Toxics Link
for a toxics-free world

Status Report: Persistent Organic Pollutants (POPs) in Uttarakhand, India

INOPOL

With funding support from

Norway

About Toxics Link

Toxics Link is an Indian environmental research and advocacy organisation set up in 1996, engaged in disseminating information to help strengthen the campaign against toxics pollution, provide cleaner alternatives and bring together groups and people affected by these problems. Toxics Link has a unique expertise in areas of hazardous, plastic, medical and municipal wastes, international waste trade, and emerging issues of pesticides, Persistent Organic Pollutants (POPs), hazardous heavy metal contamination, etc. We have successfully implemented various best practices and have contributed to policy changes in the aforementioned areas apart from creating awareness among several stakeholder groups.

Toxics Link's Mission Statement - "Working together for environmental justice and freedom from toxics, we have taken upon ourselves to collect and share both information about the sources and the dangers of poisons in our environment and bodies, and information about clean and sustainable alternatives."

About Norwegian Institute for Water Research

The Norwegian Institute for Water Research is Norway's leading institute for fundamental and applied research on marine and freshwaters. Our research comprises a wide array of environmental, climatic, and resource-related fields. NIVA's world-class expertise is multidisciplinary with a broad scientific scope. We combine research, monitoring, evaluation, problem-solving, and advisory services at international, national, and local levels.

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About this report

Persistent Organic Pollutants (POPs) are a group of hazardous chemicals that pose serious risks to the environment and human health globally. POPs are persistent, highly bioaccumulative, and capable of long-range environmental transport. They are known to cause long-term adverse effects on endocrine functions, including developmental, reproductive, neurological, and immune system impacts in both humans and wildlife.

Many scientific studies have extensively documented the sources, exposure pathways, and health impacts of POPs worldwide. India is a signatory to the Stockholm Convention on POPs and is in the process of updating its National Implementation Plan (NIP). In this context, Toxics Link, in collaboration with the Norwegian Institute for Water Research (NIVA), has developed this report titled "*Status Report of Persistent Organic Pollutants in Uttarakhand, India.*"

This report collates findings from published research and available data on the state of Uttarakhand and identifies key gaps and challenges related to POPs in the state. It provides an overview of the current status of POPs in the state from regulatory and policy perspectives, highlighting their presence, potential sources, and associated risks, and emphasizing their environmental and public health implications. The report aims to supplement the efforts of the National Implementation Plan by raising awareness among the stakeholders, thereby promoting safer and more sustainable environmental and public health practices in the state.

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List of Abbreviations

BAT	Best available techniques
BEP	Best environmental practices
CPCB	Central Pollution Control Board
DDT	Dichlorodiphenyltrichloroethane
HCH	Hexachlorocyclohexane
HHPs	Highly hazardous pesticides
MoEF&CC	Ministry of Environment, Forest and Climate Change
NIP	National Implementation Plan
OCPs	Organochlorine pesticides
PAHs	Polycyclic aromatic hydrocarbons
PBDEs	Polybrominated diphenyl ethers
PCBs	Polychlorinated biphenyls
PCDD/Fs	Polychlorinated dibenzo-p-dioxins and dibenzofurans
PFAS	Per- and polyfluoroalkyl substances
POPs	Persistent organic pollutants
UKPCB	Uttarakhand Pollution Control Board

01 Introduction

1.1 What are POPs?

Persistent Organic Pollutants (POPs) are a group of hazardous, carbon-based chemicals known for their persistence in the environment and their ability to accumulate in living organisms (Ivbanikaro, et.al., 2025). They are resistant to degradation, allowing them to remain in the environment for decades and biomagnify up the food chain (Raheem, et.al., 2025). Scientific studies have shown that long-term exposure to certain POPs compounds under specific conditions, even at low levels, can increase the risk of certain cancers, reproductive disorders, alterations of the immune system, neurobehavioral impairment, endocrine disruption, genotoxicity, and increased birth defects (Rokni, et.al., 2023)

Additionally, these chemicals are globally pervasive; they can be transported by air, water, or migratory species across international borders, reaching places where they have never been produced or used **(Figure 1).** POPs that were banned decades ago, such as Dichlorodiphenyltrichloroethane (DDT) and Hexachlorocyclohexane (HCH) etc., around the globe can still be detected in the environmental matrices ranging from polar icecaps to the tissues of organisms in the most remote areas on earth (Marathe et.al., 2021; Luarte, et.al., 2023).

The chemicals categorised as POPs have diverse chemical compositions and applications, making them key ingredients in various products and production processes throughout the supply chain. However, in the environment, their sources can be broadly classified into three categories:

- Pesticides, including organochlorine pesticides (DDT, Heptachlor, and their by-products such as α-HCH, Dichlorodiphenyldichloroethane (DDD), Dichlorodiphenyldichloroethylene (DDE)

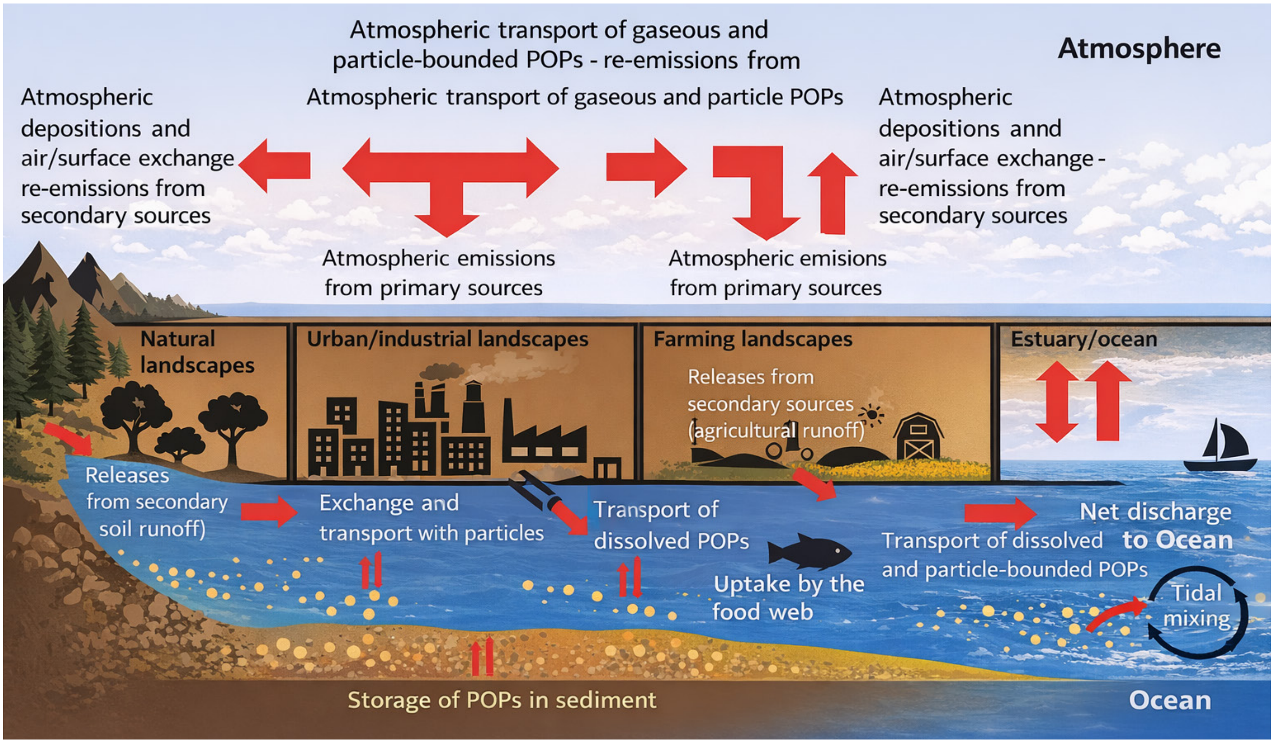


Figure 1: Movement of POPs from source to sink (Nizzetto, et.al., 2023).

- Industrial chemicals in the form of plasticisers, additives or flame retardants (per- and polyfluoroalkyl substances (PFAS), Pentachlorophenol (PCP)
- By-products/Unintentional production from industrial and decomposition processes (Polychlorinated dibenzodioxins (PCDD), Polychlorinated Biphenyls (PCBs)

1.2 Environmental and Health Impacts of POPs

POPs are released into the environment from industrial processes, agricultural applications, or as by-products, in the form of gases or particles. This physicochemical behaviour enables long-range transportation in the atmosphere and oceans, as well as absorption by biological systems. Once they get deposited in the lipid tissues of an organism, they bioaccumulate and biomagnify along the food chain and transfer to higher organisms leading to sub-chronic and chronic effects on reproductive functions (Grandjean and Landrigan, 2014), on immune response, and act as carcinogens, with documented behavioural and cognitive impacts (Basterrechea, et.al., 2014).

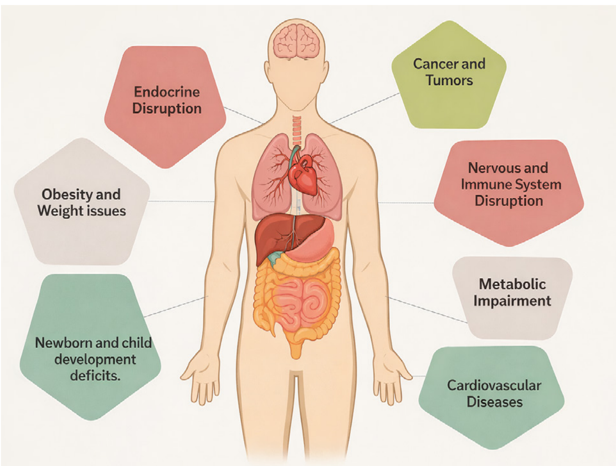


Figure 2: Human health impacts of POPs on exposure.

In human beings, POPs exposure has been linked to the development of metabolic (like diabetes), reproductive, neurological, cardiovascular, and developmental disorders **(Figure 2)** (Fitzgerald and Wikoff, 2014; Wahlang, 2018). Several POPs can penetrate the placental barriers, putting the growing foetus at high risk of cancer, benign tumours, neurological impairment, developmental abnormalities, and mortality. Infants are further exposed via breastfeeding, as POPs are transferred from the mother's milk. Limited fat deposits, developing organ systems, and the inability to metabolize toxins make the early developmental stages (foetus, infant, and child) critical windows of exposure (Damstra, 2002). Even if adverse effects are not immediately evident in children, they are more likely to develop disease later in life (WHO, 2010).

A study published by the American Chemical Society (2019), on Asian Indian immigrants in the United States found that the presence of DDT was directly linked to the risk of metabolic diseases, with dietary exposure and unsafe occupational environments in India, and identified as key contributing factors (Merrill, et.al., 2019). Similarly, in India, Kaur et.al. (2019) have found links between the increase in the incidence of breast cancer in young women and exposure to organochlorine pesticides (OCPs) like dieldrin, heptachlor, endosulfan, and HCH. High exposure to PFAS has also been linked with decreased fertility and fecundity in women in Singapore (Cohen, et.al., 2023).

Due to their persistence and semi-volatile nature, POPs have been detected across varied environmental matrices, including air, sediment, surface water (around major river systems), and even glaciers. According to Khuman and Chakraborty (2019), a study on the air-water exchange in the lower stretch of the transboundary river Ganga found OCPs such as hexachlorocyclohexane (HCH), dichlorodiphenyltrichloroethane (DDT) and endosulfan at concentrations 6 ng/L, 4 ng/L and 36 ng/L in surface water and 888 pg/m^3, 1689 pg/m^3 and 429 pg/m^3 in atmosphere, respectively. These findings signal potential risks to lower trophic-level organisms, particularly from DDT and lindane, within the Gangetic River ecosystem (Subramanian et.al., 2015).

Other planetary crises, such as climate change and global warming, are also greatly threatening the release of legacy POPs into vulnerable environments. Studies have identified Himalayan glaciers as major secondary contributors of PCBs and high-molecular-weight Polycyclic Hydrocarbons (PAHs). The proportion of glacial meltwater to downstream pollutant discharge in parts of Central Gangetic Plain has been estimated to range between 2% and 200% (Sharma, et.al., 2015a). In addition, 'new' POPs such as perfluorooctanoic acid (PFOA) and perfluorooctane sulfonate (PFOS) show mean cumulative discharges in the order of 240 and 210 g day $^{-1}$, respectively (Sharma et.al., 2015b).

Despite widespread environmental contamination, over 90% of human exposure to POPs occurs through contaminated food, particularly food of animal origin (Rodríguez-Hernández et.al., 2015). Up to 55 POPs compounds were detected in milk, yogurt, and Indian cottage cheese, with DDT congeners dominating the contamination profile, and DDE showing the highest prevalence (up to 54.8 ng/g.l.w. (gram lipid weight) in cottage cheese). Along with DDT, HCH, PCB, and PBDE have been detected in small concentrations across different milk products. However, the highest concentrations of POPs are still reported in fish fillets (p,p'-DDE, 813 ng/g.l.w. in fish). Poultry products (chicken egg and meat) and goat meat show lower concentrations than fish. However, HCB, PeCB, and γ-HCH are regularly detected in eggs and meat, with poultry meat showing the highest concentration of HCB (0.6-2.8 ng/g.l.w.) (Sharma et.al., 2021).

This contamination occurs primarily via human activities, particularly in the industrial and agricultural sectors. Even when the existing levels of POPs decrease due to regulatory interventions, they are often replaced by equally hazardous and persistent substitutes. For example, in South Korea, a country that has long banned PCBs, OCPs, and PFAS, there has been a slight increase in the environmental levels of certain POPs, resulting in continued transfer to infants through human milk (Rokni, et.al., 2023).

1.3 Status of POPs in India

To address this global concern, in 1995, the United Nations Environment Programme (UNEP) expanded its research and investigation on POPs with an initial focus on what became known as the **"Dirty Dozen"**. These were a group of 12 highly persistent and toxic chemicals: aldrin, chlordane, DDT, dieldrin, endrin, heptachlor, hexachlorobenzene, Mirex, polychlorinated biphenyls, polychlorinated dibenzo-p-dioxins, polychlorinated dibenzofurans, and toxaphene. Subsequently, in May 2001, 90 countries, including India, signed the United Nations treaty in Stockholm and agreed to eliminate the production, use, and/or release of 12 key POPs, the dirty dozen. The Convention also specified a scientific review process to enable the addition of other POPs of global concern. As of 2025, the Stockholm Convention's list comprises 37 chemicals.

India ratified the Stockholm Convention in 2006, which came into force on April 13, 2006, followed by the development of a National Implementation Plan (NIP) in 2011. The Government of India has since made significant efforts to place regulations on POPs to ban or restrict their production, use, import and export in the country. Simultaneously, strategies were drafted in the NIP to deal with the twelve POPs, or the "Dirty dozen".

The Government of India implemented the regulation of Persistent Organic Pollutants Rules, 2018, prohibiting the manufacture, trade, use, import and export of seven chemicals (Chlordecone, Hexabromobiphenyl, commercial octa-BDE, penta-BDE, Pentachlorobenzene, hexabromocyclododecane and Hexachlorobutadiene) (MoEF&CC, 2018). At present, India has banned the manufacture, sale, and use of 21 POPs, which includes 12 legacy (old) POPs and 9 newly listed POPs. Dicofol, an organochlorine pesticide, was the latest addition, banned alongside three other highly hazardous pesticides (HHPs) in 2023 (MoAFW, 2023). A detailed list of the legal status of each POP in India is given in **Table 1**.

Table 1: Regulatory status of POPs in India (INOPOL, 2025).

S. No	POPs	Category	Uses	Legal status in India
1.	Lindane (γ-Hexachlorocyclo-hexane)	Pesticides	Used as a broad-spectrum insecticide for seed and soil treatment, foliar applications, tree and wood treatment, and control of ectoparasites in veterinary and human health applications.	Banned for manufacture, use, import, export w.e.f. 25th March 2011and banned for use w.e.f. 25th March 2013. In rare cases, illegal use has been reported for agricultural pesticides and vector-borne disease control. Studies have detected isomers β-HCH and α-HCH in agricultural patches where lindane is applied for vector-borne disease control.
2	Chlordecone	Pesticides	Used to control banana root borer, as a fly larvicide, as a fungicide against apple scab, powdery mildew, rust mite, and for the protection of other plants. It can also be used in household products such as ant and roach traps.	National ban on the manufacture, use, import, export, and disposal of waste since 2018.
3	Decabromodiphe-nyl ether (decaBDE)	Industrial chemical	Used as an additive flame retardant with applications in plastics, polymers, composites, textiles, adhesives, sealants, coatings and inks. DecaBDE-containing plastics are used in housings of computers and televisions, wires and cables, pipes and carpets.	E-waste Management Rules (2016) allows the use of polybrominated diphenyl and polybrominated biphenyl ethers only up to 0.1% by weight in homogenous materials for electrical and electronic products. Suspected use in the textile, chemical, and electronics industries
4	Dechlorane Plus	Industrial chemical	A polychlorinated flame retardant used in electrical wires, cable coatings, plastic roofing materials, and connectors in televisions and computer monitors.	No laws, policies or legislations are currently in place to regulate these POPs. Use is suspected in the electronics industry.
5	Dicofol	Pesticides	An organochloride miticidal pesticide previously used on field crops, fruits, vegetables, ornamentals, cotton, and tea, etc.	All certificates of registration stand cancelled, and sale, distribution or use has been prohibited since 2023. Use is suspected in agriculture.

S. No.	POPs	Category	Uses	Legal status in India
6	Endosulfan	Pesticide	Previously used as an insecticide to control aphids, thrips, beetles, foliar feeding larvae, mites, borers, cutworms, bollworms, whiteflies and leaf hoppers on a variety of crops.	Banned by the Supreme Court on 13th May 2011; final disposal completed on 10th January 2017. Cases of cross-contamination have been observed in animal feed and fodder; current application on crops has not been reported.
7	Hexabromobiphe-nyl	Industrial chemical	Used as a fire retardant in acrylonitrile-butadiene-styrene (ABS) thermoplastic for construction business, machine housings and industrial and electrical products, and polyurethane foams used in auto-upholstery.	Nation-wide ban on manufacture, use, import, export, etc. since 2018. There are no reports of its use. Environmental concentration has not been reported.
8	Hexabromocyclo-dodecane (HBCDD)	Industrial chemical	A flame-retardant additive that provides fire protection during the service life of vehicles, buildings or articles. It is mainly used in expanded and extruded polystyrene foam insulation.	Banned for manufacture, use, import, export, etc. since 2018. Environmental concentration has not been reported. However, potential use in the automobile, chemical and textile industries cannot be ruled out.
9	Hexabromodi-phenyl ether and heptabromodiphe-nyl ether	Industrial chemical	Used as main components for commercial octabromodiphenyl ether production for flame retardant applications.	Banned for manufacture, use, import, export etc since 2018. No reports of use in the state. Environmental concentrations have not been reported yet.
10	Hexachlorobutadi-ene (HCBD)	By product	Commonly used as a solvent for chlorine-containing compounds, as a scrubber for chlorine-containing gases or to remove volatile organic components from gas; hydraulic and transformer fluid; and in production of aluminium and graphite rods. HCBD is also produced unintentionally during the manufacture of chlorinated aliphatic compounds.	Banned for manufacture, use, import, export, etc. since 2018. No reports of its use in the state. Suspected to be used in the chemical industry, electrical and automobile industries.

S. No.	POPs	Category	Uses	Legal status in India
11	Methoxychlor	Pesticides	Used to protect crops, ornamentals, livestock and pets against fleas and insects; intended as a replacement for DDT.	Not registered under the Insecticides Act 1968. Suspected use in agriculture and/or public health protection from vector-borne diseases.
12	Middle Chain Chlorinated Paraffins (MCCPs)	Industrial chemicals	Used as a binder, disintegrant and bulking agent	No laws, policies or Legislations are currently in place. India is a manufacturer and user of chlorinated paraffins. MCCPs have been detected in air, sludge and sediments in India and have been widely detected in PVC products, including consumer goods such as children's toys.
13	Pentachlorobenzene (PeCB)	Pesticides/ by product	Used in PCB products, in dye carriers, as a fungicide, a flame retardant and as a chemical intermediate e.g. previously to produce quintozene.	Banned for manufacture, use, import, export etc since 2018. Suspected use in the textile & dye and chemical industries.
14	Pentachlorophenol and its salts and esters	Industrial chemical/ Pesticides	Used as herbicide, insecticide, fungicide, algaecide, disinfectant and as an ingredient in antifouling paint.	Banned for use in agriculture (exact date not available) but is allowed for limited industrial purposes such as wood preservatives. Suspected use in leather and paper mill industries.
15	Perfluorohexane sulfonic acids (PFHxS)-related compounds	Industrial chemical	Used in aqueous film-forming foams for firefighting, metal plating, textile, leather and upholstery, polishing agents, and cleaning/ washing agents, etc.	No laws, policies or Legislations are currently in place for these POPs. Suspected use in chemical, textile, leather, paint, electronics, and semiconductor industres.
16	Perfluorooctane sulfonic acid (PFOS), its salts and perfluorooctane sulfonyl fluoride (PFOSF)	Industrial chemical	Commonly used as flame retardants and incorporated as salts into larger polymers. Also used in firefighting foams, carpets, leather/apparel, paper and packaging, coating and related additives.	No laws, policies or Legislations are currently in place for these POPs. Suspected use in the automobile textile, aerospace and semiconductor industries.

S. No.	POPs	Category	Uses	Legal status in India
17	Perfluorooctanoic acid (PFOA), its salts and PFOA-related compounds	Industrial chemical	Used widely in fluoroelastomers and fluoropolymers for non-stick cookware products, textiles, paper, paints, fire-fighting foams.	BIS announced adopted PFOS and PFOA and PFOA International Standards Organisation (ISO) benchmarks as India Standards (IS) on 28th September 2020, but it has not been notified yet. Used in chemical, textile, paper, and non-stick cookware manufacturing. It is also released into environment through incineration of fluoropolymers and fluoroelastomers.
18	Polychlorinated napthalenes	By product	Used in insulating coatings for electrical wires, storage batteries, capacitors, and lubricants.	Banned in printing ink for food packaging (since 2004) under the BIS standard IS 15495:2004 Suspected use in the electronics industry
19	Short-chain Chlorinated paraffins (SCCPs)	Industrial chemical	Used primarily in metalworking applications. Other uses include flame retardants or plasticizers in PVC, paints, adhesives, sealants in building, car carpet, textile, and other polymers.	No laws, policies or Legislations are currently in place for these POPs. Suspected use in the textile, chemical and electronics industries
20	Terabromodiphenyl ether and pentabromodiphenyl ether (commercial pentabromodiphenyl ether)	Industrial chemical	Used as a flame-retardant additive in consumer products.	Banned for manufacture, use, import, export, etc. since 2018. Suspected use in the automobile, textile, and electronics industries.
21	UV-328	Industrial chemical	Used a light stabiliser in plastics and other organic substrates.	No laws, policies or Legislations are currently in place for these POPs. No studies reported, suspected use in automotive, paints and ink industries.
22	Chlorpyrifos	Pesticide	This organophosphate pesticide is used to control foliage and soil-borne insect pests on food and non-food crops, including cereals, fruits, vegetables, and cotton. Also used in termite control, mosquito control, and public health pest management programmes.	Banned for use in Ber, Citrus and Tobacco since September 29, 2023. The Punjab and Uttar Pradesh state governments imposed a complete ban on the use of chlorpyrifos on basmati crops in 2025. Multiple studies have confirmed its use in India.

S. No.	POPs	Category	Uses	Legal status in India
23	Long-chain Poly-fluorocarboxylic acids, their salts and related compounds	Industrial chemicals	Used in the production of fluoropolymers, fire-fighting foams, and surface coatings. Also found in stain-resistant textiles, paper coatings, and non-stick cookware applications.	No laws, policies or legislations are currently in place for these POPs. No studies reported; suspected use in textile, paper and polymer manufacturing sectors.

Despite the continuous inclusion of newer POPs under the Stockholm Convention, there remains a significant lack of information in India regarding the presence of these hazardous chemicals in the environment, their use in consumer products, and their annual production volumes. For instance, although there is some evidence indicating the presence of perfluorooctanoic acid (PFOA) and perfluorooctane sulfonate (PFOS) in consumer products and environmental matrices in India, comprehensive data on their annual production and sector-wise consumption remain scarce. Similarly, while stockpile data are available for certain legacy POPs such as aldrin and chlordane, obtaining comparable information for the other POPs, including hexachlorobenzene, hexachlorocyclohexane, endosulfan, and lindane, continues to be challenging.

These data gaps represent major limitations that have contributed to inadequate monitoring, regulation, and enforcement of POPs pollution control in India. Consequently, to meet the country's commitments under the Stockholm Convention and to ensure effective consumer and environmental protection, the generation of comprehensive, transparent, and up-to-date data on the domestic use and distribution of POPs is essential. In this context, the present report aims not only to identify potential industrial users of POPs but also to map probable hotspots of POPs contamination across the country to mitigate the effects of legacy use.

1.4 Aims and Objectives of the Study

The hotspot mapping in Uttarakhand aims to identify and evaluate regions and sectors with a high potential for the use, release, or accumulation of POPs. Given the state's extensive industrial base and expanding agricultural activities, this study seeks to establish a clear understanding of where, how, and through which pathways POPs may be entering the environment. This would further assist regulatory authorities and policymakers in decision-making for pollution control, waste management, and public health protection.

The primary objectives of this study are as follows:

- Combine existing secondary data with field studies to determine potential hotspots for different POPs across key and emerging industrial sectors.
- Identify critical gaps in data availability, institutional practices, and policy frameworks that need to be addressed to reduce the risks of human and environmental exposure to POPs.
- Build knowledge and skills of relevant stakeholders to improve the monitoring, assessment, and management of POPs, and formulate actionable recommendations for reducing POPs releases, protecting communities and ecosystems, and informing policy and regulatory decision-making.

02 About Uttarakhand

2.1 Geography

Uttarakhand, a northern state of India, is situated in the foothills of the Himalaya. This landlocked state shares its state lines with Uttar Pradesh (south) and Himachal Pradesh (northwest), and its international borders with China (Tibet) to the north and Nepal to the east. The state covers an area of 53,483 square kilometers and encompasses a wide range of physiographic features, which can be categorised into three distinct elevation zones:

- The High Himalayas, featuring snowcapped peaks like Nanda Devi
- The Middle Himalayas, home to popular tourist destinations like Mussoorie
- The Bhabar and Terai plains, which are agriculturally significant regions along the southern foothills.

The entire state lies within the Himalayan Mountain system, with around 86% of its land area classified as mountainous and approximately 65% covered by forests (Census of India, 2011). The Ganga and Yamuna, two of India's most sacred rivers, originate in the Gangotri and Yamamori glaciers, situated in the Garhwal region of Uttarakhand. Other major rivers include the Alaknanda, Bhagirathi, Mandakini, and Kali, all of which contribute to the Ganga River system. The higher reaches of the state are marked by alpine glaciers and high-altitude meadows (locally known as Bugyals). The lower elevations comprise Terai-Duar savanna grasslands and moist deciduous forests along the border with Uttar Pradesh. Although large areas of lowland forests have been cleared for agriculture, fragmented forest patches still exist (Census of India, 2011). Forest cover in Uttarakhand accounts for 45% of the state's total geographical area (FSI, 2019). ranging from subtropical forests in the plains to alpine vegetation in higher altitudes supporting high levels of biodiversity. There are approximately 40 rivers in the state, including the Ganga, Yamuna, Bhagirathi, Alaknanda, Ramganga, Nayar, Kosi, and Sarayu, which constitute critical freshwater resources for both human populations and wildlife. Consequently, the production, use and improper disposal of hazardous compounds such as POPs, pose significant risks of contaminating surface water, soil, and biota, with potential adverse impacts on ecosystems and human health.

The state's steep slopes, fragile geology facilitate the long-range transport and downstream movement of contaminants. Regulatory agencies like the Uttarakhand Pollution Control Board (UKPCB) and research institutions conduct environmental monitoring activities. However, the complex Himalayan terrain, scattered settlements present challenges for comprehensive monitoring, enforcement, and remediation efforts.

2.2 Population

According to the Census of India (2011), Uttarakhand had a total population of

10,086,292 (approximately 1.01 crore), comprising 5,137,773 males and 4,948,519 females. The state accounts for about 0.83% of India's total population. The population density was recorded at 189 persons per square kilometre, significantly lower than the national average, due to its mountainous terrain and dispersed rural settlements. Dehradun, the state's capital, is the most populous district, followed by Haridwar and Udham Singh Nagar, which have also seen high rates of urbanisation and industrialisation.

The population of Uttarakhand is primarily rural (70%). It has a sex ratio of 963 females per 1000 males, indicating relatively balanced gender demographics. The literacy rate stands at 80%, with male literacy at 87% and female literacy at 71%, reflecting a gender gap that has been gradually narrowing through government education initiatives.

In recent years, Uttarakhand has been facing a steady decline in its youth population, due to migration, especially from remote hill villages to towns and cities within the state or to other parts of the country. This migration is primarily driven by the search for better employment opportunities, educational institutes, and healthcare facilities. As a result, several villages have experienced depopulation, posing socio-economic and administrative challenges for balanced and sustainable development of the region.

2.3 Economy

Uttarakhand's economy is diverse and rapidly evolving, marked by the interplay of agriculture, industry, tourism, and the services sector. Since becoming a separate state in 2000, Uttarakhand has made substantial progress in economic development through infrastructure improvement and industrial expansion. It has become India's 20th largest economy with its Gross State Domestic Product (GDP) projected to be Rs. 4.29 trillion (US $50.26 billion) in FY2026. Between FY2019 and FY2026, the GSDP of the state is estimated to increase at a compound annual growth rate (CAGR) of 8.8%. This represents a 13.5% growth from 2023-2024, when the GSDP was at Rs. 3,32,998 crores. The per capita income is also projected to reach Rs. 2,74,064, which is significantly higher than the national average of Rs. 2,00,162 (Uttarakhand Government, 2024) **(Figure 3).**

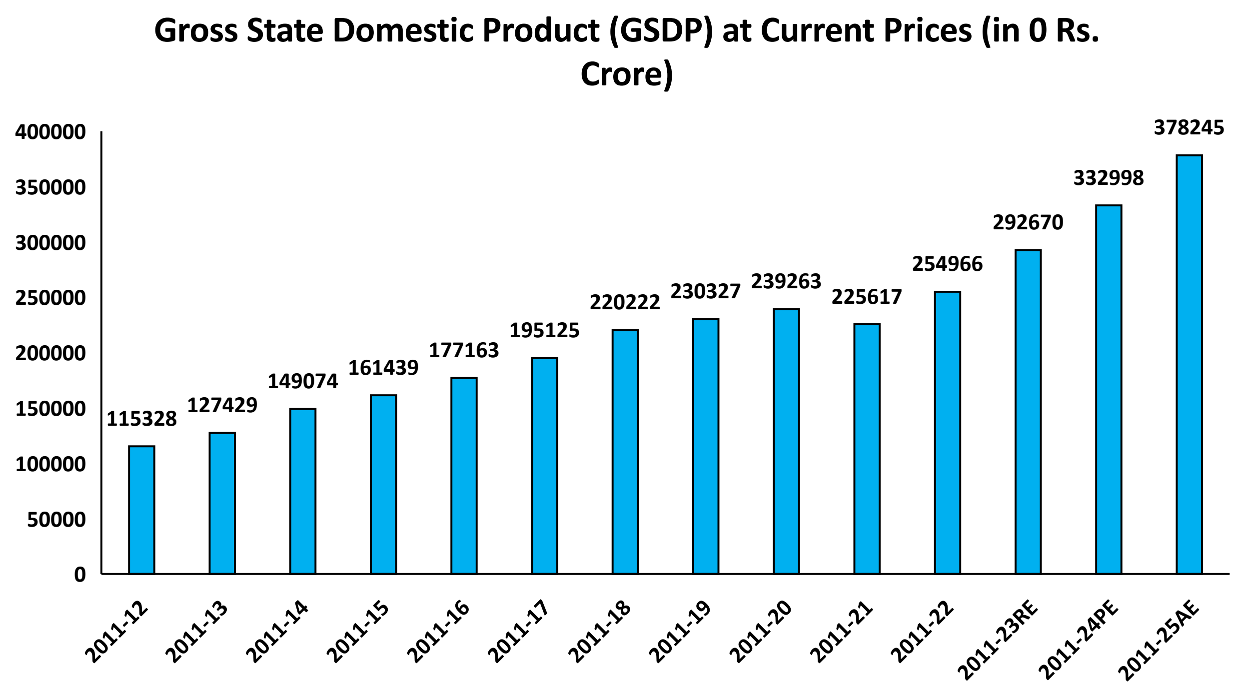
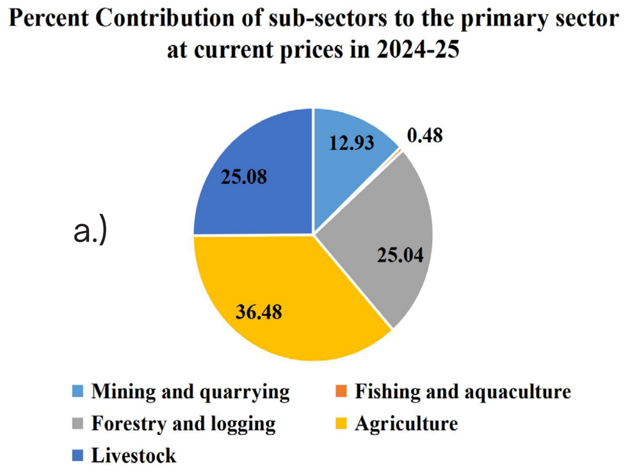


Figure 3: State Gross Domestic Product of Uttarakhand between 2011-2012 and 2024-2025 (Uttarakhand Government, 2024)



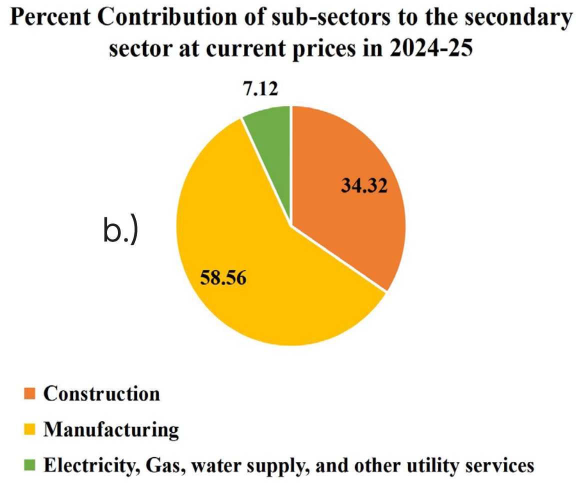


Figure 4: Contribution of primary (a) and secondary (b) sectors to the overall state GDP (Uttarakhand Government, 2024).

Agriculture is the largest source of income for the state, accounting for nearly 36% of the GSDP of the primary sector **(Figure 4a and 4b)**, followed by animal husbandry, forestry and logging, fishing and aquaculture, and mining sectors. In the secondary sector, manufacturing comprises more than half of the sectoral GSDP, followed by construction, electricity, and other utility services.

Uttarakhand is slowly emerging as a pivotal production hub for the automobile, pharmaceuticals, electronics, plastics, and textile industries. Various policies, such as the MSME Policy 2023, Mega Industrial Policy 2021, and Customized Incentive Policy, are currently in place to expand manufacturing capacity through the means of fiscal incentives, subsidised land rates, streamlined land allotment processes, and development of sector-specific industrial clusters. This trend can also be observed in the higher annual and decadal growth rates of the manufacturing and industrial sectors compared to traditional sectors, such as agriculture **(Table 2)**.

Table 2: Uttarakhand sectoral growth rates and decadal growth averages of growth rates (Niti Aayog, 2025).

Sector	Latest Annual Growth Rate (2022- 2023)	Average of Growth rates (b/w 2018-19 and 2022-23)	Decadal Average of Growth rates (b/w 2013-14 and 2022-23)	Decadal Average of Growth rate for India (b/w 2013-14 and 2022-23)
Agriculture	-3.0%	1.2%	0.7%	4.1%
Industry	7.9%	1.1%	4.2%	5.2%
Manufacturing	6.0%	-0.04%	3.4%	5.5%
Services	9.6%	4.4%	7.3%	6.6%
Gross State Value Added (GSVA)	7.7%	2.4%	5.0%	5.7%
Gross State Domestic Product (GSDP)	7.6%	2.2%	5.0%	5.8%

03 POPs-linked Industries In Uttarakhand

3.1 Automobile

Economy:

The automobile sector is one of the key drivers of the Indian economy, accounting for 7.1% of the country's GDP, and providing direct and indirect employment to 29 million people. With a current annual production of 25 million vehicles and export of 3.5 million vehicles, the automobile industry is currently worth US$74 billion. It is expected to grow to 300 billion by 2026 at a CAGR of 15%.

Uttarakhand has steadily emerged as a key hub for the automobile and auto-component manufacturing sector in northern India. The state hosts around 8–10 major automobile and component manufacturers, most of which are located in dedicated industrial estates notified by the state government. The combined vehicle production capacity of the three leading manufacturing companies alone accounts for approximately 2,575,000 units (Embassy of India Bangkok, Thailand, 2026).

The state also comprises a large network of ancillary units, which spurred the establishment of original equipment manufacturers (OEMs) and downstream processing activities. This industrial ecosystem, in turn, stimulated the growth of technical institutes and skill training programmes, promoting entrepreneurship among small and medium enterprises, and generating direct and indirect employment. Fuelled by a combination of strategic geographic advantages, conducive industrial policies, and proactive government initiatives, such as the Electric Vehicle (EV) policy, the sector is expected to experience accelerated growth in the coming years.

Geographical context:

Industrial estates such as Pantnagar in Udham Singh Nagar district and SIIDCUL (State Infrastructure and Industrial Development Corporation of Uttarakhand Ltd), Haridwar, have been central to the growth of the automobile sector due to their proximity to major economic zones and automobile clusters such as the Delhi National Capital Region (NCR) **(Figure 5).** Thus, automobile giants such as Tata Motors, Hero MotoCorp, Ashok Leyland, and Mahindra & Mahindra

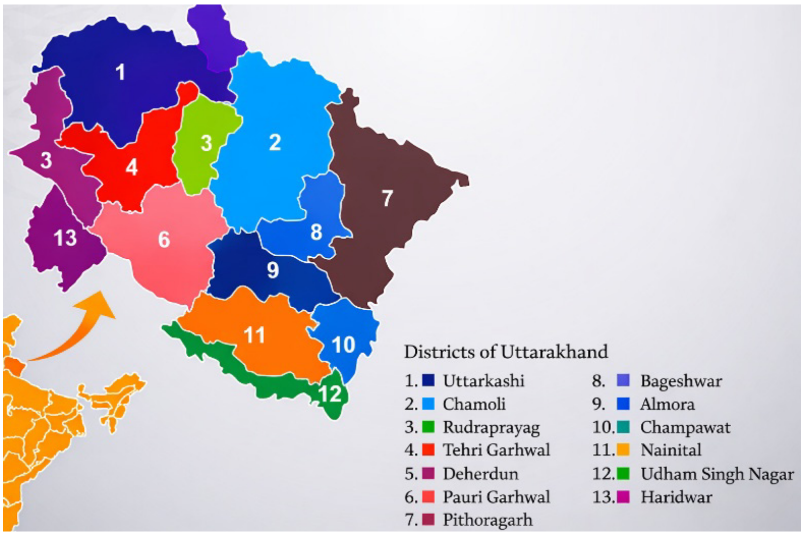


Figure 5: Leading districts for the automobile industry in Uttarakhand (Embassy of India Bangkok, Thailand, 2026)

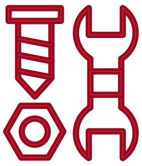
have established multiple manufacturing units across the Haridwar district and Pantnagar area in Udhamsingh Nagar district.

Tata Motors' facility at Pantnagar is a key manufacturing unit for light and medium commercial vehicles, while Hero MotoCorp's Haridwar plant is among its largest production facilities globally, rolling out millions of two-wheelers annually. Ashok Leyland, an Indian automobile manufacturing company, is located in the Pantnagar Industrial Area of Udham Singh Nagar district and is engaged in the manufacturing of commercial vehicles. OEMs have, in turn, attracted numerous tier-1 and tier-2 suppliers to the region, including Bosch, Minda Industries, Lumax, and Delphi-TVS, creating an integrated supply chain and boosting ancillary industrial development.

Sources of POPs:

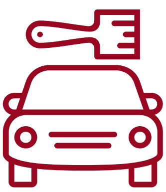
The automobile industry is one of the primary manufacturing sectors that utilises multiple POPs in the manufacturing of different vehicle components. Studies have shown the presence of brominated flame retardants such as polybrominated diphenyl ether (PBDE) and hexabromocyclododecane (HCBD) in interior components (Liu, et.al., 2019), chlorinated paraffin use in car tyres (Brandsma, et.al., 2019), and PFAS in vehicle parts, such as engines, power trains, brakes, and batteries (Drobny, 2007). PBDE-laden dust has also been detected in plastic component manufacturing facilities, posing risks to occupational health and indoor environmental quality (Alaee, et.al., 2003)

Due to this extensive use of POPs in manufacturing, potential hotspots may arise from emissions or discharges during both production and post-production phases. Key uses and potential sources of emissions include:

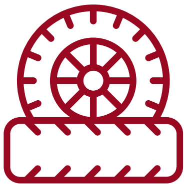


Metal processing and welding: Dioxins and furans can be unintentionally released during thermal processes, such as welding, cutting, or high-temperature treatment of metals, especially in the presence of chlorinated compounds (e.g., PVC coatings) (Institute of Medicine (US) Committee on the Implications of Dioxin in the Food Supply, 2003). The use of chlorinated degreasers or solvents for cleaning engines and metal parts may result in residual contamination and subsequent release of POPs. Material flow analysis, substance flow analysis, or life cycle assessment studies have also revealed the presence of PFAS compounds (Bulson et.al., 2023).

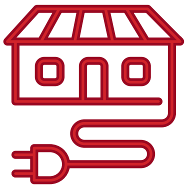
Plastic and rubber components: Thermoplastic and thermoset polymers used in dashboards, wiring insulation, seat cushions, etc., may contain brominated flame retardants, including POPs like PBDEs. During moulding, burning of plastics, accidental fires, or illegal waste burning, toxic substances such as dioxins and furans may be released (Fent et.al., 2020).



Paint shops and surface coatings: Automotive polymers such as polypropylene, polyurethane foams, polyvinyl chloride (PVC), and ABS (acrylonitrile butadiene styrene) are frequently treated with halogenated flame retardants, especially PBDEs and HBCD (hexabromocyclododecane). These additives are persistent, bio-accumulative, and toxic, and may be released during application or disposal processes.



Tyre components and rubber components: Components, especially tyres, seals, hoses, and bushings, are processed using sulphur-based vulcanisation and additives like chlorinated paraffins. Decomposition of these compounds during curing, combustion, tyre pyrolysis or accidental burning can lead to the release of PCNs, PCBs, PCDD/Fs, and chlorobenzenes, many of which are classified as POPs (Zhang, et.al., 2022).



Electric arc furnaces (EAFs): Used in automobile component manufacturing and metal recycling, EAFs can emit high levels of PCBs, PBDEs, and PAHs. A study conducted in Turkey in 2009 found stack emissions from EAFs averaging 611 ng/m^3 of PCBs, 165,000 ng/m^3 of PAHs, and 33 ng/m^3 of PBDEs, with higher concentrations noted when scrap preheating was involved (Odabasi, et.al., 2009).

3.2 Plastic Industry

Economy

The Indian plastic industry is a significant economic sector that employs more than 4 million people and comprises 85-90% small and medium enterprises, generating a total economic activity valued at Rs.3,00,000 crore (US$37.8 billion). Similarly, the Uttarakhand plastic industry accounts for about 47% of the GSDP. Industrial policies like the Uttarakhand Mega Industrial & Investment Policy, 2025, have targeted plastics as a priority sector, offering capital subsidies and fiscal incentives to attract investment and enhance production capabilities (Uttarakhand government, 2026). The establishment of dedicated plastic parks, notably the Sitarganj Plastic Park with 45 industrial plots, aims to strengthen cluster development, boost local value addition, and expand employment opportunities in the polymer and plastic conversion industries. Uttarakhand's plastics output caters to both domestic and export markets, with large manufacturers such as Nilkamal Ltd. (Dehradun) and Appl Industries Ltd. (Gadarpur) anchoring the sector (Uttarakhand Government, 2024).

Geographical context

Uttarakhand's plastic clusters are concentrated in industrial pockets such as Haridwar, Dehradun, and Udam Singh Nagar, particularly along the Pantnagar–Gadarpur axis (Uttarakhand Government, 2024). This location is strategic: the northern part of the state is mountainous and forest-rich (with over 80% mountainous terrain and 60% forest cover), which restricts large-scale industrialisation and necessitates environmentally sensitive planning. Consequently, industrial zones are established primarily in the southern plains, with transport links to major markets and raw material supply chains, thus minimising risks to ecologically sensitive mountain ecosystems. However, large-scale tourism and the influx of disposable plastics, especially in foothill areas and pilgrimage/tourist towns, exacerbate plastic waste management challenges, placing increased burden on the existing waste collection, recycling, and disposal infrastructure.

Sources of POPs

Manufacturing: Additives such as flame retardants, surfactants, and plasticisers (PCBs, PCDD/Fs) incorporated during production are a primary source of POPs. Improper handling or processing practices, including open burning and informal sector recycling, can release these chemicals into the air, water, and soil. Moreover, industrial waste from plastic production releases POPs via stack emissions, effluent discharges, and long-term leaching from disposal sites, contributing significantly to atmospheric and environmental contamination in India

Waste management: Pyrolysis-based plastic recycling units, like the one in Bhimtal (Nainital District), convert plastic waste into diesel and other by-products; however, it may result in unintentional release of POPs if not operated at appropriate temperatures or without adequate emission control systems. Elevated levels of PBDEs and PCBs have been recorded at Indian dumpsites with frequent waste burning, indicating that these toxic flame retardants persist and accumulate in the environment due to plastic waste mismanagement.

Informal sector: Segregation, smelting, and shredding of plastic waste in the informal sector, often conducted without adequate pollution control measures, result in the direct emission of dioxins, furans, and other POPs into the environment.

Environmental deposition can also occur via surface runoff and improper disposal of plastic waste, posing a particular risk in the fragile Himalayan ecosystem, and forested areas of Uttarakhand.

3.3 Paper and Pulp industry

Economy:

India's Paper Industry accounts for about 5% of global paper production. The estimated turnover is over Rs. 1,00,000 crore, and its contribution to the exchequer exceeds Rs. 5,000 crore. The industry provides direct employment to 500,000 persons, and indirectly to around 1.5 million. Most of the paper mills have been in operation for a long time and hence present technologies fall in a wide spectrum ranging from oldest to the most modern systems. The mills use a variety of raw materials, viz., wood, bamboo, recovered paper, bagasse, wheat straw, etc. In terms of share in total production, approximately 18-20% is wood based, 74-76% is based on recycled fibre, and 6-8% on agricultural residues. The geographical spread of the industry, as well as the market, is mainly responsible for the regional balance of production and consumption (IMPA, 2026).

The pulp and paper industry in Uttarakhand has a long and rich history, deeply intertwined with the region's natural resources and economic development. Over the years, Uttarakhand has emerged as a key player in the production of paper and cellulose-based fibre products, owing to its vast forest reserves, and abundance of raw materials (Bisht, 2023). In the early years, paper mills in Uttarakhand primarily relied on traditional, energy-intensive manufacturing processes with significant environmental impact. However, with the advent of stricter environmental legislation and growing market and compliance pressures, the industry underwent a transformative phase to adopt more sustainable practices. One notable aspect of the pulp and paper industry in Uttarakhand is its significant reliance on biomass-based energy. Pulp and paper mills in the state generate a significant portion of their energy needs from biomass-derived residues, such as black liquor, clean bark, wood chips, and sawdust.

Geographical context:

The paper and pulp industry forms a vital part of Uttarakhand's industrial landscape, particularly in the agriculturally rich and forest-abundant Terai region. This region covering Kashipur, Lalkuan, Jaspur, Sitarganj, and Roorkee, provides easy access to raw materials like wood, bamboo, and agricultural residue, making it an ideal location for paper manufacturing units (CPCB, 2018). The state houses over 50 paper mills, ranging from large integrated plants to medium-scale units (Rentech Digital, 2023). Prominent among them is Century Pulp & Paper in Lalkuan, one of the largest producers in India, manufacturing writing and printing paper, tissue, and paperboard, with a capacity exceeding 500,000 metric tonnes per annum (MTPA) and plans for further expansion. Other key players include Naini Papers, Cheema Papers, and Aadharshree Paper Mills, all of which contribute significantly to the local economy through employment generation, infrastructure development, and trade activity (Paper Index, 2024).

These industries benefit from infrastructural support provided by SIIDCUL, which has developed industrial estates in Rudrapur, Pantnagar, Haridwar, and Sitarganj, offering tax benefits, logistics support, and access to power and water. The strategic location of Uttarakhand, near key markets like Delhi-NCR and other northern states, further strengthens its industrial competitiveness.

Sources of POPs

The industry faces a range of challenges. Environmental degradation is a major concern, with reports of water pollution, deforestation, and air quality issues linked to traditional pulping methods and untreated effluents being discharged into local rivers. In areas like Lalkuan and Kashipur, residents have raised concerns over the discharge of chemical waste and its adverse effects on water sources and agricultural lands **(Figure 6)**. To address these issues, several mills have begun adopting sustainability measures, such as recycling wastepaper, use of non-wood fibres, implementation of water audits, and a shift to biomass-based boilers to reduce dependence on fossil fuels (Elion, 2023).

The paper and pulp industry is also a potential emitter of POPs through raw material processing, bleaching, dyeing, and waste disposal practices. One of the most significant sources is the chlorine-based bleaching of wood pulp, which leads to the unintentional formation of dioxins and furans (PCDD/Fs) (UNEP, 2019). In India, many mills, especially older or non-integrated units, have historically used elemental chlorine

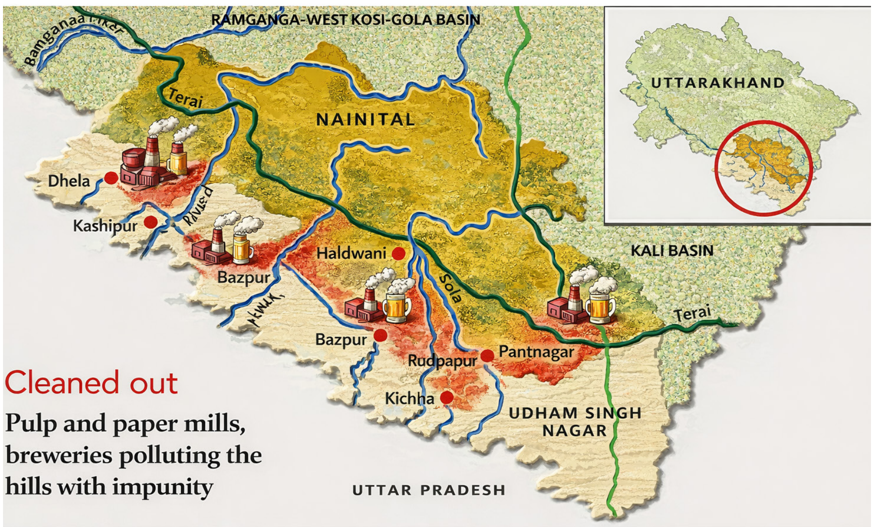


Figure 6: Map showing major mills and water bodies in Uttarakhand (Down to Earth, 2009)

bleaching (ECB), which releases PCDD/Fs into effluent streams (CPCB, 2015). Although some larger plants like Century Pulp & Paper have adopted elemental chlorine-free (ECF) or totally chlorine-free (TCF) processes, smaller units continue to pose risks due to inadequate effluent treatment systems, and outdated technologies.

Moreover, the use of optical brighteners, synthetic dyes, and additives in paper finishing stages may introduce other POPs, such as PFAS, commonly found in coated or water-resistant paper (Sharma et.al., 2023). Studies have reported elevated levels of PFAS in sludge from Indian paper mills, indicating their potential entry into terrestrial and aquatic food chains (Saini et.al., 2021). Additionally, combustion of biomass or fossil fuels in boilers and lime kilns used in pulping operations may emit polycyclic aromatic hydrocarbons (PAHs).

In Uttarakhand, the concentration of mills in the Terai region raises concerns about cumulative POPs discharge into nearby water bodies and agricultural lands, especially in the context of limited regulatory enforcement and environmental monitoring capacity (India water portal, 2023). As India is aligned with the Stockholm Convention on POPs and its regulatory framework, there is increasing pressure on pulp and paper units to adopt cleaner technologies, improve effluent treatment systems, and shift toward green chemistry alternatives for coatings, dyes, and sizing agents.

3.4 Textile industry

Economy

The textile sector is one of the oldest and most diverse industries in the country, with roots stretching back centuries. As of 2025, India ranks among the top five global exporters in several textile categories, with exports expected to reach US$100 billion. The sector itself contributes approximately 2% of India's GDP and about 11% of manufacturing Gross Value Added (GVA). The sector is slated to double its contribution to the GDP by the end of this decade, owing primarily to the rapid growth in technical textiles, sports textiles, and home textiles segments (IBEF, 2025).

The textile sector in Uttarakhand is relatively nascent compared to major hubs such as Gujarat, Maharashtra, Uttar Pradesh, NCR, Madhya Pradesh or Tamil Nadu. Nonetheless, it is an important centre for traditional textiles and wool production, which has a profound socioeconomic impact on rural livelihood development, employment generation, and women's empowerment (Dobriyal and Sarkar, 2024). Currently, its growth is driven primarily by the state's focus on artisan training, investor-friendly policies, geographical proximity to Delhi-NCR, and an increasing emphasis on sustainable and small-scale manufacturing.

In the Uttarakhand Industrial Policy, 2019, the Government of Uttarakhand identified the textile sector as a priority industry, which offers a suite of incentives including capital subsidies, SGST reimbursement, interest subsidies, and exemptions on stamp duty, aimed to attract both domestic and foreign investment (Government of Uttarakhand, 2019).

Geographical context:

Key industrial clusters are located in the plain regions of Sitarganj, Rudrapur, Kashipur, and Haridwar, where large-scale industrial infrastructure has been created by SIIDCUL. The Integrated Industrial Estate Sitarganj is a notable example, hosting several textile and garment manufacturing units, producing woven fabrics, readymade garments, hosiery items, and synthetic blends (SIIDCUL, 2024). These clusters benefit from shared facilities, common effluent treatment plants (CETPs), and streamlined licensing mechanisms, thereby reducing entry barriers for new businesses.

From a resource perspective, Uttarakhand does not produce significant quantities of cotton, but its location near the cotton-rich states of Punjab, Haryana, and Rajasthan provides accessibility to essential raw materials. Additionally, wool from sheep-rearing communities in hill districts such as Chamoli, Uttarkashi, and Pithoragarh supports local weaving and handloom activities.

Sources of POPs:

- **Dyes and pigments:** Synthetic dyes and pigments used in the textile industry contribute to POPs contamination as unintentional by-products, degradation products, or chemical impurities. PCBs, though banned under the Stockholm Convention, remain present as impurities in certain pigments, such as phthalocyanine blue/green, and diarylide yellow, allowing them to re-enter the environment through textile manufacturing and waste streams (UNEP, 2016).

  Multiple research studies from India demonstrate that dyeing clusters remain active sources of POPs. Industrial wastewater from Gujarat reportedly contains PCB congeners and azo dye metabolites linked to untreated discharges into rivers. National level reviews of textile effluents reported the presence of dioxins, furans, chlorobenzenes, heavy metals, and other POPs affecting soil and aquatic environments (Kishor et.al., 2021).

- **Flame retardants:** Flame retardants are widely used in textiles such as upholstery, mattresses, curtains, protective clothing, and children's sleepwear, to improve fire safety. Most commonly used chemicals were the brominated flame retardants, including polybrominated diphenyl ethers (PBDEs) and hexabromocyclododecane (HBCD), which are now classified as POPs under the Stockholm Convention (UNEP, 2017). These substances have been used in back coatings, polyurethane foam, and synthetic fibres, and continue to be released from legacy textiles through abrasion, washing, and degradation (Alaee, et.al., 2003).

  Inadequate disposal of flame-retardant-treated textiles, particularly open burning or low-efficiency incineration, further contributes to POP emissions, including unintentional dioxins and furans (Weber et.al., 2011). Strengthened regulation, adoption of safer alternatives, and improved waste management practices remain essential, as flame retardants such as HBCD and PBDEs are frequently detected in wastewater, sludge, sediments, indoor and outdoor dust and even human tissues, demonstrating their long-range transport and bioaccumulative nature (Hites, 2004; Covaci, et. al, 2006, 2006; Chakraborthy, 2022).

- **Waterproofing and stain-resistance agents**: Waterproofing and stain-resistant finishings used in textiles such as outdoor gear, uniforms, carpets, and upholstery commonly rely on PFASs, including PFOS and PFOA, which are listed under the Stockholm Convention due to their persistence and toxicity (UNEP, 2019). These chemicals are applied during finishing to impart water- and oil-repellence but are released throughout the product's lifecycle, from manufacturing and laundering to disposal, resulting in contamination of water, soil, and indoor environments (Wang et.al., 2014).

  In India, textile hubs in Tamil Nadu, including cities like Tiruppur and Karur, have been identified as hotspots for PFAS pollution (Hariharan, et.al., 2023). This contamination has been attributed to the discharge of untreated or inadequately treated textile wastewater, and leachates from improper disposal and washing of coated fabrics (Herzke, et.al., 2012). Consumer products can also act as a diffuse source, contributing to the presence of PFAS in household dust, sewage sludge, and landfill leachate.

- **Surfactants and detergents:** Surfactants and detergents are extensively used during scouring, bleaching, dyeing, and finishing processes. Textile detergents may contain perfluorinated surfactants (e.g., PFOS-based wetting agents), especially in older formulations, contributing to the broader family of PFAS regulated under the Stockholm Convention (UNEP, 2019). These fluorinated compounds are released during cleaning, drying, and effluent disposal, and have been detected in textile zones in Tamil Nadu and tanneries in Maharashtra (Gautam, et.al., 2025a).

- **Chlorinated solvents and carriers:** Chlorinated solvents and dye carriers such as trichloroethylene (TCE), tetrachloroethylene (PCE), dichlorobenzenes, and short-chain chlorinated paraffins (SCCPs) have long been used in disperse dyeing of polyester and nylon to enhance dye penetration. These compounds not only pollute industrial effluents and sludge but can also convert into highly toxic POPs under thermal stress or improper waste treatment conditions (Weber, et.al., 2011). Studies from textile hubs like Ahmedabad and Surat have detected SCCPs in wastewater and sediments, confirming ongoing discharge of these POPs (Ghosh, et.al., 2020).

  Monitoring by the Central Pollution Control Board (CPCB) has also reported PCE residues in treated textile effluents exceeding regulatory limits (CPCB, 2022). During high-temperature processing or disposal, these chlorinated chemicals can generate highly toxic dioxins and furans, contributing to air and soil contamination (UNEP, 2016). Their detection in finished textiles indicates potential release during use, washing, and end-of-life stages, underscoring the need for stronger regulation and safer alternatives in dyeing operations.

- **Plastic-based fibres and coatings:** Plastic-derived fibres and coatings in textiles, including polyester, nylon, acrylic, PVC-based synthetic leather, and polyurethane (PU), often contain additives such as brominated flame retardants (BFRs), phthalates, short-chain chlorinated paraffins (SCCPs), and PFAS, to enhance performance. Several of these substances are listed as POPs under the Stockholm Convention due to their persistence and toxicity (UNEP, 2019).

  In India, SCCPs have been detected in sludge and sediments near textile units in Gujarat (Ghosh, 2020), while PFOA and PFOS have been detected in the Noyyal River, linked to industrial activity such as textile factories that dump directly into the river (Sunantha & Vasudevan, 2016). Since these additives are not chemically bound to the polymer matrix, they can leach during product use, washing, incineration, and disposal, contributing to contamination (Gluge, et.al., 2020) of different environmental matrices. For example, studies from Chennai and Delhi have recorded PCBs, PBDEs, and SCCPs in dust and air samples near garment factories and dumpsites, suggesting volatilisation and open burning of plastic-coated waste as major emission pathways (Ramesh, et.al., 2021).

  Additionally, microplastics derived from synthetic fibres can adsorb and transport POPs like PAHs and PCBs into aquatic environments, enhancing their bioavailability and toxicity potential (UNEP, 2021). As plastic fibre-based materials dominate fast fashion and technical textiles, their additive burden and improper end-of-life treatment make them a growing source of POPs across urban and rural Indian landscapes.

- **Textile waste and incineration:** The disposal and incineration of textile waste are significant sources of unintentional POPs such as polychlorinated dibenzo-p-dioxins, polychlorinated dibenzofurans, polychlorinated biphenyls, and polycyclic aromatic hydrocarbons. These compounds are generated when textile materials containing synthetic polymers, dyes, flame retardants, and plastic-based coatings are exposed to high temperatures during incineration or open burning.

  In India, several studies have confirmed POPs emissions from textile waste burning - Ramesh et al. (2021) identified elevated levels of PCDDs, PCDFs, and PBDEs in ambient air and dust around informal textile waste incineration sites in Delhi and Chennai, suggesting incomplete combustion of synthetic fabrics and coatings. While Venkatesan and Swaminathan (2009) reported PCBs and PAHs in fly ash and soil around brick kilns and waste-burning zones in Tamil Nadu, where mixed textile waste is often used as supplementary fuel. Additionally, (Gautam et al., 2025b) highlighted the presence of POPs-bound microplastic in rural waste-dumping sites in Tamil Nadu, underscoring the dual threat of plastic and chemical pollution.

In India, where formal incineration capacity for textile waste remains limited, and open burning is still prevalent in urban and peri-urban areas, this pathway is particularly critical. Despite regulatory provisions under the Hazardous Waste Management Rules (2016), enforcement remains weak, especially in informal textile production and export-oriented zones. Therefore, improved segregation of textile waste, investment in non-thermal disposal technologies (e.g., material recovery, biodegradation), and strict controls on synthetic additives are critical to reducing POPs emissions from this overlooked but growing pathway.

3.5 Agrochemical industry

Economy

Agriculture is a critical sector for Uttarakhand's economy and rural society. It provides direct or indirect livelihood to more than 65% of the state's population. Although the sector showed steady economic growth, rising from Rs. 23,388.41 crore in 2019–2020 to Rs. 28,059.66 crore in 2024–2025, its share in the Gross State Domestic Product declined to around 9–10% due to faster growth in other sectors (Vista Academy, 2026). However, farming remains crucial for food security, especially in the hill districts where agriculture shape's cultural identity, sustains traditional practices, and supports local economies.

Aligned with the vision for sustainable agricultural transformation, Uttarakhand has simultaneously developed its agrochemical industry that includes both conventional chemical manufacturers and an expanding bio-pesticide sector. The state now hosts several agrochemical firms such as Euro Life Agro, Singh Associates, and Agriliv India Pvt. Ltd. located within the key industrial clusters in Udham Singh Nagar, Haridwar, and Dehradun. Moreover, policy reforms like the Uttarakhand Organic Agriculture Act, 2019, which prohibited the use of highly hazardous pesticides, such as acephate, atrazine, and carbendazim, and strengthened penalties for non-compliance, have opened new market opportunities for organic inputs and environmentally safer pest management solutions.

Geographical context

Uttarakhand has roughly 0.8 million hectares of cultivated land, representing 16% of the state's total geographical area. The net sown area varies widely between the hill and plain regions. In the plains districts of Haridwar and Udham Singh Nagar, net sown areas constitute 52.18% and 53.57%, respectively, of the total district area. On the other hand, in districts like

Uttarkashi (3.79%) and Chamoli (3.84%), have very limited cultivated land **(Figure 7)**. The small amount of net sown area in the state leads to limited agricultural production, and therefore, over the years, the farmers have to rely primarily on subsistence-oriented cultivation to fulfil their domestic requirements (Government of Uttarakhand, 2017).

The SIIDCUL-managed estates in Udham Singh Nagar, Haridwar, and Dehradun host numerous agrochemical and bio-input companies, including Euro Life Agro, Singh Associates, and Agriliv India Pvt. Ltd. This emerging bio-pesticide manufacturing base supports the state's transition toward sustainable and organic agriculture. However, variations in farmer knowledge and awareness, difficult terrain, and uneven access to extension services create pockets of improper pesticide use and increased environmental vulnerability.

Sources of POPs:

POPs are primarily used in the agricultural sector in the form of pesticides. While chemicals such as aldrin, DDT, lindane, dieldrin, and heptachlor are no longer legally used in Indian agriculture, they remain detectable due to environmental persistence and ability to migrate through soil, water, and air. Their presence in agricultural soils has been documented in northern India, particularly around historical storage and application sites, signalling long-term contamination risks (Sharma, et.al., 2019). Studies conducted in 2021 reported residues of OCPs like γ-HCH (lindane) in different plant species, including stems (581.14 ng/g in paddy and 585.82 ng/g in tapioca) and leaves (583.3 ng/g in tomato), with concentrations 10–50 times higher than the permissible Maximum Residue Limits (MRL, 0.01–0.1 mg/kg) (Chandra, et.al., 2015).

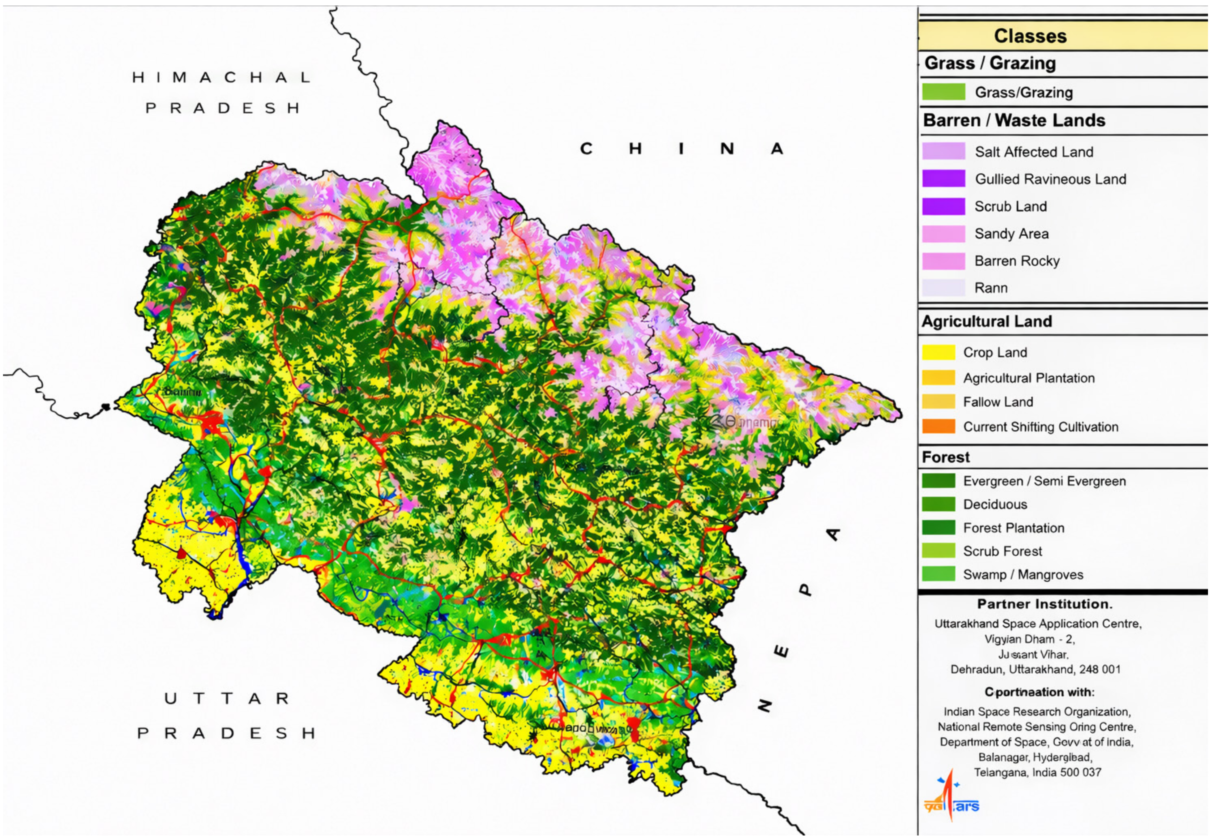


Figure 7: Ecological land use in Uttarakhand (Gairola et, al, 2025)

Currently, chlorpyrifos remains the only pesticide active ingredient listed under the Stockholm Convention still permitted for agricultural use in India, despite mounting evidence of its toxicity and persistence. It is permitted to be applied to rice, beans, gram, sugarcane, cotton, groundnut, mustard, brinjal, cabbage, onion, apple, ber, citrus and tobacco crops, targeting pests, including termites, stem borers, aphids, jassids, whiteflies, plant hoppers, etc., and mosquitoes in public health programmes (NPCI, 2011).

In Uttarakhand, while the use of highly hazardous pesticides is declining due to the Organic Agriculture Act, 2019, formulation and handling units located in the SIIDCUL estates may still be associated with unintentional POPs formation and release. Unintentional POPs, such as hexachlorobenzene (HCB) and PCDD/Fs, can form during high-temperature processes or waste incineration involving halogenated compounds as observed in areas surrounding industrial clusters (e.g., Baddi in Himachal Pradesh) (CEMC, 2020).

Furthermore, improper disposal of pesticide containers and outdated stockpiles can leach POPs into the surrounding surface and groundwater, as observed in environmental samples collected near pesticide warehouses in Dehradun and Udham Singh Nagar (Tripathi, et.al., 2022). The Central Integrated Pest Management Centre (CIPMC) in Dehradun has documented cases of pesticide misuse and poor waste handling, emphasising the need for stricter monitoring of hazardous residues (DPPQS, 2023).

3.6 Electronics and E-waste

Economy:

India is a popular manufacturing hub of electronics items, with domestic production expanding from US$29 billion in FY2015 to US$101 billion in FY2023. The electronics sector contributes around 3.4% of the country's GDP and is one of the primary exporters to the USA, UAE, Netherlands, UK, and Italy. The Government of India committed nearly US$17 billion to four production-linked incentive (PLI) schemes, covering semiconductor and design, smartphones, IT hardware, and electronic components (IBEF, 2026).

Driven by rapid infrastructural growth, government policy incentives, and the presence of major manufacturers, Uttarakhand is emerging as a major electronics manufacturing hub. The state presently hosts 300+ manufacturing units, and is home to defence electronics establishments, including Bharat Electronics Limited, Opto Electronics and Defence Electronics Laboratory. Uttarakhand has also been successful in establishing the EMS (Electronics Manufacturing Services) and OEM (Original Equipment Manufacturer) ecosystems (Government of Uttarakhand, 2025).

To support the sector, Uttarakhand has implemented forward-looking policies such as the IT and ESDM Policy 2019 and the Electric Vehicle (EV) Policy 2019, which provide fiscal incentives, concessional land, capital subsidies, and tax exemptions to attract electronics and EV component manufacturers (Government of Uttarakhand, 2018; Government of Uttarakhand, 2019). Moreover, the Industrial Policy of 2023 strengthens incentives for anchor enterprises and emphasises the development of electronics system design and manufacturing (ESDM) clusters (Government of Uttarakhand, 2023). Capacity building is supported by training centres like the Electronics, Service and Training Centre, Ramnagar, the Centre of Excellence for Drone Tech, Dehradun, and the Drone Application Research Centre, Dehradun.

With rising consumption and production rates, e-waste recycling in Uttarakhand has also been gaining momentum. The state complies with the national E-Waste Management Rules, 2022, which require all manufacturers, producers, refurbishers, and recyclers to be registered with the CPCB portal. As of FY2024, the state had seven registered recyclers and processed

113,562.55 MT of e-waste, down from 134,255.106 in FY2023 (MoEF&CC, 2025).

Despite progress, the state still faces many challenges; it currently utilises only about one-third of its e-waste recycling potential (Sudhanshu, et.al., 2025). The informal sector still plays a dominant role, posing environmental and economic risks if not mainstreamed effectively into formal systems. Nonetheless, collection rates and recycling efficiencies have improved, in line with national trends. Recent data suggests that over 70% of e-waste is now being processed in the formal sector nationwide, indicating a positive impact in Uttarakhand (MoEF&CC, 2025).

Geographical context

Key electronics manufacturing hubs have emerged in Pantnagar, Haridwar, Rudrapur, and Selaqui, largely due to the development of industrial estates by the SIIDCUL. The state has a dedicated electronics cluster, called 'Electronic Park' in Kashipur, spanning 133 acres, which offers facilities tailored for electronics and electrical industries (Government of Uttarakhand, 2022). Companies like Dixon Technologies, one of India's leading electronics manufacturing services firms, operate large-scale facilities in Dehradun, producing LED televisions, washing machines, and smart devices. Similarly, Micromax has set up an advanced manufacturing unit in Rudrapur with a surface-mount technology (SMT) line capable of producing over 1.6 million devices per month, including smartphones and televisions (Micromax Informatics, 2022). Other notable players such as Havells, ABB, Bajaj Electricals, and Schneider Electric also maintain manufacturing operations in Haridwar and Pantnagar, contributing to the state's industrial output (Zonora, 2023). In line with the sectoral expansion goals, the state plans additional clusters in Udham Singh Nagar, Sitarganj, and multisectoral parks in all districts (Government of Uttarakhand, 2022).

Major e-waste recyclers operate in Haridwar (E-waste Recyclers India) and Dehradun (BRP Infortech). A notable addition to this network is a commercial-scale recycling plant for lithium-ion batteries and electronic waste in Sitarganj, Udham Singh Nagar, established through a partnership between the Technology Development Board (TDB) and Remine India Private Limited. Updated lists of authorised facilities are periodically updated and published by the Uttarakhand State Pollution Control Board.

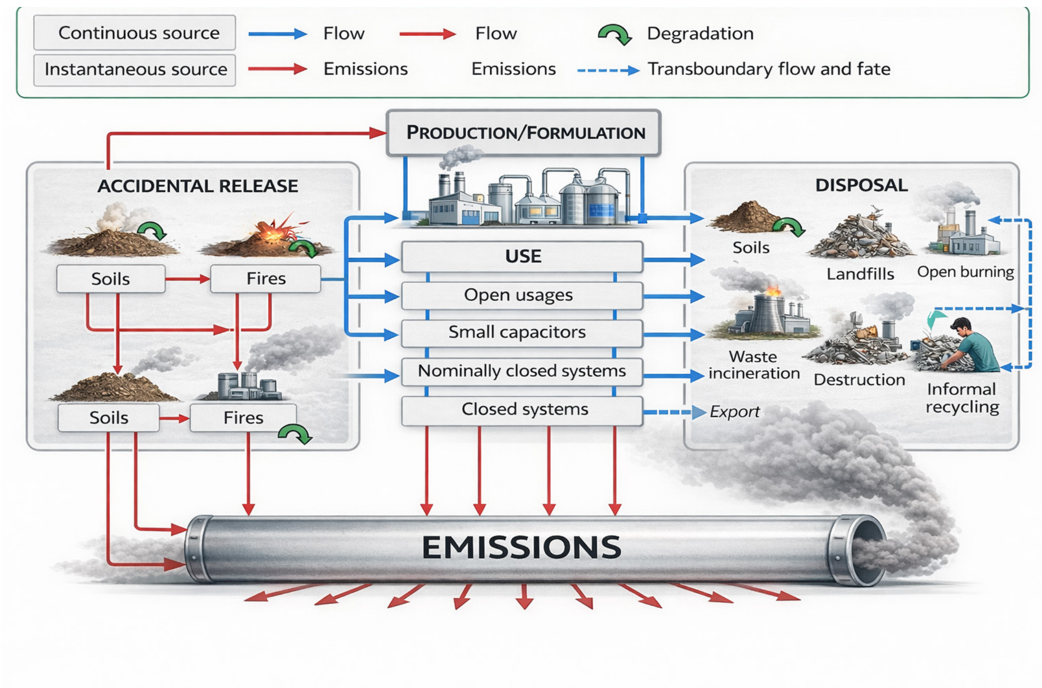


Figure 8: Emission scenarios for selected PCBs accounting for transboundary movement of e-waste from OECD to non-OECD nations (Breivik et al., 2015)

Sources of POPs:

The electronics industry, through manufacturing, informal recycling and disposal, is a significant source of intentionally and unintentionally released POPs. Among the most prevalent are polybrominated diphenyl ethers (PBDEs), used as flame retardants in printed circuit boards, plastic casing, and cables. Although many PBDEs, such as penta-BDE and octa-BDE, are restricted under the Stockholm Convention, they continue to be detected in legacy products and e-waste, especially in developing countries like India, where informal dismantling processes are prevalent (Tiwari et al., 2021). Polychlorinated biphenyls (PCBs), historically used in capacitors, transformers, and dielectric fluids, are released from older equipment during recycling or open burning. High soil and air contamination have been reported in informal e-waste hubs, such as Seelampur and Moradabad **(Figure 8)** (Ghosh et al., 2019).

Polychlorinated dibezo-p-dioxins and dibenzofurans (PCDD/Fs) are not added deliberately but are formed as byproducts during thermal processes, such as soldering and open burning of chlorinated materials, etc. Elevated concentrations have been detected around informal e-waste processing sites in Delhi, suggesting ongoing U-POPs formation (CSE, 2014). Furthermore, the growing use of PFAS in semiconductor manufacturing, photoresists, and anti-reflective coatings contributes to contamination through industrial wastewater discharges. Wang et al., in 2017, detected PFAS in water bodies and sludge near electronics and plating industries in India and East Asia, reflecting global concerns over their persistence and bioaccumulation.

Other POPs present in electronic waste streams include hexabromocyclododecane (HBCD) and short-chain chlorinated paraffins (SCCPs) that are used in high-impact polystyrene casings and cable coatings, respectively. SCCPs, now listed under the Stockholm Convention, have been detected in the vicinity of plastic recycling industries in northern India (Sharma et.al., 2020). Moreover, combustion and high-temperature processing during circuit board etching or plastic extrusion release polycyclic aromatic hydrocarbons (PAHs), contributing to ambient air and soil pollution (Rajender et.al., 2015). Another emerging concern is the use of UV-328, a UV stabiliser in plastic and rubber electronics components, which has been recently added to the Stockholm Convention due to its detection in wildlife and sediments across regions, with preliminary evidence from India (NIE, 2023).

Global studies further validate the significant contribution of the electronic industry in releasing POPs into the surrounding environmental matrices. Guiyu, China, one of the world's largest informal e-waste recycling sites, was found to have soil concentrations of deca-BDE (BDE-209) exceeding 1,100 ng/g due to open burning and manual dismantling, while levels as high as 17,587 ng/g were reported at Nigeria's Alaba market (Besis and Samara, 2012; Tue et.al., 2016). A multi-country review revealed PFAS contamination in groundwater near fluorochemical plants in China, with PFOA levels ranging from 44 to over 11,000 ng/L, substantially above international drinking water safety limits (Wang et.al., 2017). In the United States, airborne emissions of legacy and emerging PFAS have been recorded near fluoropolymer manufacturing sites, contaminating particulate matter and entering the surrounding ecosystem via atmospheric deposition (Xiao et.al., 2023). Additionally, PFAS contamination has been reported across air, soil, water, dust, and human serum samples near electronics facilities in Asia and North America, suggesting widespread dispersal from both primary manufacturing and downstream waste treatment activities.

04 Recommendations

India has ratified the Stockholm Convention and is currently updating the NIP to minimise risks associated with POPs. The State agencies, particularly SPCB, play a crucial role in managing POPs at both upstream and downstream stages. The state is emerging as an important industrial hub, with industrial estates in Haridwar, Dehradun, and Udham Singh Nagar hosting agrochemical, automobile, textile, and e-waste recycling units. These activities raise concerns about the presence of several POPs, including per- and polyfluoroalkyl substances (PFAS) and brominated flame retardants (BFRs), as well as the unintentional release of POPs, such as dioxins and furans, from industrial processes and waste-handling practices. In view of the persistence of POPs and the vulnerability of the state's diverse ecosystems, the establishment of adequate safeguards is essential to minimise associated risks and protect the wider environment.

1. Assessment of pollution sources

- The state can develop a comprehensive state-level POPs inventory covering industrial estates (e.g., SIDCUL areas), agricultural zones, and e-waste clusters, including the mapping of legacy stockpiles and unintentional releases such as dioxins, to identify contamination hotspots.
- Conduct baseline human health surveys in and around identified hotspots, including biomonitoring of vulnerable populations.
- Engage local research institutions in environmental monitoring and in the development and deployment of sustainable remediation technologies.

2. Monitoring and Surveillance

- Strengthen state-level infrastructure for POPs management by establishing dedicated POPs monitoring laboratories.
- Ensure continuous monitoring of soil, surface water, groundwater, and biota in industrial and surrounding areas to assess environmental contamination and associated public health outcomes.
- Strengthen monitoring mechanisms for POPs contamination in food and drinking water, particularly in rural and high-altitude areas, and integrate advanced tools such as remote sensing to track bioaccumulation in livestock and aquatic species.

3. Information Dissemination

- Conduct periodic training and capacity-building programmes for regulatory departments and officials on POPs risk management, monitoring tools
- Establish a structured system for disseminating information and raising public awareness about POPs and their associated public health and environmental risks.

4. Adoption of BAT and BEP

- Promote the adoption of Best Available Technologies (BAT) and Best Environmental Practices (BEP) in key industrial sectors associated with the use, generation, or release of POPs.
- Encourage sustainable agricultural practices, including Integrated Pest Management (IPM) and substitution of Highly Hazardous Pesticides with environmentally safer alternatives.
- Integrate POPs management considerations into other state-level action plans, including climate change, environmental protection, and related sectoral policies.

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