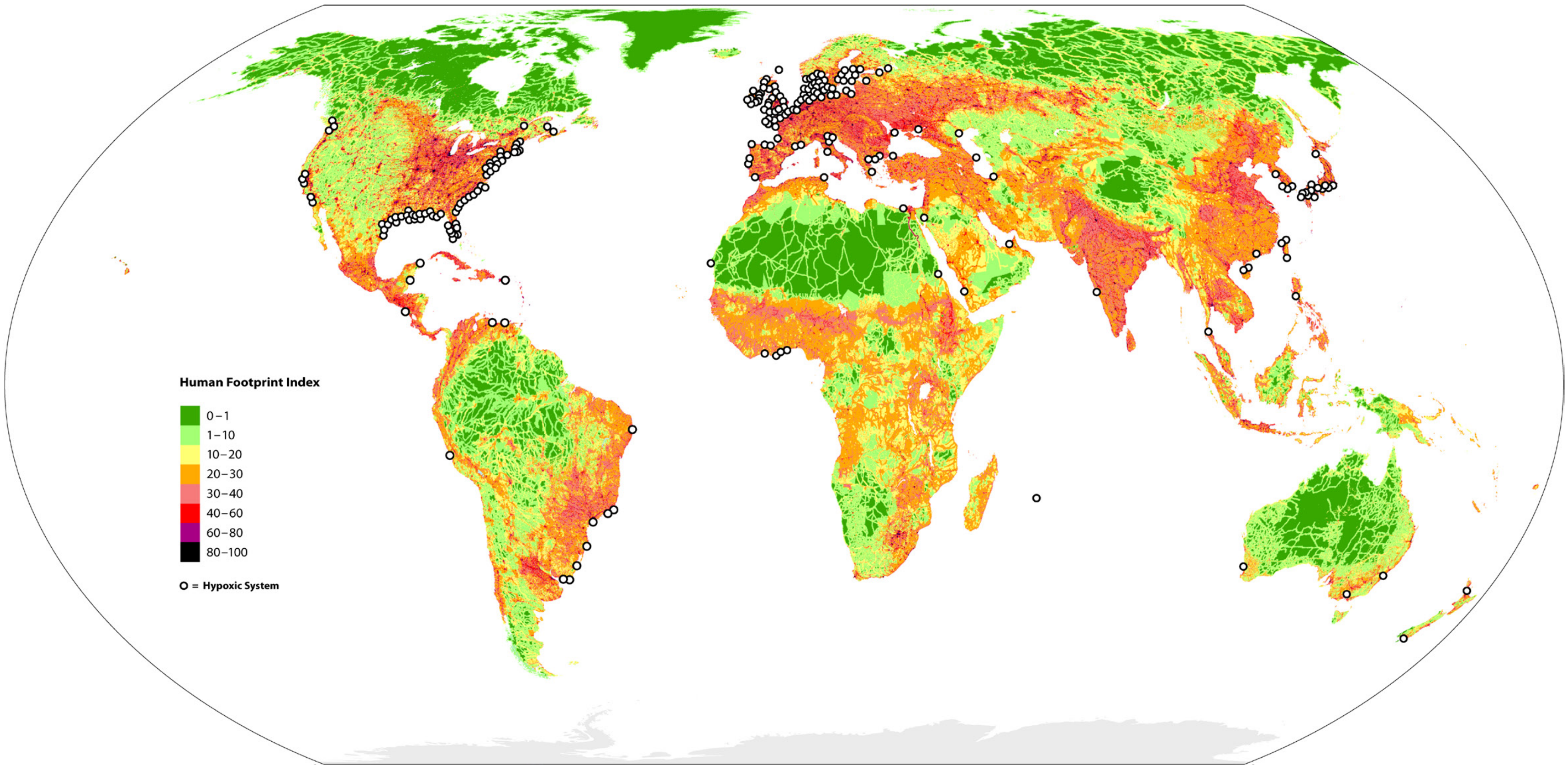
Industrial risk

Eutrophication is not only a challenging issue, but also a costly one. In the U.S. alone, damages to freshwater bodies from eutrophication exceeded $2.2 billion in 2009, including the loss of value from reduced recreational usage, impacted waterfront real estate, loss of biodiversity, and impaired drinking water quality [122].

The Consumer Staples sector was identified as the leading global contributor of human-driven nutrient loading, but it is also exposed to water risks associated with eutrophication. For example, eutrophication has forced some countries to implement remediation requirements or strict controls, leading to new expenses for the owners of farms, businesses, or facilities that generate high nutrient loads. In the U.K, one estimate pegs the costs to farmers who adopt new farm practices aimed at reducing nutrients in established nitrate sensitive aquifers at as much as $4.75 million an-

Global map of eutrophicated ecosystems and coastal hypoxic areas

Figure 21: Map of coastal hypoxic areas due to eutrophication. Human footprint in the figure was estimated based on four types of data that represent human influence on nature: population density, land transformation, accessibility, and electrical power infrastructure. The map shows the global distribution of over 400 ecosystems that have scientifically reported of being eutrophicated and matches the global human footprint [117]. Visualization credit: Charles Gibbons/Ceres.



nually [123]. Existing private investment in food and agriculture assets is at high risk from the hidden system costs and risks (costs arising from their impact on health, nutrition, and the natural environment). Mitigation policy costs related to freshwater eutrophication damages in England and Wales were estimated to be as high as $77 million per year, with over $15 million borne by industrial sectors, including tourism [114].

Food-related industries could save more from investing in the transition to less nutrient dependent production than would be spent on such hidden costs in the future [124]. Without large-scale environmental improvements focusing on mitigating water impacts, the Food Products and Beverage industries face overall water-related financial risks of as much as $196 billion, compared to the $11 billion it would cost to reduce water impacts [7],[125].

Mitigation

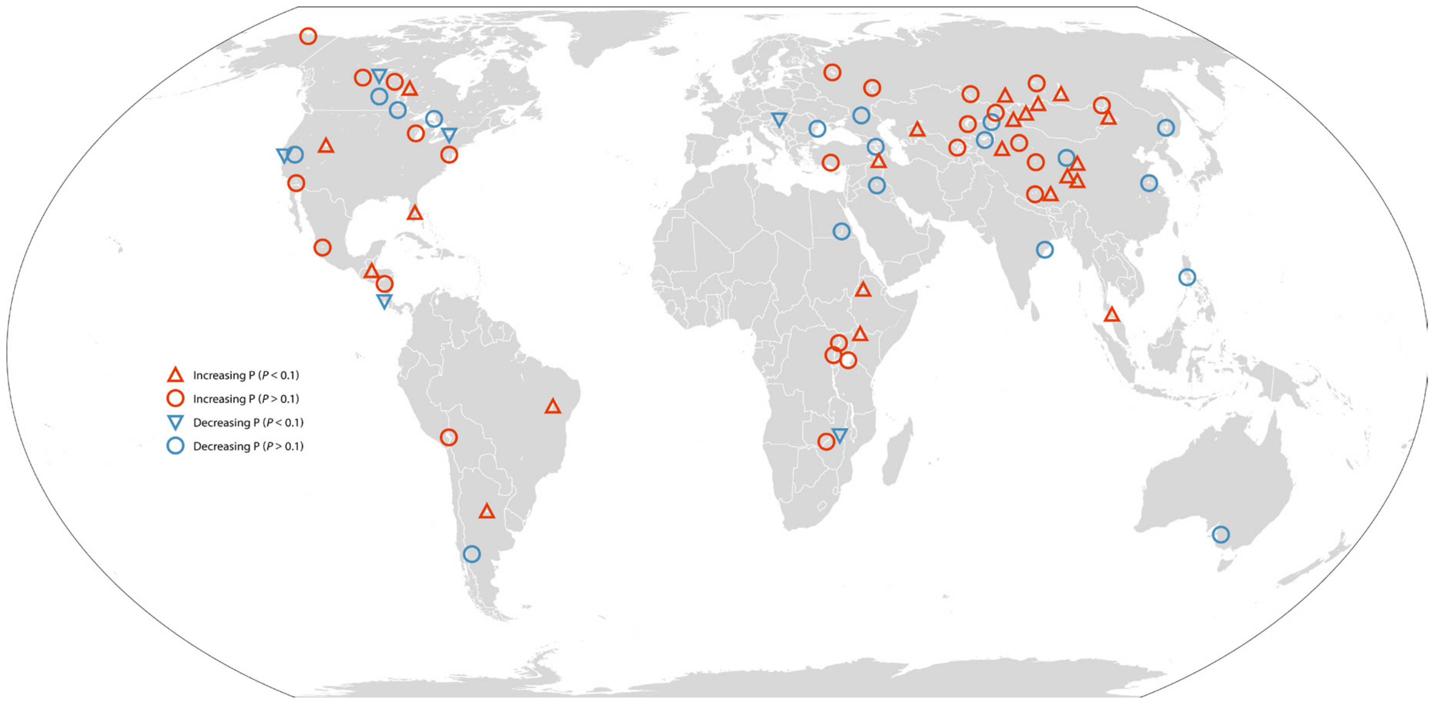
Many countries, including the European Union, Australia, and the U.S., have banned the use of phosphates in detergents. Companies, including Procter & Gamble and Seventh Generation, have removed phosphates from all of their laundry detergents worldwide. Yet, while North America and Europe are enacting policies to limit phosphate use, it is estimated that nutrients in municipal wastewater systems will increase by a factor of 4 to 8 in sub-Saharan Africa, and 3 to 5 in South Asia by 2050 [126].

Practices contributing to nutrient pollution in the Food Products industry, such as agriculture and livestock production, have tended to be less regulated globally. Even as it acknowledges that more than 80,000 miles of rivers and streams are impaired due to nutrient pollution, the EPA has not prioritized combating nonpoint pollution from nutrient runoff and has opted for more voluntary programs. State regulations have also been generally weak, whether for large-scale poultry producers in North Carolina or corn and soybean producers in the Midwest [127]. In recent years, there has been much more scrutiny on the overall practices of the food-producing industry, but the focus on water remains a neglected component [128]. Europe has taken stronger regulatory measures, but challenges persist.

A recent report by the European Commission warned that, even as Europe has taken steps to reduce nitrate pollution over the past 30 years, between 2016 and 2019, 14% of groundwater supplies still exceeded nitrate levels for drinking water, while roughly a third of coastal waters and lakes were eutrophic [129]. The European Green Deal calls for reducing nutrient losses into water bodies by at least 50% by 2030 [130].

Measures that can reduce nutrient pollution include best management tillage practices, improved manure management, increased crop nutrient efficiency, larger buffer strips, constructed or restored wetlands, and improved wastewater treatment plants [131]. While voluntary industry-led initiatives are underway in the U.S. to adopt such practices, these efforts are mostly small-scale in nature. Many smallholder farms in developing countries do not use best management practices, compromising both the environment and crop yields. Nature-based solutions that emphasize natural processes in practices should be prioritized. Implementing such practices can enhance water availability through soil moisture retention and groundwater recharge, improve water quality by maintaining wetlands and building riparian buffers, and reduce risks associated with water disasters through the restoration of ecosystems.

Figure 22. Global distribution of lake bloom intensity trends since the 1980s [119]. P refers to the statistically significant level determined for the study. Lakes that have seen a significant decrease ($P<0.1$) in bloom intensity are rare (less than 8%). Visualization credit: Charles Gibbons/Ceres.



2. Groundwater Depletion

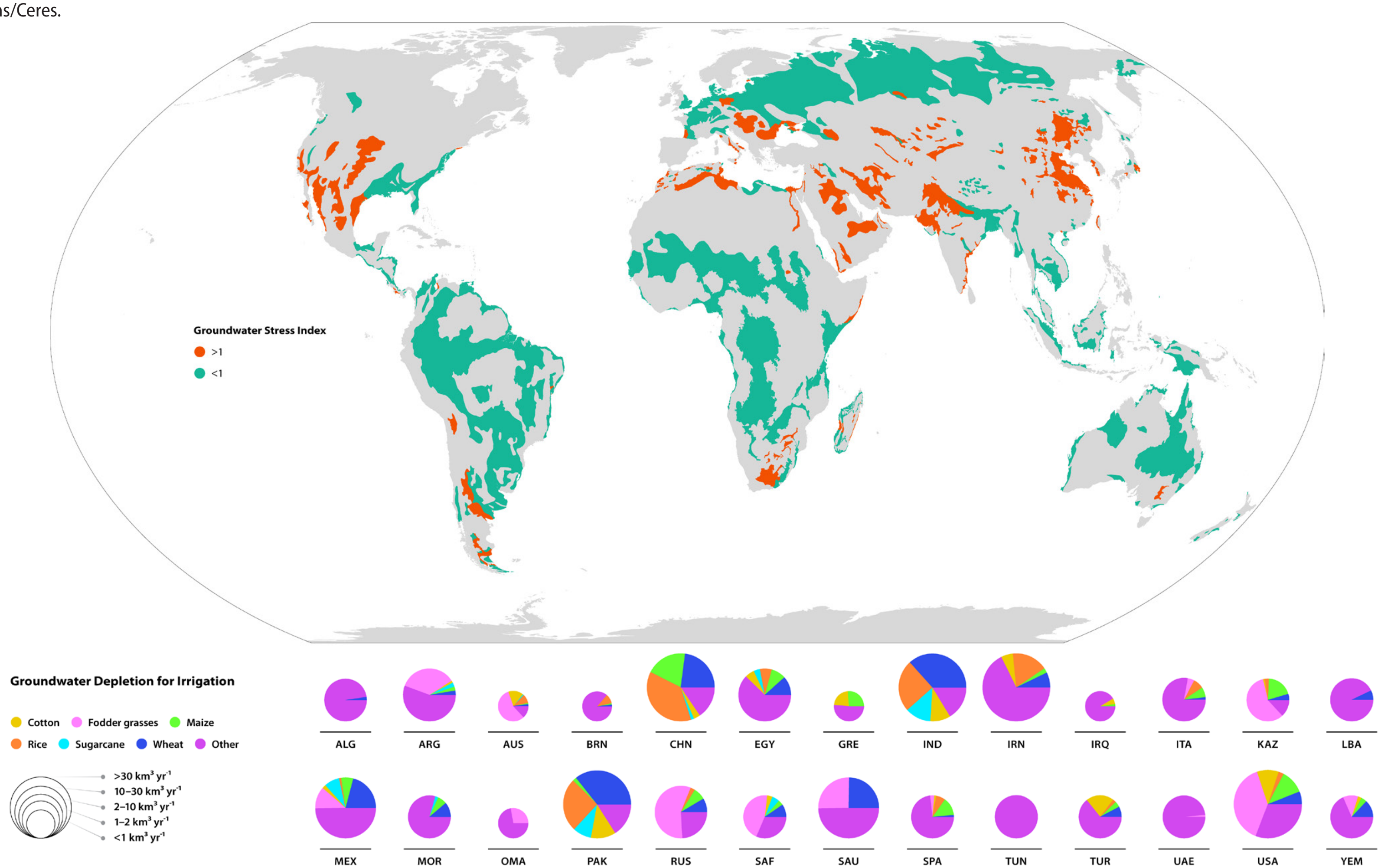
Groundwater depletion is an escalating global threat that has led to groundwater wells drying up due to excessive water extraction that exceeds natural recharge capacity. Left unchecked, the hydrological and socioeconomic impacts of this unsustainable water use will be profound.

Industrial practices

The primary activity causing groundwater depletion is irrigation within the Food Products industry. Irrigation is an essential part of farm-based food production at the beginning of the

Global depletion of groundwater aquifers due to crop production

Figure 23. Crop-specific contribution to groundwater depletion worldwide in 2010. Note: This study simulated crop water use for 26 irrigated crop types, including food crops and cotton. The pie charts show fractions of groundwater depletion (GWD) for irrigation of major crops by country, and their sizes indicate total GWD volume. The background map (in grey) shows the groundwater stress index for major aquifers [132],[133]. Visualization credit: Charles Gibbons/Ceres.



industrial value chain. Global groundwater depletion of aquifers increased by 22% from 2000 to 2010, mostly due to crop-related irrigation (Figure 23). Depletion rates are much higher in countries, such as India, Pakistan, China, and the U.S., that are heavily reliant on groundwater for crop irrigation. Mexico, the Middle East, and North Africa also have high depletion rates due to irrigation. High intensity groundwater depletion caused by crop cultivation is observed in Kuwait, which uses 1,900 liters of water per kilogram of wheat, in Iran, which uses 21,00 liters of per kilogram rice, and Saudi Arabia, which uses 790 liters of water per kilogram of maize. A 2019 study estimated that, without better management, between 42% and 79% of watersheds that pump groundwater globally could pass ecological tipping points by 2050. An example of a watershed at risk is the Ogallala Aquifer, an enormous water source that runs beneath eight states in the U.S. Great Plains [4].

Metals and Mining and Oil and Gas are other major industries that are severely stressing groundwater resources. In addition to overextraction, mining and fossil fuel activities can dramatically alter groundwater systems by physically damaging aquifers. For example, hydraulic fracturing can lower groundwater levels, further increasing erosion and sedimentation and habitat fragmentation and depleting surface waters, as shown by field studies in Michigan [134]. Fracking fluids and methane, as well as volatile organic compounds released by the Oil and Gas industry can contaminate groundwater quality [135].

Global trends

Groundwater is the primary water source for up to 40% of irrigated lands globally and 60% within the U.S. [136],[137]. It is also intensively used as an additional water source during drought periods. Irrigation by the Food Products industry has been the primary stressor in many arid and semi-arid regions globally, including the Ganges Basin in northern India and the Arabian Aquifer underneath Saudi Arabia and several other Middle East nations. The U.S. (such as California's Central Valley and the Ogallala Aquifer, which account for up to 50% of the country's groundwater depletion since 1900), Mexico, North Africa, India, Pakistan, and China also have severe groundwater depletion from crop-related overexploitation [74],[133]. In 2010, wheat production was the biggest cause (22%) of global groundwater depletion, followed by rice (17%), sugar crops (7%), cotton (7%), and maize (5%) [133]. India and Pakistan used the most groundwater, 30% and 11%, respectively, contributing to global groundwater depletion. China and the U.S. used the most groundwater for maize production, 4.7 and 3.0 km3 per year, respectively [133].

The mining industry in northwest Australia has been one of the world's largest groundwater users, causing severe depletion of the Canning Basin Aquifer. Satellite data has shown that this aquifer had the world's third highest rate of groundwater depletion, with annual loss rates ranging from -10.74 to -8.06 mm from 2003 to 2013 [74].

Industrial risks

Groundwater levels are dropping in many parts of the world, resulting in higher capital costs and operating costs to pump water, along with other negative economic externalities. Additional costs for Food Products companies, for example, can be declining yields and crop areas that will affect the key inputs to this industry. In northern India, cropping intensity, or the number of crops a farmer can grow in a given year, decreased by 68% due to groundwater depletion [138]. Depletion also caused reduced yields for winter wheat, rice, and maize in India from 2004 to 2013 [139]. Similar trends are underway in California, where devastating droughts and groundwater depletion forced farmers to leave millions of acres unplanted in recent years [140]. Competition between groundwater users is becoming more common as the resource becomes scarcer, potentially leading to conflict and reputational risks for industry.

Mitigation

Among the 38 OECD countries, policy instruments are more commonly used to protect surface water than groundwater, according to a recent OECD report. Only 36% of the countries use policy incentives, such as allocation, taxes, and charges, to recover groundwater supply costs for agricultural food production [141]. Government policies and management practices in some regions where groundwater is being depleted are actually promoting depletion. In Syria and India, energy subsidies have been used to defray groundwater pumping costs and irrigation system expansion. These policies fail to balance short-term agricultural productivity with long-term depletion impacts. In many water-stressed regions, including Spain and Portugal, irrigation systems are being expanded without appropriate water planning and regulation (for example, better soil and canopy management), resulting in inefficient water use and the planting of water-intensive crops, such as orchard trees and wine grapevines [142],[143].

Agricultural food and water policies have been strengthened in many OECD countries over the past dozen years. In the case of groundwater management, licensing schemes and pricing are popular tools for water allocation systems and groundwater use. In Australia, most states' groundwater rights have been separated to the extent that water can be traded between properties using the same aquifer. In Belgium, every groundwater extraction site has been required to use a water flow meter for agriculture and horticulture irrigation since 2010. California's Sustainable Groundwater Management Act, approved in 2014 and taking effect in 2022, is designed to limit water users' (including farmers') access to water in accordance with aquifer recharge needs [140],[144].

3. Diversion and Transfer of Water

Large-scale water diversion includes transferring water from one river basin to another and artificially concentrating water in large quantities using man-made channels and reservoirs. These activities fundamentally change the hydrology and critical habitats of river basins.

Industrial practices

Water diversion and transfer projects typically bring water to dry, water-scarce regions, primarily for the Food Products, Renewable Electricity (specifically hydropower plants and consumable fuels) and Metals and Mining industries. Crop irrigation uses pipes, canals, and sprinklers to draw water from natural water sources. This allows farmers to grow crops on a consistent schedule, especially when facing irregular water supplies. But large-scale water transfers can also disrupt natural water flows, causing unequal disparities in water distribution and negative impacts on soil health (e.g., increasing salinity).

The Renewable Electricity industry diverts water to generate hydropower and produce consumable fuels such as biofuels. Energy production accounted for 15% of all global water withdrawals in 2010. By 2035, it is expected to be 20% [145]. Nearly a fifth of all the power generated in California is for water-related uses, particularly to pump and transport water hundreds of miles to farmers in arid southern California.

Water diversion projects, both from their construction and operational activities, impact rivers and lakes across the world. Dams and reservoirs can have high levels of evaporative losses and leakage if they are not well maintained. They can cause salinization, sedimentation, and nutrient enrichment in dams, reservoirs, and watersheds due to water regulation processes. Regulation processes alter water flow conditions, which can further accelerate eutrophication and disrupt aquatic habitats. This can promote the transmission of waterborne disease, as has occurred in many dammed rivers, such as the Mekong River in South Asia and the Volta River in Ghana [146],[147]. Diversion projects can also lead to neg-

Table 3. Future water transfer megaprojects (either under construction or planned) in the world [150].

Continent	# of projects	Total distance of water transfer (km)	Total volume of water transfer (km^3/year)	Total cost of project (billion US$)
North America	34	24,800	1,333	1,883
Asia	17	28,631	321	532
Africa	9	6,600	233	128
Australia	7	8,238	12.9	72
South America	6	11,780	8.2	36
Europe	3	347	2.1	1.7

ative socioeconomic ripples, including human relocation, destruction of livelihoods, and increased probability of conflicts between users. Among the most glaring examples is China's Three Gorges Dam, which forced between 1.1 and 1.6 million residents along the Yangtze River to relocate [148].

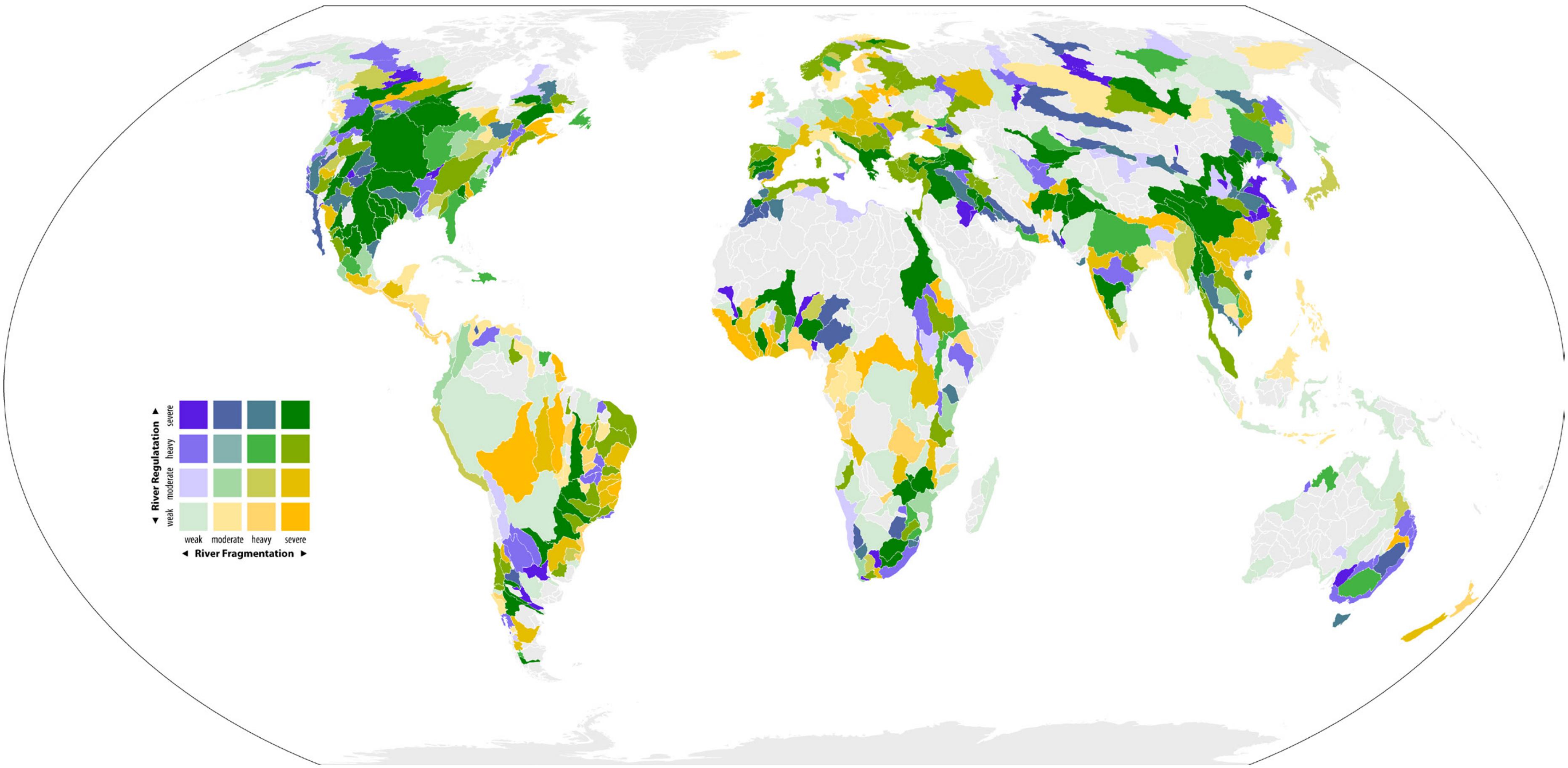
Global trends

Natural water systems are being disrupted by large-scale water diversion projects globally. Between 1985 and 2017, the number of inter-basin water transfer projects (man-made transfers of water that cross basin boundaries) grew eightfold in the U.S., from 256 to 2,161.

Dams built for food product-related irrigation are centered mostly in Asia (India, China, Middle East) and South America (Peru, Bolivia). Asia's dams also provide hydroelectricity. Dams in North America were built primarily for flood control, hydroelectricity, irrigation, and recreation [149].

Global map of river basins with flow regulation and fragmentation

Figure 24. Fragmentation and flow regulation of global river systems disturbed by hydropower dams at the sub-basin level. The map was built using a dam impact matrix that measures the impact of dam construction on river fragmentation and flow regulation. The total impact was categorized into 16 classes with different color codes. Visualization credit: Charles Gibbons/Ceres.



Globally, there are 34 existing water transfer megaprojects (defined as those with construction costs over $1 billion, transfer distance over 190 kilometers, or volume transfers exceeding 0.23 km3 each year). As seen in Table 3, a total of 76 projects are under construction or in planning phases, most of them for agriculture development (19 in North America, eight in Asia, and Africa, three in Australia and South America, and one in Europe). Another 13 are for hydropower generation (seven in North America, three in Africa, two in Asia, and one in Europe) and seven for the mining industry (one in Africa, two in Asia, two in Australia, and two in South America [150].

Water diversion and transfer projects impact both the contributing and receiving regions through streamflow alteration and fragmentation. Over 48% of global river basins are severely affected by water diversion projects, especially in North America and Asia. Figure 24 shows that a total of 407 global basins (21% of global river volume) are severely affected by both flow regulation and fragmentation (green colors), especially in basins with a long history of dam building, such as the Nile and Mississippi [151]. Withdrawals from China's Yellow River have decreased annual streamflow by 10% compared to historical averages. Global river fragmentation will likely double if the nearly 4,000 planned hydroelectric dams are built globally [151]. Water transfer projects also cause conflicts in water-stressed regions, as evidenced in the Middle East and South Asia.

Industrial risks

Reduced allocations for irrigation systems can reduce crop yields and overall financial returns in water-stressed regions. Water use competition can also increase water prices. For example, farmers in Colorado normally pay $0.05 to $0.08 per 1,000 liters of irrigation water. During water shortages, however, those prices can increase by a factor of 15 to 20 [152]. Climate change is causing additional threats, especially as more hydropower dams confront increasing drought and flood risks, which can negatively affect hydropower generation and water infrastructure. Declining water levels in the Colorado River have decreased the Hoover Dam's hydropower capacity by 25% in 2021 compared to the 1930s, while also reducing boating and other recreational activities [153].

The lack of well-maintained infrastructure is another growing financial risk for companies, as the systems may not continue to provide reliable supplies. In 2020, thousands of residents were evacuated after the failure of two dams in Michigan due to heavy rainfall. The event caused an estimated $175 million in damages [154]. Maintenance of water diversion projects and cost-effective solutions for aging infrastructure are an ongoing challenge around the world. In the U.S. alone, more than 91,000 dams are at high risk of failure and need over $64 billion in repairs [155]. The high risk of aging infrastructure threatens the safety of residents, increasing the risk of large-scale displacement and social costs in the face of climate change.

Mitigation

Ongoing efforts to mitigate the impacts of water diversions are minimal. One effort includes water rights trading and allocations in countries, including the U.S. and China. In the U.S., there is a growing use of water trading, including programs in Arizona, California, and Colorado. These programs attempt to use the market to promote more efficient water allocation and use. Federal and state funding is also being used to retire water rights in over-appropriated sub-basins. In the Rio Grande basin in Texas, water rights are managed using a "first in time, first in right" priority system, and water below Lake Amistad is prioritized for all municipal accounts [156]. China has initiated a nationwide water rights pilot scheme that aims to develop regulations and guidelines at the national level on water rights verification, registration, and trading. To facilitate water rights trading, China established a water exchange market center in 2016 that provides services for trading consultation, technical evaluation, market information, intermediary services, and public services. These attempts could help reduce conflicts between water users through market reallocation to the users with the greatest need and potentially mitigate impacts of water diversion projects in basins. However, more inclusive social elements and concerns should be incorporated to ensure these schemes are effective and efficient and that they minimize impacts on communities and workers.

4. Metals Contamination

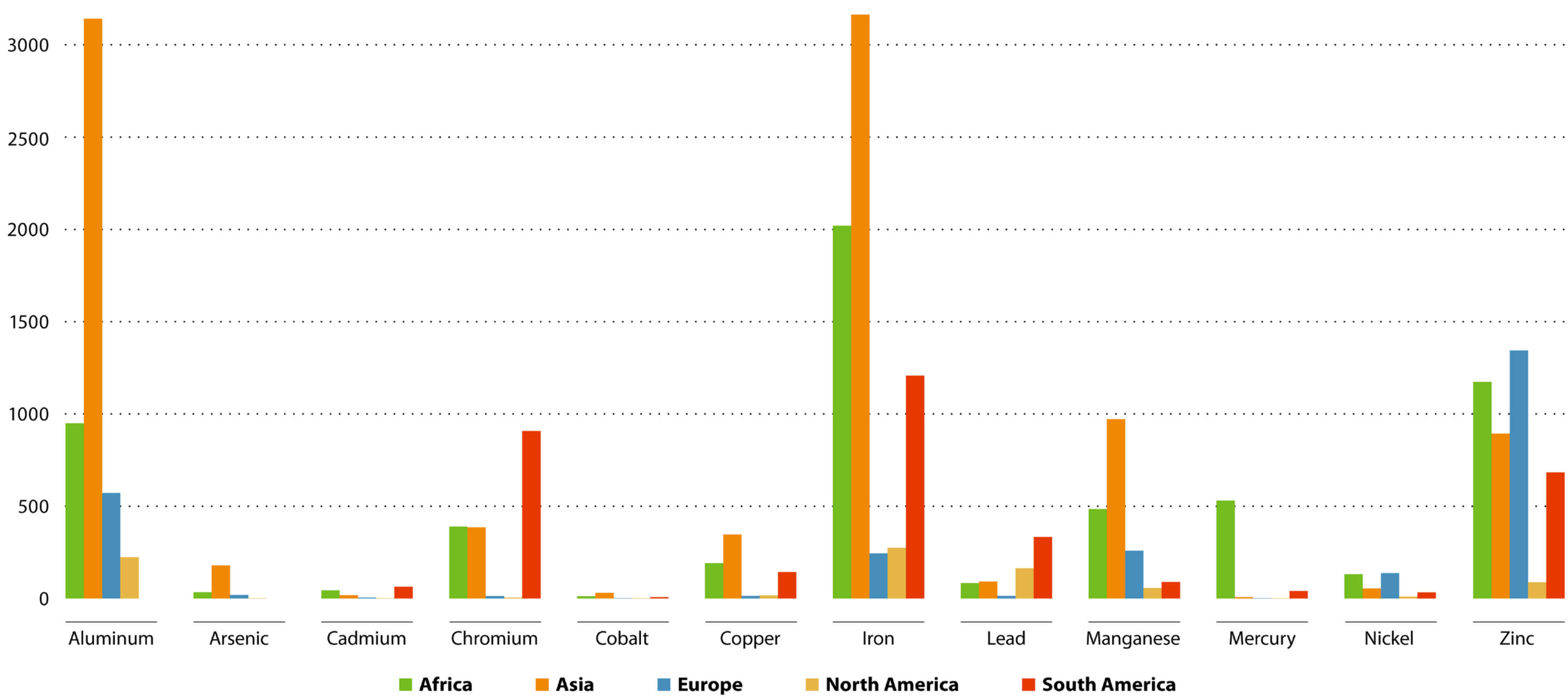
Metals can be toxic even in relatively low concentrations in water. They are also long-lasting and bioaccumulate. If untreated or inadequately treated, metals can damage natural ecosystems and pollute drinking water, threatening human health.

Industrial practices

The Materials and Information Technology (IT) sectors are the primary sources of metal contamination. Within the Materials sector, the Metals and Mining industry releases contaminants during raw material extraction. Acid mine drainage and the chemical agents used to separate minerals and ore can be a source of pollution. The IT sector produces semiconductors, circuit boards, and batteries that release wastewater containing a variety of metals, including mercury, copper, iron, zinc, nickel, chromium, lead, tungsten, and lithium. E-waste from semiconductors, circuit boards, and batteries also contributes to metal leaching into water.

Global hotspots of metal concentrations in lakes and rivers

Figure 25. Mean concentrations of metals throughout Africa, Asia, Europe, North America, and South America based on metal sampling data in lakes and rivers from 1972-2017 [157]. Metals in the figure include cadmium (Cd), lead (Pb), chromium (Cr), mercury (Hg), zinc (Zn), copper (Cu), nickel (Ni), aluminum (Ai), manganese (Mn), iron (Fe), arsenic (As), and cobalt (Co). Visualization credit: Charles Gibbons/Ceres.



Global trends

Heavy metals are being found in high levels in rivers and lakes globally, with the highest concentrations in Africa, Asia, and South America, and lower levels (though still toxic) in Europe and North America, as shown in Figure 25. Based on sampled data published in academic literature from 1972 to 2017, a synthesis found that Asia accounted for approximately 42% of metals found, Africa 27%, Europe 12%, South America 16%, and North America 3%. Overall metal concentrations were lower in the 1970s and 1980s, and higher from 1990-2017 [157]. In this review of 12 heavy metals (Figure 25), lead and aluminum are two metals that have higher concentrations in the main rivers of North America—greater than the published threshold limits—as per the standards of the World Health Organization (WHO) and the EPA. Of the 12, the number of metals with concentrations found higher than these limits by continent are Europe (six), South America (seven), Asia (nine), and Africa (10) [143]. The situation is likely worse because data on the whole spectrum of metals are underreported. Metal concentrations are higher in developing nations due to the lack of environmental regulations and wastewater treatment. In China, there are approximately 1.5 million sites with heavy metal exposure, releasing an estimated 740.15 tons of heavy metals into water bodies in 2011 [158].

Industrial risks

Many countries with mining operations are experiencing declining water availability, including Peru, Chile, Australia, South Africa, and Mongolia [159]. Given that mining operations are tied to locations where the resources exist, companies do not have the option to transfer operations to less risky environments. According to a 2020 CDP report, 91% of Metals and Mining companies that responded reported exposure to water-related risks, with an estimated financial impact of $24.9 billion [160].

With increasing social and government scrutiny of the impacts associated with industry, the costs of wastewater treatment for companies will likely increase. While the costs vary depending on the mining activity, current estimates find that metal waste management practices typically account for at least 2% of total cash costs of companies. [161].

Mitigation

Some companies have implemented water treatment techniques, including common membrane filtration, activated carbon adsorption, and electrocoagulation, to reduce metals discharges [162]. However, if regulations are weak, which they often are, there is less motivation for companies to adopt advanced technologies since they are expensive and energy intensive. This is usually the case in many low-income and developing countries. There are cheaper alternatives that can be used for the absorption and removal of heavy metals, such as coconut shell, almond shell, fertilizer slurry, palm tree cobs, petroleum coke, and pine saw dust. These low-cost materials have been found to remove over 90% of various metals, such as cadmium and zinc [163].

5. Plastic Pollution

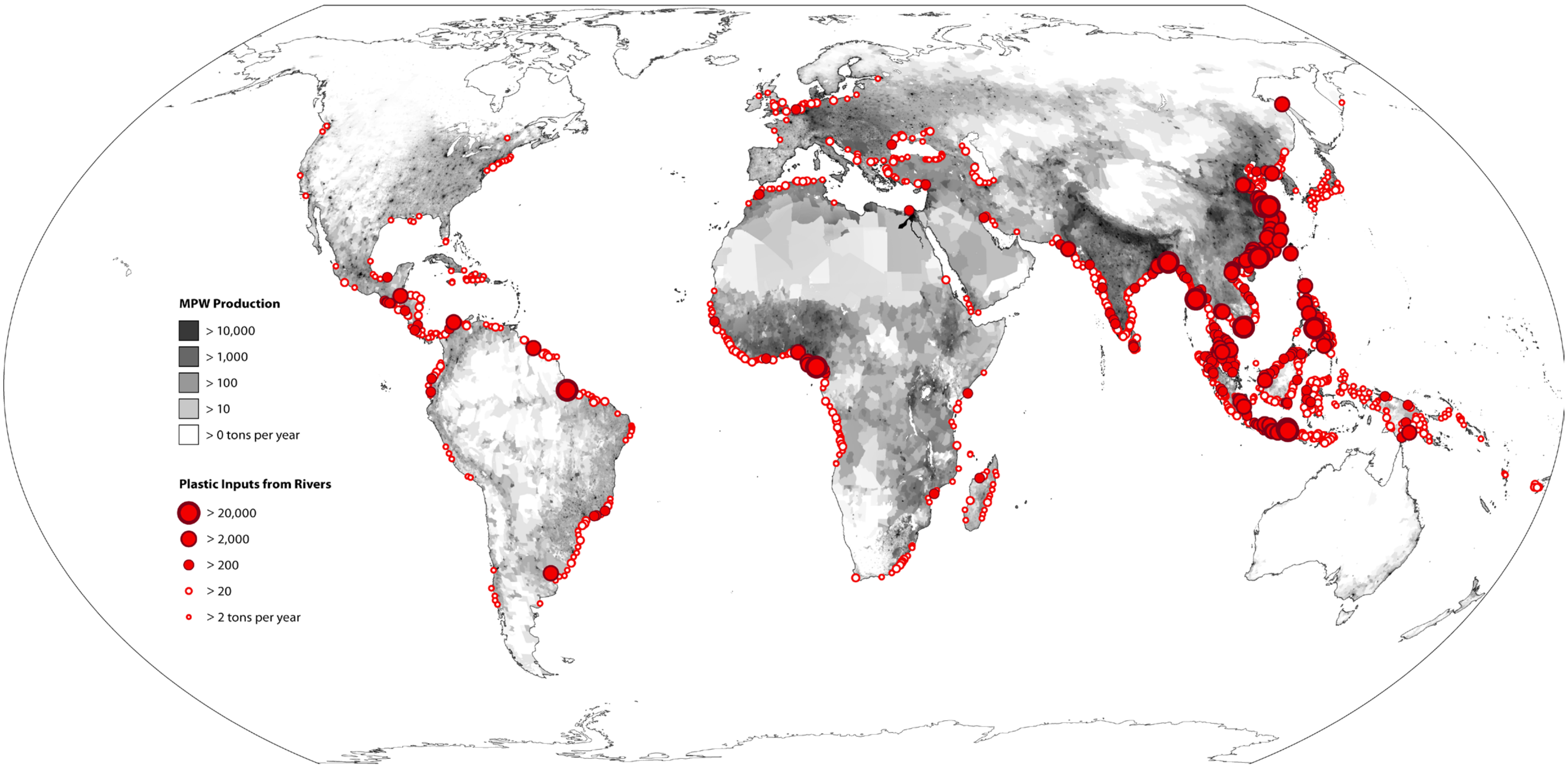
Plastic is a relatively cheap and lightweight material that many industries use for production and packaging, making it ubiquitous and a major source of global water pollution if not managed appropriately. The world produces more than 405 million tons of plastic each year, 3.5% of which ends up in our oceans, becoming a major pollutant and impacting aquatic species through entanglement and ingestion of plastics.

Microplastics (plastics less than 5 millimeters in size) are of particular concern because of their persistence in the environment and bio-accumulation in food chains (given their small size, they can easily enter the bodies of living things).

Up to 80% of plastics that end up in the world's oceans are transported there by rivers [164]. A study in California was the first to report concentrations of microplastics in river surface waters through sampling in the Los Angeles River, San Gabriel River, and tributary Coyote Creek

Global map of plastic waste input from rivers into the oceans

Figure 26. Map of river plastic flowing into oceans [67]. Visualization credit: Charles Gibbons/Ceres.



[165]. For a given location, the study found up to three orders of magnitude difference between plastic concentrations measured during dry and wet periods, implying that runoff plays an important role in the transport of plastics into freshwater systems.

Industrial Practices

Plastic waste is generated from many industrial sectors through a wide range of practices, ranging from raw material extraction and packaging to end-of-life product use. The Consumable Staples and Consumer Discretionary sectors are two major sources of plastic pollution, including microplastics, due to the packaging of their products and washing and maintenance of textiles. Plastic packaging is widely used in the Food and Meat Packaging, Beverage, Household and Personal Products industries (all industries within the Consumable Staples sector). Personal product use and vehicle tire abrasion also contribute significantly to plastic pollution. A global report estimated that washing synthetic textiles and tire abrasion from driving are the largest sources of microplastic water pollution, accounting for two-thirds of total microplastics released [166]. Microplastics are typically released from domestic wastewater systems and through urban and stormwater runoff.

A major source of plastic pollution is the improper disposal of end-of-life products. Poor waste management in Asian countries has resulted in them being a top hotspot for producing plastic pollution [67]. Single-use products, such as plastic food serviceware, that are commonly disposed of improperly can easily flow to water bodies creating massive volumes of plastic pollution [167].

Plastic waste also has associated harmful chemicals that can impair waterbodies and harm aquatic species. These chemicals are normally divided into three categories: the ingredients of plastic materials; the byproducts of manufacturing plastics; and chemicals from the environment absorbed by plastic pollution. If ingested by species, plastic pollution can lead to toxicological responses, which are caused by chemical additives to plastics, including heavy metals, pesticides, polycyclic aromatic hydrocarbons (PAHs), and polychlorinated biphenyls (PCBs). These chemicals can disrupt important physiological processes of organisms, causing disease and reproductive issues. Thousands of additives are used in plastic production, many of which are well-known environmental contaminants that accumulate in fatty tissues of aquatic animals. A recent study illustrated how plastic pollution generates diverse risk potential because the chemical additives to plastic are continually evolving, while the synergistic effects of the various chemicals remain unknown [168].

Global trends

Global plastic production continues to proliferate, growing at a compound annual rate of 3.5% in the past 10 years alone. Up to 14 million tons of plastic waste end up in oceans every year, 80% of which come from river systems. That is equivalent to setting eight garbage bags full of trash on every foot of coastline around the world [169]. Approximately 20.94 to 25.35 million tons (11%) of plastic waste generated globally in 2016 entered aquatic ecosystems. This volume could reach up to 58.42 million tons per year by 2030 [170]. In Europe, studies estimated that the Danube River releases 584–1,653 tons of plastic into the Black Sea annually [171].

A review of 340 original publications on the topic reveals that at least 690 different species have been impacted by marine debris globally - 92% of which is due to plastic marine debris [172]. A World Economic Forum report forecasted that plastics will outweigh fish in the ocean by 2050 [173].

The global distribution of plastic pollution is not uniform, since different countries have greater discharges into the ocean, particularly Asian countries [174]. The top five countries identified as having the most mismanaged plastic waste systems are China, Indonesia, the Philippines, Vietnam, and Sri Lanka. Rivers, themselves very polluted with plastics, transport plastic pollution to oceans. Asian rivers account for an estimated 86% of total plastic releases to ocean waters globally. The rest of the world accounted for the remaining 14% of river plastic mass input (Africa 7.8%, South America 4.8%, Central and North America 0.95%, Europe 0.28%, and Australia-Pacific 0.02%) [174]. In Asia, the Yangtze (China), Ganges (India), Xi (China), Huangpu (China), and Javanese, and Brantas (Indonesia) rivers carry significant plastic pollution loads to the ocean. Plastic pollution is also a growing concern in the African Great Lakes, including Lake Victoria, the world's second largest lake, where one in five fish have ingested plastic, according to a 2019 study [175]. A classic transboundary challenge, most plastics production and dumping are in developing countries, while the biggest users of plastics are developed countries.

Industrial risks

Plastic pollution poses a major reputational risk to companies, as public awareness of its impacts grows. Many public advocacy groups are urging companies to use less plastic material and seek sustainable alternatives. The Beverage industry has been front and center in these debates. Globally, millions of tons of single-use plastic beverage bottles are produced every year that are not properly disposed of, ending up in waterways or landfills that are mismanaged and are a pollution source [176]. The increasing advocacy for corporate action around plastics has helped bring more attention and action on the issue [176]. In response, some companies have tried to develop new types of packaging that use less plastic or alternate materials that may be less harmful when in the environment. For example, some companies have produced single-use packaging products from plant-based materials. However, it is often unclear how these alternative products will persist in the environment and if there will be in fact less of an impact if disposed of improperly. If additional actions that fully address the entirety of the problem are not undertaken, industries and companies will face additional reputational risks.

Mitigation

Mitigation paths for plastic pollution include a reduction in the use and phase-out of single-use plastics and small plastic particles (microplastics), along with additional and improved wastewater and runoff treatment. Many countries and regions have undertaken policy and regulatory initiatives to prevent plastic pollution from entering waterways through the development and implementation of advanced technologies. Government agencies, such as the regional water quality control boards in California, have enacted urban runoff and stormwater discharge restrictions to capture plastic pollution before it enters a water body through the use of full capture technologies [177]. California's Ocean Protection Council also initiated a multi-year roadmap aimed at establishing the state as a national and international leader in managing microplastic pollution through a two-track approach to managing microplastics in California: immediate actions with multi-benefit solutions and research to enhance science-based solutions [178].

In addition, many governments have imposed restrictions on the use of single-use plastic products to limit their proliferation in the environment. For example, the Canadian federal government recently released draft regulations to ban six kinds of harmful single-use plastic (straws and stirring sticks, six-pack rings, grocery bags, cutlery, and difficult-to-recycle takeout containers) [179]. Many local communities globally have already taken similar regulatory action to curb single-use plastics use and drive the use of reusable alternatives.

Water treatment techniques for removing microplastics include common membrane filtration, activated carbon adsorption, and electrocoagulation. Some technologies specifically focus on collecting microplastic waste in waterways, but the implementation and effectiveness is limited [180].

Climate Change — A Threat Multiplier

Climate change is directly impacting the global water cycle and the distribution and availability of freshwater around the world. Increasing temperatures, melting ice sheets and glaciers, changes in the distribution of water, and uncertainty associated with climate change all intensify the impact and development of critical threats to freshwater. These impacts on freshwater will also increase risks to industries that rely on freshwater resources. Responding to these critical threats will require more focused consideration of climate change's role as a threat multiplier.

Rising temperatures and eutrophication

Climate change is already leading to increased water demand because of rising temperatures, increasing evaporation, and more frequent droughts, all of which combine to decrease water availability. Warmer temperatures promote algal blooms in freshwater systems, which are occurring more in freshwater bodies. Such eutrophication is driven by excessive nutrients, abundant sunlight for photosynthesis, and suitable temperatures for rapid plant growth. Climate change is causing rising temperatures, more intense storms, and earlier snowpack melt, intensifying nutrient runoff and eutrophication in more areas of the globe.

Climate change, groundwater depletion, and contamination

Climate change is driving greater water demand in water-stressed regions, often leading to significant depletion of groundwater resources. Groundwater withdrawals for irrigation in drylands, including in California, Northern China, and India, are now more visible than ever before [10]. Groundwater extraction often exceeds local groundwater recharge capacity, stressing the availability of this critical resource to many industries, in particular industries with agricultural supply chains.

The melting of glaciers and polar ice caps is driving sea level rise, threatening inundation of major population centers and critical agriculture zones. Rising sea levels are increasing the frequency of storm surges and causing seawater intrusion, resulting in the salinization of key aquifers and threatening industrial activities along the coastal zones. In Sonora, Mexico, seawater intrusion from the Gulf of California has occurred in several coastal irrigation districts, resulting in salinity concentrations that limit water use for irrigated agriculture [181].

Changing precipitation patterns and extreme climate events

Climate change is expected to further alter the water balance in many parts of the world, changing the patterns of precipitation in space and time. Warming temperatures have already increased the frequency and intensity of extreme weather events around the world.

Warmer air holds more moisture, which can translate into heavier rainfall and stronger storms, causing extreme floods and flash floods. These intense storms can lead to increased risk of pollution overflows that can overwhelm waste treatment facilities. Heavy precipitation also increases the chance of potential leaching from hazardous waste and mine tailings sites. Increased storm events will also intensify runoff, releasing pollutants, such as microplastic and veterinary pharmaceuticals. Warming temperatures are melting glaciers and releasing chemicals such as PFAS that have been trapped within the ice after air transport [182]. The worst scenario shows that strong storms could become as much as 14 times more common by 2100 across Europe compared to the beginning of this century [183]. Flood damage in Europe, particularly in northern European regions, could increase from current levels of €7.8 billion annually to €48 billion by 2100 [184].

At the same time, drought leads to a decrease in water volume and increased concentration of chemical and biological pollution, increasing stress and toxicity on ecosystems dependent on that water. A recent estimate shows that the absence of climate action (4 °C in 2100 with no adaptation) could increase annual drought losses in the European Union and the U.K. from the current level of €9 billion annually to more than €65 billion, which could reduce regional agriculture economic output by 10% [185].

Extreme events accelerated by climate warming increases risks to industries at various levels. From floods to crop failure due to excessive heat, the impact on industries, including agriculture, manufacturing, and mining are significant. According to insurance company Swiss Re, the world will lose 18% of its current GDP by 2050 if no mitigation action is taken against climate change, with Asia being hit the hardest.

Changes in Streamflow

As global temperatures increase, the cumulative impacts of rapidly melting glaciers and ice sheets and changes in annual snowpack will significantly alter stream flows[186]. When this impact is combined with increasing freshwater extraction from rivers and river fragmentation, the impact on river ecosystems will magnify[151]. As climate change intensifies water scarcity and weather patterns, the global distribution of water will become less balanced, triggering more water diversions to support energy and food production. This imbalance could also catalyze more migration towards water secure areas[187].

The disappearance of mountain glaciers is increasing the frequency of melt-induced disasters, including floods and landslides, and risks to glacial-melt water supplies. These consequences will become more serious in high mountain and foothill areas, threatening multiple industries. For example, the shrinking of the Andean glaciers has diminished spring flows in the headwaters of the Querococha basin in Peru and reduced water availability in dry seasons, which has affected livestock productivity. The disappearance of glaciers has also negatively affected the tourism industry in many mountain areas, including Austria, Canada, and Switzerland [188].

Emerging threats identified through the assessment. **Figure 27.** Chart of emerging threats as identified through the literature review.

Emerging Threat	Defined Threat	Identified Sector/ Industry	Geographic Distribution	Environmental Impacts	Human Health Impacts	Socioeconomic Impacts
PFAS	"Forever chemicals," a group of highly persistent, man-made chemicals widely used by industry	Materials (Chemicals), Consumer Discretionary (Textile & Apparel, Household Durables), Consumer Staples (Food/ Personal Products)	Most data found in Western Europe, China, Korea, Japan, and North America	Bioaccumulation in organisms	Cancer, thyroid disease, high cholesterol, liver damage, kidney disease, low birth weight, immune suppression, ulcerative colitis, and hypertension	In 2018, 3M paid $850 million in a settlement to provide clean-up of PFAS in Alabama
Pharmaceuticals	Pharmaceutical drugs treat and prevent disease, but with increased production and use have become ubiquitous in water bodies	Health Care (Pharmaceuticals, Healthcare Providers), Consumer Staples (Food Products, e.g., Animal Raising)	Identified in 71 countries, lower middle income countries expected to have higher concentrations	Toxicity and endocrine disruption in organisms	Antimicrobial and antibiotic resistance	Estimated that the socioeconomic impact of antibiotic resistance will cost $3.5 billion per year
Social Conflicts/ Justice	Increased global water consumption and diversion escalates water scarcity for downstream nations, leading to conflict and tension	Consumer Staples (Food Products, Beverage), Utilities (Renewable Power, e.g., Hydropower), Energy (Oil and Gas)	Most impact in arid climates, such as Western USA, Northern Africa, Ecuador, India, and Syria			Tensions and conflict between nations, communities, and industries

Emerging Threats

Recent research that includes economic and environmental projections highlight additional emerging threats to freshwater resources that are not well understood, requiring heightened attention from industry and policymakers. These emerging threats are intricately linked with industry practices that are expected to grow in the coming years and have recently been identified as threats. For example: even as thousands of pharmaceutical drugs are polluting water resources across the U.S., most of them are not subject to federal safety limits and are currently not being measured in drinking water supplies or being removed during wastewater treatment processes. Per- and polyfluoroalkyl substances (PFAS), a group of artificial toxic chemicals known as "forever chemicals" (since they never break down), are widely used to make various types of everyday products, but they are also largely unregulated. In fact, public water systems in the U.S. are not required to monitor for any PFAS. As global demand for everyday products continues to grow, identifying and responding to these emerging threats must be an important priority in the years ahead.

(I) PFAS

Per-and polyfluoroalkyl substances (PFAS) are a group of artificial chemicals widely used by industry to create non-stick coatings on cookware, carpets, and food packaging. PFAS, also known as "forever chemicals," are highly persistent and bioaccumulate, becoming a critical toxin in surface and drinking water. It is nearly impossible to avoid PFAS which is used in brand-name products like Scotchgard, Teflon, and Gore-Tex. They have been found in water, air, food, and blood, making them a key emerging issue for environmental and human health. PFAS water contamination is primarily associated with Chemical sector discharges, specifically fluorochemical production effluent. Other sectors using PFAS include Consumer Staples, Consumer Discretionary, and Textiles. For all of these industries, PFAS are released mostly in domestic wastewater and leaching from landfills. A recent study found nearly 42,000 potential sources of PFAS that are coming from more than 120,000 locations across the U.S. The testing found that a significant portion of landfills and industry sites in Michigan and California were discharging PFAS at unacceptable concentrations, while oil and gas industry is ranked as the biggest user of PFAS [189].

PFAS have been found in all parts of the world, including glaciers where PFAS have accumulated in Arctic Sea ice through atmospheric transport, which will release more PFAS as ice caps melt [190]. PFAS have been found in drinking and coastal marine waters, primarily in western Europe, China, Korea, Japan, and North America. Testing and data is limited in South America and Africa [190]. PFAS have many human health implications, including cancer, thyroid disease, high cholesterol, liver damage, kidney disease, low birth weight, immune suppression, ulcerative colitis, and hypertension.

PFAS could be a potentially expensive liability for major industry users. In 2018, 3M reached major financial settlements with the states of Minnesota and Alabama over water contamination from these chemicals. The Minnesota settlement was for $850 million [191].

To mitigate this growing threat, the Stockholm Convention on Persistent Organic Pollutants in 2015 added PFAS as a compound that needs to be phased out. New actions are being taken to mitigate the threat, such as the adoption of the Toxic Substances Control Act in the U.S., which requires PFAS manufacturers to provide information on PFAS [192]. Other steps include wastewater treatment and setting limits for drinking water.

(II) Pharmaceuticals

Modern medicine has widely expanded different treatments and drugs that are available and essential for human health. However, there has been less focus on the environmental threats that these life-saving pharmaceuticals are creating. Many wastewater treatment plants are not equipped to remove these complex chemical compounds, which, as a result, are being continuously released into water bodies [62]. Researchers have pointedly noted that escalating releases of so many prescriptions and over-the-counter drugs in water resources will have long-term damaging impacts on human and environmental health [62]. The Health Care sector is the primary source of pharmaceuticals, whether from drug production effluent, hospital effluent, or consumer use. The Consumer Staples sector is another emitter, through veterinary pharmaceuticals used on-farm in agriculture to treat and prevent disease within farm animals.

Pharmaceuticals are ubiquitous in water bodies worldwide and have been identified in surface water, groundwater, drinking water, manure, soil, and other environmental matrices in every continent in the world [60],[65]. However, the full extent of the impacts from many of the most common pharmaceuticals in waterbodies remains unknown [65]. Between 1995 and 2015, research found that pharmaceutical-related risks to global aquatic ecosystems have risen 10- to 20-fold [193]. Studies show that pharmaceuticals in water can impact antimicrobial and antibiotic resistance, create toxicity and endocrine disruption in organisms, and affect reproductive health in humans. Antimicrobial resistance leads to bacterial evolution and drug-resistant strains, creating a significant health hazard. It has been estimated that socioeconomic impacts of antimicrobial resistance will cost $3.5 billion per year to the healthcare services of the 33 OECD and EU countries between 2015 and 2050 [194]. Policy instruments to mitigate pharmaceuticals threats include substance bans, stringent water quality standards, industry discharge permits, and subsidies for "green" innovation.

(III) Social conflicts

As the world continues to consume and divert more water at an alarming rate, downstream nations are at risk of being left behind, and this will only worsen with climate change. Increasing water use by the private sector undoubtedly contributes to rising tensions and conflicts as communities, companies, and entire countries compete for clean water to provide drinking water, food, and energy security. Economic sectors that have triggered social conflict include the Consumer Staples and Energy sectors due to their water intensive activities related to food production, food and beverage manufacturing, and energy production. Water withdrawals from rivers, reservoirs, and groundwater in water-scarce areas will be especially prone to social and political conflicts. Water-driven conflicts are already occurring in the western U.S., northern Africa, Ecuador, India, Syria, and Taiwan.

Companies are starting to be impacted by government actions to ensure critical water needs are met. For example, in 2021, Taiwan's government reduced water supplies to the country's massive chip manufacturing sector due to a prolonged drought. Taiwan has also experienced water pollution conflicts between the semiconductor industry and residents.

Efforts have been made by industry, governments, and other stakeholders to solve conflicts among water users, such as broad-based engagement of water users fostering shared decisions about the management of water resources. For example, The Restoration Initiative (TRI), a project implemented by United Nations Environment Programme with broad stakeholder engagement, has successfully helped over 100 villages in Kenya's Tana river delta restore and better manage their land and water resources, reducing long-term local tensions between local farmers and animal herders [195]. But far bigger actions, both by industry and governments, are urgently needed.

CHAPTER 4

STRATEGIES TO MITIGATE INDUSTRY IMPACT ON GLOBAL FRESHWATER RESOURCES

The motivation and objectives of this report are to compile and communicate the scientific evidence about water risk in a way that informs investor decision-making. The results of this undertaking are clear: the private sector is an integral component of the water cycle, directly influencing water quality, quantity, and distribution around the world. As presented in this report, current industry practices are leading to severe and systemic impacts to freshwater resources globally that jeopardize their business future and society at large.

However, industry impacts on global water systems do not have to be a net negative. The private sector and investors are positioned to lead the world in adaptation and innovation in response to pressing systemic threats to global water and climate systems. They can go beyond their direct operations and expand their sphere of influence – across their value chains and through collaborations with industry and government – to help solve these systemic challenges.

By focusing and investing in these challenges today, companies can substantially reduce financial risks and bottom-line losses down the road. Drawing on the available body of scientific literature and Ceres' vision of sustainable business leadership, we offer a practical set of recommendations to help companies respond and get ahead. Many of the recommendations are adapted from the Ceres Roadmap 2030, a 10-year action plan to help companies strategically navigate ever-changing business realities in a warmer, resource-stressed world.

1. Water Quantity

Companies should ensure their practices are not negatively impacting water availability, with particular attention to water scarce basins across their value chains.

To kickstart these efforts, companies should immediately assess water quantity impacts of direct and supplier operations and then set water use reduction targets that are informed by local conditions, prioritizing watersheds with high water stress and high use. They can support these efforts by investing in systems to improve supplier reporting and traceability of water intensive inputs and commodities. They should also directly engage suppliers to identify solutions for reducing water use and provide meaningful incentives to support investments in water efficiency and reuse.

2. Water Quality

Companies should ensure that their activities are not polluting local and regional water bodies.

Companies should immediately assess water quality impacts in direct and supplier operations and across product life cycles (where relevant) and use this assessment to inform target-setting and develop short-term priority actions.

They should also evaluate the use of chemicals of concern across operations, products, and material inputs, identifying opportunities to transition to safer chemical alternatives and invest in solutions when safer alternatives are not yet available. They should then set robust targets to reduce pollutant discharges of concern, with an immediate focus on eliminating pollutants of greatest industry concern, such as persistent organic pollutants and heavy metals. They can further support these efforts by aligning new research and development, capital expenditures, and merger and acquisition activity with targets for reducing the discharge of pollutants of concern.

3. Ecosystem Protection

Companies should ensure that natural ecosystems are not degraded from business activities and help restore ecosystems that their businesses depend on.

Companies can start by assessing their operations and value chain practices to analyze critical resource flows based on their dependency and impact on natural resources, ecosystems, and biodiversity – steps that will allow them to identify material issues and prioritize action. Companies should embed circular economy principles as a priority in decision-making across operations, design, sourcing, and supply chain management. Lastly, they should set interim and long-term resource protection targets toward the achievement of resource positivity and ensure all capital expenditures and sourcing decisions do not contribute to conversion of natural ecosystems. Achieving these objectives will require decoupling business growth from the destruction of natural resources and committing to be resource positive in ways that strengthen ecosystems and prioritize resource access for vulnerable communities.

4. Access to Water and Sanitation

Companies should collaborate on efforts to support access to clean water and sanitation in the communities they interact with and impact.

Companies should invest in solutions and multi-stakeholder collaborations that not only benefit the community, but also strengthen local water infrastructure, improve employee and community health, and enhance the social license to operate.

Companies can commence these efforts by adopting a corporate policy with designated financial and human resources that respects the human rights to water and sanitation. They can implement safe water sanitation and hygiene at the workplace and engage in actions to support the same for suppliers. They can reinforce these goals by supporting public policies and investments that promote increased community access to clean water and sanitation.

5. Business Integration

Companies should ensure that water-related risks and opportunities are systematically integrated into corporate governance and decision-making from the boardroom and senior management to employees at all levels of the workforce.

A key first step is to formalize board of director and senior management oversight of water management efforts and integrate these issues into their decision-making on strategy, risks and revenues.

Board directors should be informed on material and salient water priorities for the business so that they can evaluate those priorities in the context of short- and long-term strategic decision-making. Executives should be held accountable for water-related goals and incentivized via clear, transparent, and publicly disclosed compensation packages. Innovation and research and development should be a key focus of water management efforts.

6. Public Policy Engagement and Water Governance

Companies should proactively support public policies and water governance structures that further sustainable water resource management.

They should advocate for international, federal, and local policies that align with the latest environmental science, internationally recognized standards, and opportunities to maximize community well-being and the human right to water.

Companies can initiate these efforts by assessing how policy engagement and lobbying efforts are exacerbating or mitigating water-related risks to the company and its value chain. They should systemize decision-making on water issues across the company, including in all direct and indirect lobbying. They should also be engaging with and advocating for trade associations to align their policies and lobbying activities in support of water-related business priorities and solutions.

7. Multi-Stakeholder Collaboration

Since water is a shared resource, companies should be boosting multi-stakeholder collaborations to ensure sustainable water resources.

They should be building, engaging, and investing in industry and cross-industry efforts that challenge traditional business practices and enable system-level changes that are needed.

By building and scaling collaborations with industry peers, civil society organizations, governments, local communities, and other industry water users, companies can positively influence broader market, regulatory, environmental, and social systems. They should encourage and support pre-competitive engagement as a way to organize diverse stakeholders and drive innovation at industry and cross-industry scale. Research and development-related collaboration to better understand the the risks of fast-proliferating pollutants should also be considered.

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Appendix A
Methodology: Data Collection and Processing

Summary

The systematic review process [196] was applied, combined with a bottom-up and top-down approach for data collection and review as explained in the following appendices. The bottom-up method was used based on big data analytics of the raw data from key industries and sectors that have relatively high occurrence of mentions among studies. The top-down method was employed to solicit expert consultation and target searches to improve the quality and coverage of data. Both approaches are explained further in Appendix B and C.

Data coverage

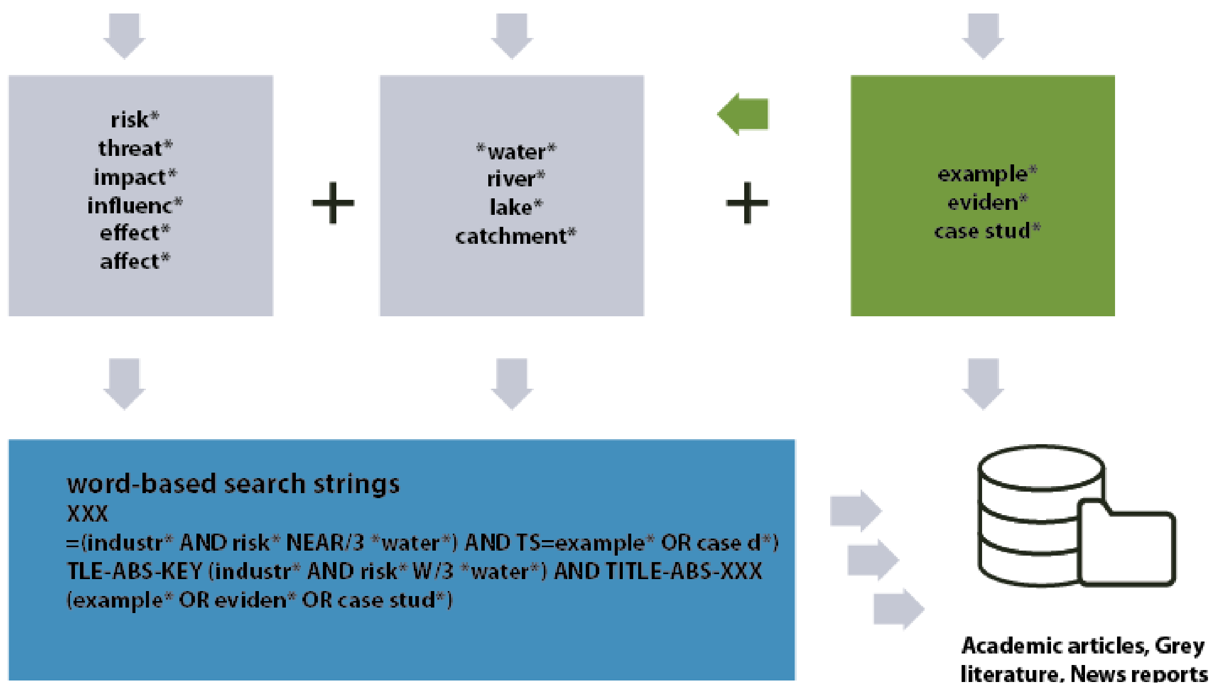
This report primarily explores industry impacts on freshwater. The data for this synthesis report is drawn from academic publications and grey literature. Academic publications are peer-reviewed papers that include review articles, research papers, and technical reports. Grey literature includes reports from various institutions and organizations, policy documents, working papers, theses, and news articles. Relevant data were retrieved from publications spanning from 1950 to January 2021.

Data retrieval

A keywords-based strategy was employed to identify relevant records in the literature. Figure A28 illustrates the logic structure of the application of the keywords-based strategy for data retrieval. It should be noted that the words in the boxes are examples that help to clarify the process. In general, the search strings contain three parts named the objective layer, the synonymous layer, and the operating layer (with the constraint). The objective layer specifies target objects (i.e., industry and water in this case) and the synonymous layer includes synonyms corresponding to those words in objective layer. Given that the report aims to synthesize evidence, theoretical and lab-based studies are viewed as irrelevant. Such exclusion was identified using a joint, automated, and manual process, which is further explained in the next subsections. The combinations of words, as search strings, are then applied to retrieve raw data from key databases, such as the Web of Science, Scopus, and Google Search.

The data collection process was made up of three parts: scoping review of existing academic review papers, target search for grey literature, and identification of available studies in a broad sense.

Figure A28. Exemplified strategy for keywords-based data retrieval



Scoping review

A scoping review is a relatively new approach for evidence synthesis. It is complementary to systematic review in that it can provide a quick overview of a study field before conducting detailed systematic review. It can therefore help to map out broad topics and determine the potential scope [197]. For this assessment, a scoping review was conducted to investigate the main industrial impacts on water that have been frequently studied and to avoid repeating existing work.

Using the search strategy shown in Figure A28, 1,985 records were initially identified from both the Web of Science and Scopus (two widely used academic bibliographic databases), and 21 reports (review documents) were found from Google and target searches within websites and databases of national and international institutions.

Apart from the 21 review documents, an additional 235 grey literature documents were found using target searches on Google Search Advances and reputable institutions. The target institutions include Accenture, CNN, Ceres, the Food and Agriculture Organization of the United Nations, KPMG, the New York Times, Pacific Institute, SEI, the Stockholm International Water Institute, Thomson Reuters, the UN, the World Bank, the World Health Organization, WRI, and WWF. All the documents were later screened to identify those most relevant for the assessment.

To identify all available evidence, a set of broader word combinations were developed for the topic search for data from the Web of Science. The topic search means that all the records were retrieved from the database if they contained any of the developed words or word combinations in their title, abstract, or keyword list. This process reduced potential bias of the review. That is, the review should not be restricted to any industries that have been identified in review reports and not be biased by the experts' opinions but be guided by what is available in the literature.

The initial search returned more than 3 million records which, after the additional scoping exercise, was reduced to 333,458 records (Table A4).

Table A4. Search strings for broad academic evidence

# of pubs retrieved	Search query	Core collection	Timespan	Retrieval date
333,458	TS=(*water* OR river* OR lake* OR catchment* OR marin* OR wetland* OR reservoir* OR lagoon* OR pond* OR canal* OR tributer* OR dam* OR stream*) AND TS=(hazard* OR risk* OR threat* OR impact* OR harm* OR influen* OR effect* OR affect* OR issue* OR spill* OR pollut* OR contamina* OR challeng* OR *secur* OR problem* OR consequenc*) AND TS=(industr* OR compan* OR business* OR sector* OR agri* OR livestock* OR aquacultur* OR horticultur* OR maricultu*) **Refined by**: [excluding] DOCUMENT TYPES: (RETRACTED PUBLICATION OR RETRACTION)	**SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI, CCR-EXPANDED, IC**	1950-2021	**Jan-21**
3,162,350	TS=(*water* OR river* OR lake* OR catchment* OR marin* OR wetland* OR reservoir* OR lagoon* OR pond* OR canal* OR tributer* OR dam* OR stream*) AND TS=(hazard* OR risk* OR threat* OR impact* OR harm* OR influen* OR effect* OR affect* OR issue* OR spill* OR pollut* OR contamina* OR challeng* OR *secur* OR problem* OR consequec*) **Refined by:** [excluding] DOCUMENT TYPES: (RETRACTION OR RETRACTED PUBLICATION)	**SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI, CCR-EXPANDED, IC**	1950-2021	**Jan-21**

Data processing to establish the bibliographic database

Scoping review data

For the scoping review data, the initial 1,985 records (after removal of duplicates) were further reduced by screening the titles and abstracts to exclude irrelevances. Irrelevant literature was classified as those that contained the developed keywords but did not really report impacts from specific industries on water systems. Papers that contained relevant contents in their titles but were unclear in their abstracts in terms of scope match were evaluated by a second round of full-text assessment. As a result, a total of 113 review papers and 20 grey literatures remained, making up the dataset of the scoping review.

Grey literature data

Similar to the review data, the initial 256 grey literature documents were further screened and those having no full text or having less content on industrial impacts on water were removed. The final screening generated a list of 149 documents, which were then grouped into 38 primary documents for further full-text assessment and 111 complementary documents for additional review.

Broader evidence data

For the broader dataset, automated big data analytics, combined with two rounds of manual screening, were undertaken. The automated analysis applied a citation network analysis with a text-mining approach to all papers obtained from the Web of Science. More specifically, networks among papers were generated using the direct citation relations extracted from bibliographic data. In other words, if paper A cites paper B (displayed as nodes in the network), then A and B are assumed to have close or similar concerns and are thus linked by an edge (displayed as a line between the two nodes in the network). Papers that have no citing and cited relations with any others are removed from the network (step 1 and 2 in Figure B29). This networking process helped to reduce initial data records from 333,458 to 227,315.

Furthermore, a text mining approach was performed to remove more papers from further review. Text-based data mining and analysis uses machine-learning artificial intelligence with natural language processing to translate human language so that computers can understand and analyze the importance of documents to this study. The approach focused on extracting key terms from the documents in the networks. All key terms were then ranked by the frequency-inverse document frequency (TF-IDF). TF-IDF is a measure to assess the importance of a word to a document in a collection of documents. The higher the score of TF-IDF, the more relevant and important the word is to the document. The text mining approach helped to further reduce data records to 123,913, to establish the third dataset. All three datasets are composed of the knowledge base of available evidence on industrial impacts on water.

Appendix B

Methodology: Key Sector and Industry Identification

Summary

In this report, key sectors and industries were defined as those that are frequently mentioned in literature. These identified sectors and industries provided a direction to determine core papers from the developed bibliographic database. It should be noted that less frequent mention of an industry in the literature does not necessarily mean the industry has less of an impact on water. It could simply mean that less research has been done on it. For example, the emerging impacts of the pharmaceutical industry could have more harmful impacts on water quality than the mining industry because more than 70% of pharmaceutical substances in water and their impacts on the human health remain unknown. Nevertheless, using occurrence frequency provides an efficient way to identify relatively important industries from such a large dataset. To identify key sectors and industries, a cluster analysis of the constructed networks and text mining of all industries and their frequency of occurrences were performed.

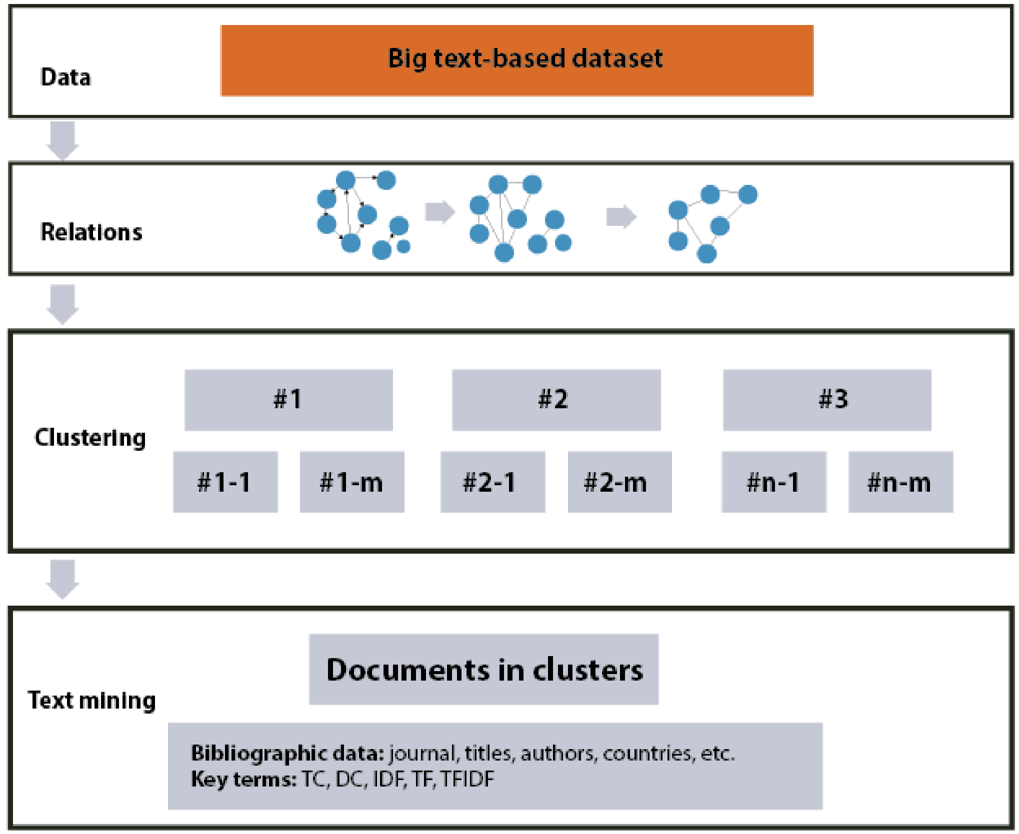
Cluster analysis of networks

The constructed networks were clustered into groups based on a modularity maximization and optimization algorithm that analyzes the structure of large networks [198]. The principal workflow of the analysis is depicted in Figure B29. Following the first two steps explained in the previous section, the processes of cluster analysis and text mining of key industries are described as steps 3 and 4 in the figure.

Modularity is a measure used to assess the structure of networks. Modularity maximization is the most widely used method for network community detection. It defines a benefit function (modularity) that measures the quality of divisions of a network into communities (clusters). When the modularity is maximized in a network, the structure of the network is well divided. Modularity optimization defines structure of the network that minimizes connections among divisions of communities (clusters) [198]-[200]. Within the algorithm, the automated clustering process runs iteratively until the number of clusters are optimized. The algorithm is specifically suitable for the clustering analysis of large networks due to its computational efficiency and the high quality of the results it returns [201]. The clustering analysis of the networks helped obtain groups of papers that reflected dominated research topics.

Using the clustering method, the entire network was divided into 147 clusters with more

Figure B29. Automated analysis of the big dataset on available evidence



than nearly 900 thousand links. Figure B30 displays the key processes of clustering analysis. The top panel in Figure B30 shows the distribution of numbers of papers in all the clusters. It can be seen that the first 29 clusters dominate the network. As a result, these 29 clusters were included as the main data for further analyses.

To better summarize research topics represented by each cluster, iterative clustering analyses were performed to those clusters that contained more than 1,000 papers in order to generate sub-clusters (the bottom of Figure B30). A total of 498 sub-clusters were generated from 29 clusters. For each sub-cluster, top clusters were included which cover more than 95% of the total number of papers.

Text mining of key terms and TF-IDF enabled the identification of the core research topic of each cluster. If irrelevant studies were found in some clusters, a data cleaning process was conducted that focused on screening out irrelevant clusters by examining titles combined with key terms extracted from each cluster. Using this approach, nine clusters were removed from the top 29 clusters. With the remaining 20 clusters, some irrelevant subclusters were also removed.

Key sectors and industries

Key sectors and industries having freshwater impact were identified by using the frequency of industries that occurred in the papers. Frequencies were obtained by text mining of abstracts, titles, and keyword lists of clustered papers in the citation networks.

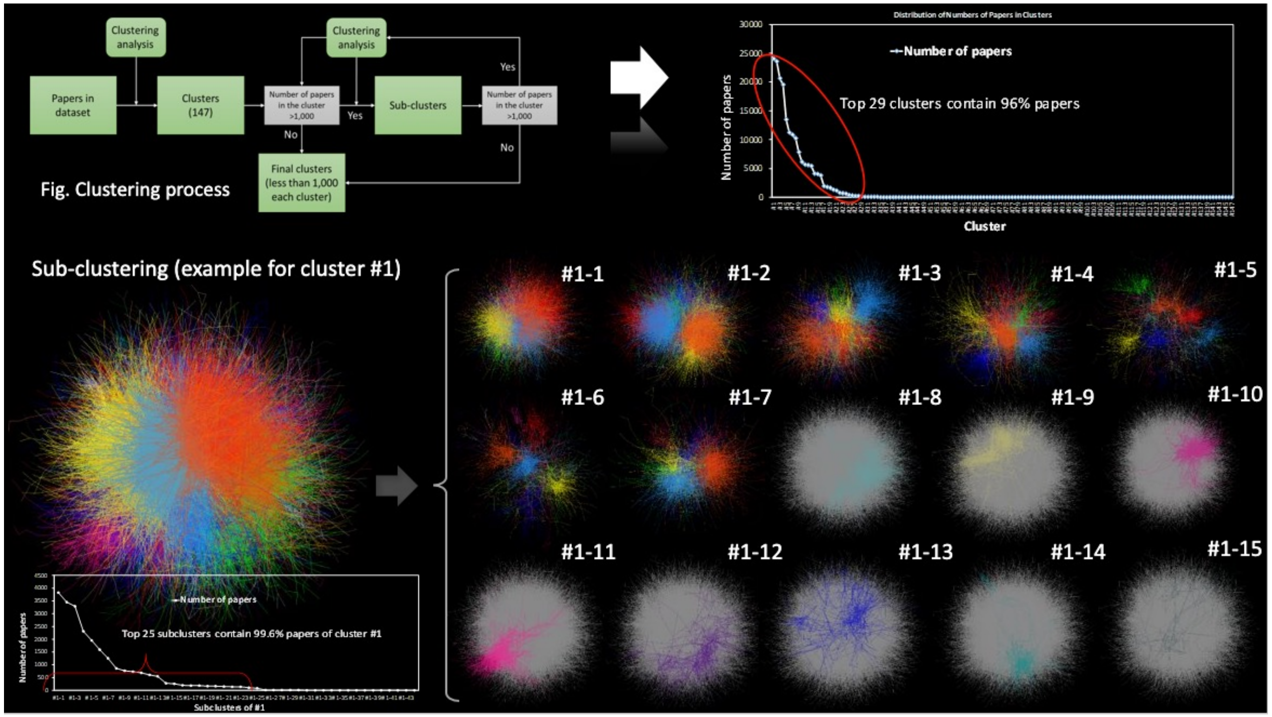
Industry classification

In this project, we use the Global Industry Classification Standard (GICS) for identifying industries and sectors under assessment. The GICS framework is an industrial taxonomy used by the global financial community. The ultimate objective of this assessment is to use scientific evidence to communicate to investors, companies, and other stakeholders towards embracing systems thinking when dealing with water impacts and risk assessment.

Retrieving full list of industries

In total, 767 clusters and subclusters were generated in which the total numbers of papers were all less than 1,000. By definition, each cluster/subcluster has a different research focus. A text mining approach was used to retrieve all industries for all clusters and subclusters. We assumed that the more frequently an industry type appeared in clusters/subclusters, the more important that industry was to the topic of the cluster/subcluster. Therefore, the prioritization of industries for freshwater impacts was obtained by the number of occurrences of industries in all clusters and subclusters.

Figure B30. Processes of clustering analysis of networks with an example



Exclusion of industries for further analysis

The full list of industries was created by merging those industries identified in reviews, grey literature, and the broad evidence dataset. Those sectors listed in GICS but that did not appear in our dataset were removed from our list of sectors. In particular, real estate and communication services sectors were excluded from this study.

Final industry selection

To obtain the final list of industries, we first extracted the full list of industries mentioned in all papers, and then we chose those industries that appeared in at least five papers. Using this list of industries, we performed a search in our metadata for the second round of assessment of relevance of the industries selected. We searched for papers in which the identified

Figure B31. Key sectors and industries identified under GICS

Key Sectors and Industries

Consumer Staples	Consumer Discretionary	Energy	Health Care	Materials	Information Technology	Utilities
Food products	Textiles, Apparel, and Luxury Goods	Oil, Gas and Consumable fuels	Pharmaceuticals	Chemicals	High-tech and Electronics	Renewable Electricity (hydroelectric power)
Beverage	Hotels, Restaurants, and Leisure	Energy Equipment and Services	Health Care Providers and Services	Agricultural Products (nonfood)	Semiconductor and Circuit board	Water Utilities
Personal Products	Speciality Retail		Health Care Equipment and Supplies	Metals and Mining	Battery Manufacturing	Electric Utilities
Food and Staples retailing	Household durables		Biotechnology	Paper and Forest Products	High tech	Independent Power and Renewable Electricity Producers
Aquaculture	Automobiles			Containers and Packaging	Nanotechnology	
Tobacco	Auto Components			Construction Materials	Electrochemical	
	Diversified Consumer Services				Electronic Equipment, Instruments, and Components	

industries were mentioned in either the title, keywords, or abstract. This yielded potential lists of papers for all initially selected industries.

Next, we conducted an assessment of the relevance of papers using two key criteria: 1) industries and papers must have reported impacts on water and 2) papers must have geolocation information reported. For industries that have more than 200 papers, an extra criterion was added, i.e., the average number of citations of papers must be greater than four on a yearly basis. Based on the criteria, we identified the list of industries that fall in seven categories of sectors under GICS (Figure B31).

Data cleaning for identified industries

Creating metadata for identified industries

We removed all the irrelevant clusters and subclusters by screening the key terms extracted and perusing the titles and abstracts of top-cited papers within the cluster. We then merged all papers remaining in clusters/subclusters to create a metadata of industries for the assessment.

Identification of papers to be reviewed

To further identify papers under each industry, we used a combined bottom-up and top-down approach. For the bottom-up approach, we first identified papers through screening in the full metadata for titles, keywords, or abstracts that mentioned the industry. To ensure the representativeness of papers, we ranked all papers based on the average number of citations the papers had per year for large industries, such as the mining and oil and gas industries. For smaller industries that had fewer papers published in the literature (fewer than 200 papers), we manually excluded those that did not report water impacts.

For large industries, we then searched for groups of topics that were out of the study scope. Next, we performed a text-based assessment of papers (based on titles, abstracts, and full text) to include the most relevant and impactful papers in the bibliographic database. Citation network analysis captured the most impactful papers and provided a good way to process the dataset. We acknowledge that the data processing may screen out some important literature or that some recent literature might not be detected by the methodology followed here. The targeted searches at the review stage helped address the disadvantage. Also, any missing literature suggested by external reviewers was added during the report review processes.

In total, 664 papers and reports were identified for final review by the study team. Information was extracted from this literature and was organized into an informatics database using the DPSIR framework as the guide (see Appendix C). The complete list of the 664 papers and reports reviewed can be found here.

Appendix C

Methodology: Information Extraction—DPSIR

Summary

In this report, the Driver-Pressure-State-Impact-Response (DPSIR) model was applied as a conceptual framework to guide information extraction from research papers and reports. The model was then used to synthesize evidence that describes the causal chain of how various industrial practices and activities affect freshwater resources. Based on the causal chain, critical impacts and associated practices were identified according to the intensity and severity that have been reported in the literature.

DPSIR framework

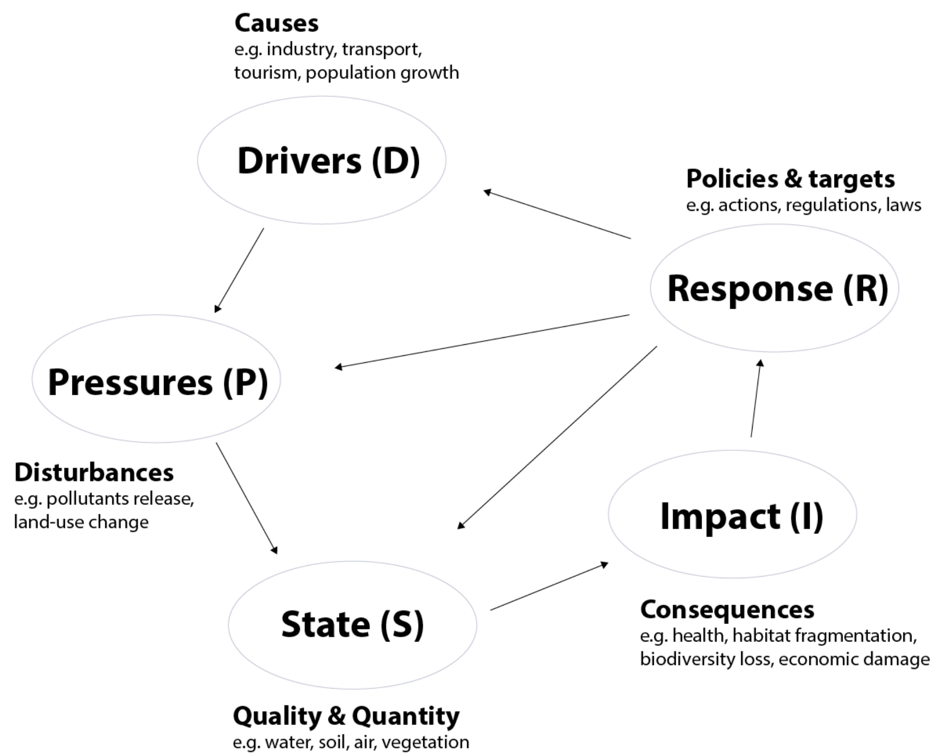
The DPSIR framework was developed by the European Environment Agency as the extension of the previous OECD's Pressure-State-Response model [12],[202]. It describes the chain of causal links starting with "drivers" through "pressures" to "states" and "impacts" on social and environmental systems, eventually leading to political "responses." The framework has been widely used to evaluate how humans affect and interact with natural environments from local to global scales, such as land degradation and ecosystem changes, microplastic pollution in marine environments, and biodiversity impacts by socioeconomic drivers [203]-[205].

In the framework (Figure C32), Drivers (D) define those factors that motivate human activities, such as agricultural production and population growth, that are formed in the long run and beyond direct control or management. At the company level, a driver can be the need to generate profit through multiple practices that involve production of commodities. These practices lead to activities exerting **Pressures** (P) on the environment, such as pollutants release and land-use change. As a result of pressures, the **State** (S) of the environment is affected, which could change the physical, chemical, and biological conditions of the environments, such as the quality of air and water. Changes in the state of the environment can have a multi-faceted Impact (I) on the environment and society, determining the function of natural systems and the welfare of humans, such as biodiversity loss and hazards to human health. To adapt to and mitigate undesirable impacts, policy makers or individuals have to make **Responses** (R), such as setting targets and implementing regulations, which can affect any part of the causal chain between drivers and impacts [206]-[209].

DPSIR framework applied to the industry-water context

The state of water is determined by natural factors such as geological characteristics but also by pressures generated by industrial activities. The DPSIR framework was used in this project to capture a broad spectrum of how industries affect freshwater systems and societal response to these impacts (Figure C33). “D” refers to the demands industrial sectors are putting on freshwater for production, including product consumption levels and production patterns. “P” describes the stresses that such production demands place on freshwater systems through multiple practices and activities, which are divided into three types: excessive use of water resources, changes in water distribution, and emissions of pollutants to water bodies. “S” indicates possible alterations to water systems from industry in specific areas, including water consumed, chemical substance concentrations in wastewater and freshwater, and biological conditions in aquatic ecosystems. “I” describes the consequences of changes in conditions and functions of water and associated social-ecological systems, including impacts on biodiversity, freshwater depletion, conflicts, and human health. “R” includes adaptive actions taken by actors, such as individuals, communities, and government agencies, to prevent and mitigate negative impacts.

Figure C32. Key sectors and industries identified under GICS

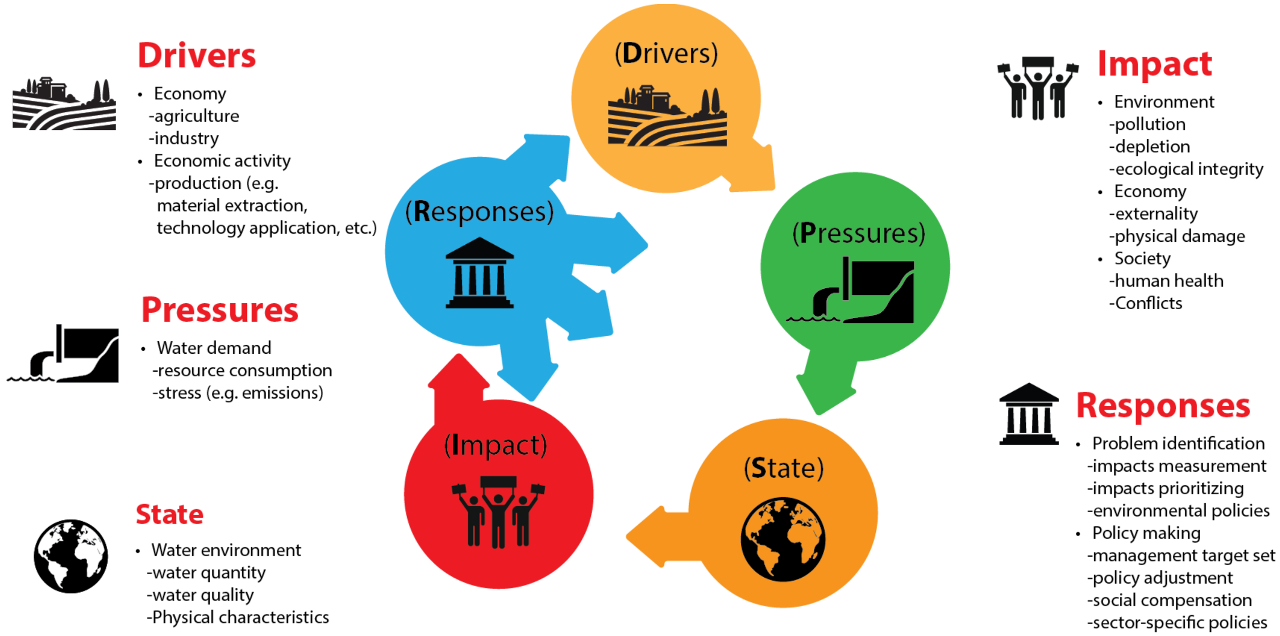


DPSIR framework for information extraction and organization

Using the defined framework, a comprehensive matrix was established to create the database for the information extraction and organization (the complete database is available upon request). In this matrix, drivers are GICS sectors and industry groups identified for the project. Pressures list all practices and activities from industries that are reported in the literature. State is organized into a hierarchical structure of conditions, starting with higher level and ending up with specific conditions, which are affected by industrial practices and activities. Specifically, the higher level of water condition is classified into water quality and water quantity, meaning that industrial practices and activities can generate pressures on water quantity or quality, or both. Under each classification, state variables are detailed at lower levels, followed by a measured quantity of variables that are reported in literature. For example, the swine farming practice can generate significant issues for water quality (high level) that involve chemical contaminants (lower level 1) and pharmaceuticals (lower level 2) and antibiotics (lower level 3). Impact in the matrix lists literature reports of consequences, which involve both direct impacts on water bodies, and indirect or consequent impacts on social, ecological, and economic systems, such as habitat fragmentation and water-related conflicts.

In this matrix, we also included information about the spatial and temporal scales of reviewed studies to specify if the reported impacts are chronic or emerging issues or shocks, and where they have occurred (applicable when they are identified in the literature). In addition, the value chain section specifies the source of the impacts along the industrial value chain. It should be noted that we ex-

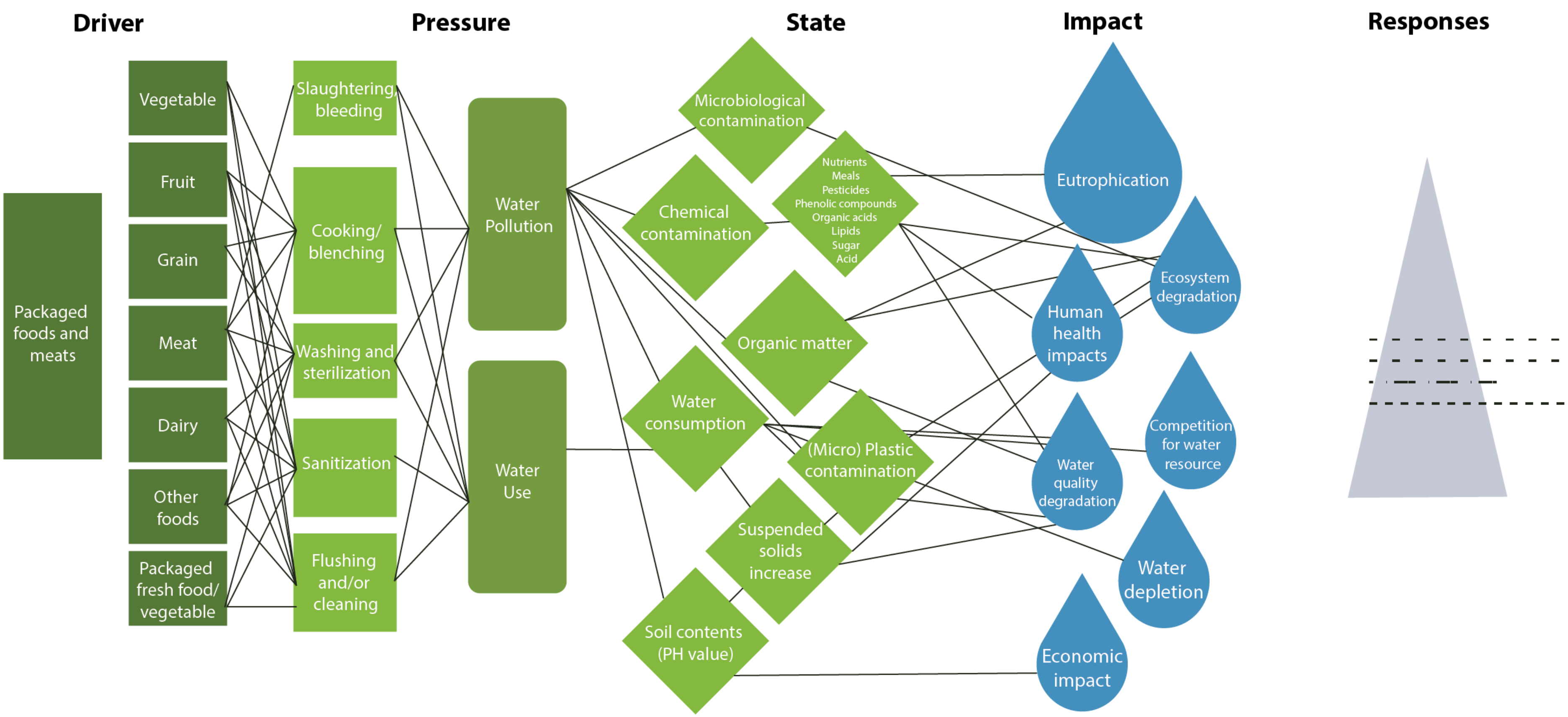
Figure C33. DPSIR framework applied to industry-water context



tracted societal responses in a separate manner, given that this piece of information is not a common focus of most studies. Specifically, we first framed casual links between industrial practices and their pathways to impact water and associated systems, and then performed targeted searches for societal responses of each link in a broad way.

With the matrix, key information was extracted and helped clarify key messages and articulate them as science-based, but understandable narratives. For example, a review paper on the Food Products industry [210] can be summarized as: the practice of swine farming in the Food Products industry exerts great pressures on the quality of water bodies adjacent to swine farms due to the application of antibiotics for treatment and prevention of disease. Water pollution results from swine waste through runoff, which contains high concentrations of chemical contaminants dominated by antibiotics and hormones. The toxic pollution of swine farming is a worldwide issue, with significant contributions to the high concentration of pharmaceuticals in aquatic environments in many countries in Asia, America, Africa, and Europe. The global average concentration of tetracycline (an antibiotic) due to swine farming practices can reach 685.60 ug per liter of freshwater near farms. This high level of toxicants can threaten the health of aquatic ecosystems and humans. Although restrictions and regulations have been implemented since

Figure C34. Example of DPSIR framework applied to agricultural industry



the 1980s in many countries, antibiotics are still in use to promote growth of food animals in several large livestock producing and exporting countries, such as China and Brazil.

The process of information extraction was conducted from sector to sector by the review team. The extracted information from literature reviewed within the same group was then synthesized to construct the casual chain between each industry and its water impacts. Figure C34 illustrates an example of how the packaged food and meat industry generates impacts on freshwater resources using the DPSIR framing and based on information extracted from literature. Based on the literature reviewed by the team, pressures by the packaged food and meat industry on freshwater are driven by practices during the production of vegetables, fruit, grain, meat, dairy products, and other foods. These production practices involve a number of water-related activities, including slaughtering and bleeding animals in factories, cooking and blanching processes, washing and sterilization, sanitization, and flushing, as well as cleaning. Intensive activities during production processes can alter the states of water in terms of its quality and quantity, which are reported in the literature to contribute to freshwater eutrophication and ecosystem and water quality degradation, and to cause depletion of water resources, water competition, and economic, as well as human health impacts.

Appendix D

Methodology: Industrial Impacts on Freshwater: Scoring Criteria

First, a set of narrative criteria for scoring impacts was established as described in Table D5, identifying four levels of severity, systemic nature, and likelihood. Metrics shown in tables D6, D7, and D8 illustrate how the scores for severity and the systemic nature of impacts should be given based on the narrative in Table D5. For each impact, severity and likelihood of impact were scored using Table D6, while the systemic nature and the likelihood of systemic impact were scored using Table D7. Further, a matrix was developed to aggregate severity and systemic nature scores into overall impact levels (table D8) based on the evidence identified in the literature. Based on literature review and extracted data, all identified impacts were classified into water quantity and quality dimensions, and their corresponding industries (Table D9). Table D9 also specified where these impacts are generated. A relative assessment was performed to produce the results presented in Table 1 and 2 in the main report.

The framing of impacts in this way allows for overall scoring and weighting of the relative impacts of these different industrial sectors, which can be helpful for investors and companies in prioritization.

Table D5. Score criteria for industrial impacts on freshwater resources.

Severity	Description	Systemic Nature	Description	Likelihood (evidence-based)	Description
Very high	Impacts are at an unacceptable level and can cause catastrophic damages and, in some cases, the damages are irreversible	Very high	Impacts significantly affect the accessibility of other water users within and across regions, and are costly for restoration	Very likely	Impacts may occur at any moment and are widespread (occurrence is almost certain)
High	Impacts are serious and can cause major damages	High	Impacts can affect the accessibility of other water users within the region, and cause substantial costs to affected industries	Likely	Impacts may occur at times and are found in some regions
Moderate	Impacts are tolerable, but substantial cost is required to restore	Moderate	Impacts can affect the accessibility of other water users, and cause moderate costs	Possible	Impacts may occur at certain times or under certain situation, and are found in few regions
Low	Impacts are at an acceptable level and can be managed with minor cost	Low	Impacts have minor or no impacts on other water users and regions, and are easy to restore	Unlikely	Impacts may occur, but are rare (it will probably never be the case)

Table D6. Severity of impacts assessment matrix. Scores the severity of impacts, based on the criteria outlined in Table D5. Severe impacts with a high likelihood of occurring are considered Very High risk and marked in red. This score is also noted in Table 1, of the main report, within the column "Severity."

		Severity of Impact (Acute)			
		Low	**Moderate**	**High**	**Very high**
Likelihood	**Very likely**	**M**	**H**	**VH**	**VH**
	Likely	**L**	**M**	**H**	**VH**
	Possible	**L**	**M**	**M**	**H**
	Unlikely	**L**	**L**	**L**	**M**

Table D7. Systemic nature of impacts assessment matrix. Scores the systemic nature of impacts based on criteria outlined in Table D5. Highly systemic impacts with a high likelihood of occurring are considered Very High risk and are marked in red. The score is also noted in Table 1, of the main report, within the column "Systemic Nature."

		Systemic Nature (Widespread)			
		Low	**Moderate**	**High**	**Very high**
Likelihood	**Very likely**	**M**	**H**	**VH**	**VH**
	Likely	**L**	**M**	**H**	**VH**
	Possible	**L**	**M**	**M**	**H**
	Unlikely	**L**	**L**	**L**	**M**

Table D8. Overall impacts assessment matrix. Compares the scores of the severity and systemic nature to obtain an overall assessment of each impact. Like Tables D6 and D7, a severe impact with a high systemic nature would have an overall classification of Very High risk and is marked in red. Scores are noted in Table 1, of the main report, within the column "Overall Impact."

Overall Impact		Systemic Nature (Widespread)			
		Low	**Moderate**	**High**	**Very high**
Severity of Impact (Acute)	**Low**	**L**	**M**	**M**	**H**
	Moderate	**M**	**M**	**H**	**H**
	High	**M**	**H**	**VH**	**VH**
	Very high	**H**	**H**	**VH**	**VH**

Table D9. A high-level summary showing water quantity and quality impacts along the value chain. Identifies the industries contributing to high and very high impacts to water resources found within the literature and specifies the impact and the location within the value chain where the impacts take place. Industries identified as having low impacts on freshwater resources are not included in the table (Hotels, Restaurants, and Leisure, Consumable Fuels, Electroplating, and Construction Materials).

Industry	Impact	Value chain
Food Products	Water scarcity (general)	On-farm/supply
	Eutrophication	On-farm/supply
	Physicochemical stressors	Direct operation/ on-farm/supply
	Groundwater depletion	On-farm/supply
	Pharmaceuticals	On-farm/supply
	Social conflicts and justice	On-farm/supply
	Pesticide pollution	On-farm/supply
	Diversion of water	On-farm/supply
	Streamflow alteration	On-farm/supply
	Bacteria and pathogens	On-farm/supply
	Erosion and sedimentation	On-farm/supply
Beverages	Eutrophication	On-farm/supply
	Physicochemical stressors	Direct operation
	Social conflicts and justice	Supply
Household Products	Eutrophication	Consumer use
	Physicochemical stressors	Consumer use
	Acidification	Consumer use
Personal Products	Plastics, micro-plastics, and phthalates	Consumer use
	Personal product chemicals	Consumer use
Textiles, Apparel, and Luxury Goods	Eutrophication	On-farm/supply
	Plastics, micro-plastics, and phthalates	Consumer use
	Pesticide pollution	On-farm/supply
	Diversion of water	On-farm/supply
	Dyes	Direct operation
Automobiles and Components	Plastic, micro-plastics, and phthalates	Consumer use
Oil and Gas	Water scarcity (general)	Supply chain
	Groundwater depletion	Supply chain
	PAH pollution	Supply chain
	Oil spills	Supply chain/direct operation
Construction and Building	Streamflow alteration	Supply chain
Pharmaceuticals	Pharmaceuticals	Consumer use
Chemicals	Plastic, micro-plastic, and phthalates	Direct operation
	PAH pollution	Direct operation
	Pesticide pollution	Direct operation
	PFAS and PFOA	Direct operation
Metals and Mining	Water scarcity (general)	Supply chain
	Metal pollution	Supply chain
	Groundwater depletion	Supply chain
	Direct ecosystem impacts	Supply chain
	Acidification	Supply chain
Paper and Forest Products	Physicochemical stressors	Direct operation
	PAH pollution	Direct operation
	Erosion and sedimentation	Supply chain
	Water scarcity (general)	Direct operation
High-tech and Electronics	Metals pollution	Direct operation/ consumer use
Semiconductors and Circuit Boards	Metal pollution	Direct operation
	PFAS and PFOA	End of life
Batteries	Metal pollution	Direct operation
	Nanomaterials	Direct operation
Renewable Electricity	Physicochemical stressors	Direct operation
	Direct ecosystem impacts	Direct operation
	Social conflicts and justice	Direct operation
	Diversion of water	Direct operation
	Streamflow alteration	Direct operation
Electric Utilities	Radioactive pollution	Direct operation

Water Quality

Water Quantity

Appendix E

Industry Sectors: Value Chain Analysis of Practices, Externalities and Water Impacts Globally *(continued)*

Apart from the twelve industries identified as having severe impacts on water resources and emerging impacts on water throughout the value chain, outlined in Chapter 2, the following section describes the other industries identified in the literature review as having impacts on freshwater.

1. Consumable Staples Sector

Household Products

The Household Products industry includes products such as soaps, detergents, and diapers. Household products are a large source of phosphates in surface water, though the use of phosphates in laundry detergent has been banned by some governments since the 1970s. While the manufacturing processes for household products have significant impacts on freshwater, the industry's biggest impact stems from consumer use. For example, wastewater discharges of detergents can cause ecotoxicity, acidification, and eutrophication. Discharges are also a major source of plastics and microplastics in water bodies. Given growing consumer demand, the impacts are likely to worsen.

Personal Products

Personal Products include cosmetics, fragrances, lotions, and sunscreens. The Personal Products industry is generating emerging contaminants, such as pharmaceuticals, surfactants, and exfoliants. The industry has impacts on freshwater mainly through consumer end uses. Among the biggest impacts associated with the use and disposal of these products are high concentrations of chemical compounds released into water bodies through municipal wastewater systems.

Figure E35. Summary of Household Products industry freshwater impacts along its value chain, including consumer use and manufacturing. Selected hotpots are the regions frequently cited in the literature.

Value Chain	Practices	Externalities	Freshwater Impact	Selected Hotspots
Full Value Chain	Raw material extraction, processing, consumer use	Water consumption	Water stress	Spain, France
Manufacturing	Product manufacturing	Wastewater discharged (including microplastics, phosphates, foaming agents)	Ecotoxicity, acidification, eutrophication, human health impacts	Brazil, Belgium
Consumer Use	Household product use	Domestic wastewater discharge	Bioaccumulation, ecotoxicity, acidification, eutrophication, human health impacts	China, USA, India, Spain, Brazil

Figure E36. Summary of Personal Products industry freshwater impacts along its value chain. Selected hotpots are the regions frequently cited in the literature.

Value Chain	Practices	Externalities	Freshwater Impact	Selected Hotspots
Consumer Use	Personal product, consumer use	Domestic wastewater discharged (including personal product compounds, fragrances, surfactants, microbeads)	Endocrine disruption, bioaccumulation	Canada, USA, UK, India, China, Brazil, Spain, Australia

2. Consumer Discretionary Sector

Automobiles and Components

The Automobiles and Components industry includes companies that produce cars, trucks, and other vehicles, and manufacturers of parts and accessories for automobiles. Water is essential for vehicle manufacturing. It is also used for producing raw materials for parts and components, such as rubber for tires. The manufacturing process produces pollutants which are discharged to water bodies.

Hotels, Restaurants, and Leisure

The Hotels, Restaurants, and Leisure industry includes a variety of sub-industries with close connections to tourism and leisure activities, including hotels, resorts, cruises, leisure facilities, and restaurants. General tourism and maintenance of golf courses are the most water intensive practices of this industry. The industry releases pollutants into water bodies, including pesticides and nutrients. Pesticides and nutrient runoff mainly stem from landscaping and maintenance practices, such as growing turf on golf courses and horticultural activities. Wastewater from restaurants and hotels is another key contributor of nutrients to water bodies.

Figure E37. Summary of Automobiles and Components industry freshwater impacts along its value chain, including on-farm production and manufacturing. Selected hotpots are the regions frequently cited in the literature.

Value Chain	Practices	Externalities	Freshwater Impact	Selected Hotspots
Full Value Chain	Complete automobile production	Water consumption	Water stress	China, Germany, South Africa
Parts and components	Rubber production	Water consumption	Water stress	
	Lithium battery production for electric vehicles	Wastewater released	Ecotoxicity, eutrophication, human health impacts	
Manufacturing	Production including surface treatments, painting, washing	Water consumption	Water stress	
	Degreasing		Human health impacts	

Figure E38. Summary of Hotels, Restaurants, and Leisure industry freshwater impacts freshwater along its value chain. Selected hotpots are the regions frequently cited in the literature.

Value Chain	Practices	Externalities	Freshwater Impact	Selected Hotspots
Full Value Chain	General tourism, (restaurants, hotels, etc.)	Water use	Water stress, water disputes and conflicts	Spain, France, small island nations (i.e. Mauritius)
	Cruises	Wastewater released	Ecotoxicity, eutrophication, invasive species	
	Golf course maintenance	Runoff including nutrients and pesticides	Ecotoxicity, eutrophication,	USA, Europe, Japan
		Water consumption	Water stress	

3. Energy Sector

Consumable Fuels

The Consumable Fuels industry includes companies that are involved in the production of consumable (biofuel) fuels used to generate energy. The value chain of the Consumable Fuels industry involves collecting fuel or gas sources, energy generation, transmission, and distribution. Within the consumable fuels industry, water withdrawals and consumption for the irrigation and production of crops used for biofuels, such as corn and wood for ethanol and soybeans for biodiesel, have the largest freshwater impacts.

4. Industrials sector

The Industrials sector encompasses industries including Building and Construction and Electroplating. These identified industries pose a great threat to water quality due to the large number of heavy metals (e.g. copper and chromium) they use. They also pose a threat to water quantity predominantly due to the consumption of water resources. (It should be noted that definitions of industries used in literature are sometimes different from those in GICS. Some industries may not perfectly correspond to GICS definitions. As building and construction industries under GICS and their impacts identified in literature involve multiple sectors, this report classifies the Construction and Building industries as a group within the Industrials sector.)

Construction and Building

The value chain of the Construction and Building industry includes the entire life cycle of buildings (both residential and non-residential), from the raw materials used in their construction to their maintenance and deconstruction. Water impacts are found along the value chain, including impacts related to the extraction and processing of certain building products, such as the production of wood building products. The built environment itself also contributes to significant water pollution through storm and urban runoff.

Figure E39. Summary of Consumable Fuels industry freshwater impacts along its value chain from raw material sourcing to energy production. Selected hotpots are the regions frequently cited in the literature.

Value Chain	Practices	Externalities	Freshwater Impact	Selected Hotspots
Gas/fuel source	Irrigation for biofuel	Water consumption	Water stress	USA
Manufacturing Consumer Use	Oil	Water withdrawals	Water stress	
	Natural gas			
	Coal			
	Biofuels			
	Fossil fuels			

Electroplating

In the Electroplating industry, metal objects are coated with a thin layer of different metals, involving three stages: pre-treatment, electroplating, and post-treatment. Electroplating is used in many transportation industries, such as automotive, aerospace, and marine, as well as in the production of electrical parts and components. This industry poses great concern for water resources due to the potential for heavy metal pollution if wastewater is improperly treated.

5. Materials Sector

Construction Materials

The Construction Materials industry includes manufacturers that produce materials for construction and buildings. This industry provides the construction and building industries with raw materials, such as brick, cement, concrete, glass, pavement, and stone. The industry's impacts on water stem primarily from the extraction and processing of raw materials, with concrete production having the most significant impacts globally. Cement production is hazardous to water quality, with discharges including high concentrations of lead, zinc, copper, nickel, iron, manganese, and aluminum.

Figure E40. Summary of the Construction and Building industry freshwater impacts along its value chain from raw material sourcing to deconstruction. Selected hotpots are the regions frequently cited in the literature

Value Chain	Practices	Externalities	Freshwater Impact	Selected Hotspots
Raw material production	Steel and concrete processing	Water consumption	Water stress	India
Construction	Rock quarrying	Blocked streams	Streamflow alteration	
	Wood building products processing	Wastewater released including organic matter and suspended solids	Ecotoxicity	
Deconstruction	Demolition			

Figure E41. Summary of the Electroplating industry freshwater impacts through its processing in factories. Selected hotpots are the regions frequently cited in the literature.

Value Chain	Practices	Externalities	Freshwater Impact	Selected Hotspots
Electroplating	Electroplating thin layers of metal	Wastewater discharged (including metals, physico-chemical stressors, salts)	Ecotoxicity, bioaccumulation, human health impacts	India, Brazil, China, Indonesia, Germany, Iran, Mexico, Turkey

6. Utilities Sector

Electric Utilities

The Electric Utilities industry encompasses companies and industries that produce electricity through coal-fired power production, natural gas, and nuclear power. The Electric Utilities industry consumes significant amounts of water, especially during cooling processes. Coal-fired power plants require water throughout the value chain, including for mining, cooling, and washing processes. Electric power facilities can release contaminants, such as heavy metals, radioactive material, heat waste, and heavy metals, such as cesium and lead, or radioactive compounds, such as argon, krypton, and xenon.

Figure E42. Summary of the Construction Materials industry impacts through production of concrete and cements for the construction and building industry. Selected hotpots are the regions frequently cited in the literature.

Value Chain	Practices	Externalities	Freshwater Impact	Selected Hotspots
Concrete production	Cement manufacturing (ingredient of concrete	Water consumption	Water stress	Phillippines, Iran
		Wastewater discharge	Ecotoxicity	
	Total concrete manufacturing	Water withdrawals	Water stress	China, India, USA, Northern Africa, Middle East

Figure E43. Summary of Electric Utilities freshwater impacts along its full value chain. Selected hotpots are the regions frequently cited in the literature. Selected hotpots are the regions frequently cited in the literature.

Value Chain	Practices	Externalities	Freshwater Impact	Selected Hotspots
Raw material extraction	Coal mining/processing	Water consumption	Water stress	China
Full value chain	Coal, natural gas, biomass energy production	Water consumption	Water stress, groundwater depletion	Europe, China, Latin America, USA, Canada, India
	Nuclear power production	Water consumption	Ecotoxicity, eutrophication	Lithuania, China
		Wastewater released (radioactive materials, metals)		