Quantification and Health Assessment of Microfiber Contamination in Selected Textile Processing Units of Punjab, Pakistan

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ABSTRACT: Microfibers (MFs) constitute small pieces of plastics produced as byproducts during the production processes of commercial products and further degradation of bulk polymers. Environmental impacts, as well as the hazard to biodiversity, are both threatened by MF pollution. Microfibers with vast utilization in the textile sector pose severe environmental and worker's health concerns in many units of Punjab. This study aims to assess the microfiber's exposure and health risk in various textile industries in Punjab. Air and water samples were taken from inside and outside of selected textile industries in the Punjab province. Fourier Transform Infrared (FTIR) Spectroscopy was also used for the identification of microfiber polymers. Hazard index was calculated for over health risk of microfiber pollution. The results revealed that the highest concentration of microfibers was detected in Sheikhupura's textile industries followed by Lahore. Among all the sections of textile industries, knitting section exhibited the highest microfiber detection /concentration. Hazard index values for air exposure in all the sections were below 1, except knitting section. Knitting section exhibited hazard index value of 1.26, indicating a potential health risk. Hazard index for wastewater and drinking water remained below 0, suggesting safe exposure levels. FTIR analyses revealed the type of MFs such as polybutylene terephthalate (3.13%), polypropylene standard (28.13%), polyisobutylene (12.5%), vinyl chloride (12.5%), polyethylene terephthalate (31.25%), low density polyethylene (3.13), and polyesters (9.38%). The most widespread were polypropylene and polyethylene terephthalate, the ones mostly utilized in various daily-use products all over the globe.

Key words: Microfiber, Health Risk Assessment, Textile Industry, Hazards, Environmental Exposure

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INTRODUCTION

The textile sector, a source of fabrics, has a large scale of industrial output as well as gives employment to millions of people, contributing a major part to global economic activity. However, the sector is also a major source of environmental pollution and emits vast amounts of microfiber in particular (Henry *et al*., 2019). It is presumed that microfibers play a crucial role in the creation of micro pollution and their accumulation in the environment. Microfibers are chemically modified polymeric fibrous particles, with an average length-to-width aspect ratio of 3:1 and <5 mm diameter (Athey *et al*. 2021).

Microfibers refer to tiny filaments shed into ecosystems during the manufacture and laundry processes of synthetic (or, less commonly, natural) fibers (Prata *et al*., 2020). The main origin of these contaminants is synthetic textiles that produce microfibers throughout their life cycle, such as polyester and polyamides, among others. Fabrics lose fibers to the environment with mechanical and chemical abrasion occurring during laundering (Falco *et al*., 2019). Due to their small size and tenacity, these particles have been deemed as new pollutants circulating in soil, water, and air environments (Dris *et al*., 2016).

Microfibers might be made from any number of materials. Synthetic materials include but are not limited to, polyester, nylon, and polyamide, upon which the majority of textiles are made (Exchangebert *et al*. 2021). Synthetic fibers account for roughly 14% of global plastic production (Gavigan *et al*., 2020; Athey *et al*., 2021). In the case of textiles, the microfibers are either discharged into wastewater or released in dryers. Three primary routes allow microfibers to reach the environment: wastewater releases from textile production and laundering, atmospheric releases from textile production and terrestrial releases from improperly disposed-of textiles that release microfiber straight into the soil (Siddique *et al*., 2021; Sources of microfibers and their distribution in the environment (2022). Home sewage systems and wastewater treatment plants (WWTPs) are the two primary routes for discharging textile microfibers into the environment (Ali *et al*., 2024; Acharya *et al*., 2021). Since each load of laundry releases a unique combination and volume of microfibers, some types will correlate with the clothes washed in that batch. Overall, a range of 700,000 to 1.5 million to 7 million microfibres are estimated to be produced per wash (Napper *et al*., 2016; Sources of microfibers and their dispersal in the environment (2022). Microfiber levels in effluent can reach 100 -1000 of fibers per liter, according to wastewater studies in the textile industries. Conventional treatment methods frequently fail to catch these particles allowing them to permeate national water bodies (Akyıldız *et al*., 2025).

For the past 10 years, microfiber pollution from textiles has continued to be a growing concern. These microfibers are considered microplastics which originated from the synthetic fibers of textiles and their apparel (Rathinamoorthy *et al*., 2024). Like the larger plastic chunks, microplastics are made up of many types of polymers like polystyrene and polyethylene. As micro-sized fragments, some of those are released into the environment others occur as a result of large plastic pieces breaking apart (Weis *et al*., 2022). Research studies indicate that while plastic and synthetic materials are a large constituent of microfibers in environmental samples, semi-synthetic (e.g., rayon) and natural (e.g. wool and cotton) materials contribute to anthropogenic sourced microfibers as significantly or more than plastic fibers, based on various global sampling surveys (Athey *et al*., 2021; Athey *et al*., 2022). Recently, it has been reported by (Bucci *et al*., 2020) that the toxicity of microfibers is greater than that of non-fibrous particles such as spheres, pieces, and pellets.

Textile auxiliaries, dyes, and finishes can also have an impact on the biodegradation of natural fibers in the environment (Lykaki *et al*., 2021; Weis *et al*., 2022). Worse, the microfibers are detected in various foods and beverages consumed by humans such as beer, shellfish (oysters), honey, blue mussels (Mytilus edulis), and in chicken through transitive of our food web which turns out to be a more serious situation ever before (Rathinamoorthy *et al*., 2021). Textile microfibers may have impact on gastrointestinal health in humans, including cancer, in accordance with occupational epidemiology (Taptiklis *et al*., 2025). Bronchitis, asthma, coughing and chronic lung inflation are among the respiratory problems that can result from inhale fibers which are frequent among textile workers and those who live closed to industrial zones (Suran, 2018). Long term exposure to textile dust and fibers has been associated with occupational lung disorders including byssinosis (Periyasamy, 2023). Ingestion of microfibers through tainted food, water and seafood can lead to gastrointestinal accumulation, changing the gut flora and perhaps leading to digestive problems (Jayavel *et al*., 2024). According to recent research microfibers may also cause inflation oxidative stress and cytotoxicity in critical organs including the liver, kidneys an even the brain after penetrating tissues (Li *et al*., 2023).

In spinning and weaving, dying, and finishing processes textile industry workers are the most exposed to exposure of microfiber (Belzagui *et al*., 2019). Very little research has been done on occupational exposure to microfibers in textile industries despite microfiber pollution being recognized more and more in environmental contexts (Hernandez *et al*., 2017). Most of the research is on microfiber contamination in water bodies which leaves a big knowledge gap on exposure and effects on textile unit workers. Pakistan’s economy is greatly dependent on the textile sector, especially in Punjab where there is thousands of textile units Pakistan being a major textile-producing country is a perfect example for research on occupational exposure as the country’s textile industries are a source of known microfiber release into the environment and indoor air (Belzagui *et al*., 2019). As Pakistan’s Manchester, Faisalabad is a major industrial hub where microfiber pollution is seen both inside and outside textile units. The workers in multiple production processes complete their tasks including spinning, weaving, and dyeing textiles, and are more prone to microfibers exposure (Yasir *et al*., 2019). According to reports, microfiber accumulation increases worker exposure and environmental pollution in these workplaces (Liu *et al*., 2019). Most of the studies represents asbestos, mineral fibers and glass fibers contamination in various workplaces. As synthetic textiles are widely used there is a knowledge gap on the health problems caused by textile workers’ excessive exposure to microfibers.

This study will quantify microfibers in the air and water of textile units to fill the information gap on microfiber pollution. The results will help develop strategies to reduce microfibers and improve human and environmental health. The objective of this research is to assess the contamination airborne microfibers and health risk in various section of textile industries located in province Punjab.

MATERIALS AND METHOD

Study area: The study targeted four textile manufacturing sites in Punjab, Pakistan including Lahore, Faisalabad, Kasur, and Sheikhupura. Lahore, positioned at approximately 31.5497° N latitude and 74.3436° E longitude, is a major urban center with rapid industrial growth affecting its surrounding semi-rural areas. Kasur, located at 31.1155° N latitude and 74.4467° E longitude, is known for its leather industry, leading to significant industrial pollution impacting adjacent agricultural lands. Sheikhupura is located at 31.7131° N, 73.9783° E and is known for its steel, textile, and chemical industries. Faisalabad, situated at 31.4504° N, 73.1350° E, is a major hub for textile manufacturing, often referred to as the "Manchester of Pakistan. All these cities play a crucial role in the country’s industrial economy with significant contributions from agriculture-based and manufacturing sectors. Therefore, these locations are ideal for a closer study into microfiber discharge because they serve as significant hubs of the textile industry.

Table 1: Characteristics of textile industries in selected cities of Punjab.

Sr.	Cities	Characteristics	References
1.	Lahore	Too many important textile-based industries	Alvi *et al*., 2016
2.	Kasur	Provide working of small industries	Ali *et al*., 2022
3.	Faisalabad	Important textile industrial center where many large and medium-sized enterprises exist	Faisalabad Industrial State (2020)
4.	Sheikhupura	Several medium to large textile plants, used a variety of unit sizes and different production techniques.	*Ayesha Group of Companies (n.d)*

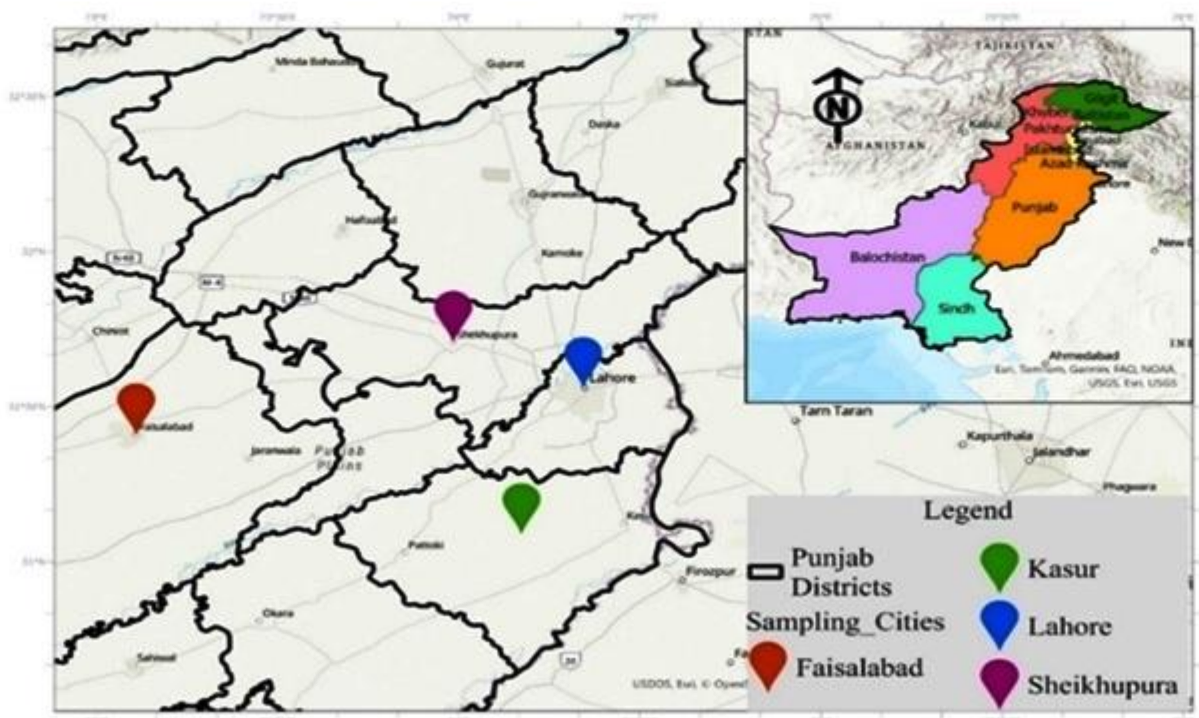


Figure 1: Study area map of selected cities chosen for microfiber detection in textile industries

Data collection: Samples from the selected textile manufacturing sites were taken for air and water monitoring for microfiber emission. For sampling airborne particles, a portable air tester was used in collecting air samples. A total of 250 samples were collected from various textile units, including spinning, knitting, dyeing, and weaving. A number of 70 drinking water samples were also taken for further quantification of public health risk. This sampling strategy has helped us include in our record the variations in the microfiber's emissions of the textile plants in Punjab, Pakistan, compared to each of their respective units. Water samples were collected in half-liter bottles, whereas, air samples were collected through filters.

Samples of water were collected from some discharge points to gauge the number of microfibers emitted during the process from textile processing units into the water. The whole process cycle was properly covered. There were three textile processing units were selected for sampling form Lahore district, mainly from knitting, printing, stitching, dyeing processes and open areas. Similarly, samples were collected from Kasur's 2 distinct textile industries. Moreover, samples were collected form 2 textile units of Sheikhupura and 1 textile unit of Faisalabad. After ten minutes were taken between the gap samples of water from the effluent of the sector as well as from drinking water stations. Microfibers in a sample were measured by using Petri dishes after removing the aluminum foil, setting the microscope on its highest clarity level, and zooming them out to 10.

Instrumentation and analytical methods: Microfibers were identified and measured with the use of a high-resolution optical microscope. Of all the microscopes that one is likely to encounter, it is the high-resolution optical microscope due to the extraordinary imaging capability and cutting-edge features that make it perfect for precise analyses that are necessary in this kind of study. Datasheet was used to identify and record micro fibers. Fourier Transform Infrared Spectroscopy (FTIR) was utilized to identify functional groups and describe the surfaces of nanoparticles. The composition and comparison made on twenty of the twenty-four samples through FTIR analysis. Descriptive statistics was set forth using Microsoft Excel while graphs were created with Origin 2016. Mapping was done using Arc Map 10.2.

Chronic daily intake of microfibers (CDI): Beside the worker's health, a human health risk assessment was carried out using non-carcinogenic CDI (chronic daily intake of microfibers) in water and air. Calculations were involved using the following USEPA equation.

Chronic daily intake (CDI) = (C × IR × EF × ED × CF)/(BW × AT)…………….1

Where C is the concentration (in md/l or mg/m3), EF is the exposure frequency (in days/years), IR ingestion/inhalation rate (in l/day or m3/day), and CDI chronic daily intake CF represents the conversion factor, and ED is a representation of exposure duration. AT represents average life time (years), and BW stands for body weight (kg/person). We have to obtain the CDI with the calculation above so that we will be able to determine the risk associated with the fibers. By calculating the HQ using the USEPA (1999) equation to assess the risk of non-carcinogenic:

HQ=CDI/RfD…………………..2

Where RFD is the reference dose or the daily dosage that will allow one to tolerate this amount of exposure over a long period without causing harm. With the addition of HQ, the hazard index (HI) of each processing unit across all industries were calculated. Then, HQs can be added together to calculate the Hazard Index (Paustenbach 2002; Zheng *et al*. 2010).

$$HI = \sum_{i=1}^{n} (HQ)\text{i}$$

Where HI represents overall hazardous risk and n is the total microfibers in numbers.

RESULTS AND DISCUSSIONS

Quantification of microfibers in textile processing: From the samples collected for the analysis of microfibers, total microfibers found in the knitting unit from Lahore textile sectors has been shown in Table 2. Microfibers are remarkably higher in the knitting section than any other unit probably because this section involves manipulation and processing of microfibers which increases fiber shedding into air.

Table 2: Composition of microfibers in selected industrial units of Lahore

Sites	Fibers	Sheets	Fragments	Foam	Beads	Total Microfibers
Knitting	160	20	10	5	5	200
Printing	60	20	10	5	5	100
Dyeing	20	10	5	5	0	40
Stitching	70	5	5	10	0	90
Drinking water	60	10	0	0	0	70
Wastewater	150	50	20	10	20	250

Table 3: Composition of microfibers from processing unit of Kasur

Sites	Fibers	Sheets	Fragments	Foam	Beads	Total Microfibers
Wastewater	150	40	10	0	0	200
Drinking water	60	20	0	0	0	80
Printing	20	5	5	0	0	30
Dyeing	30	10	5	5	0	50
Stitching	80	10	5	5	0	100
Knitting	70	20	5	5	0	100

Table 3 represents, the samples collected from Kasur's textile units, microfibers detected in samples of knitting were 100, stitching was 100, printing section was 30, and dyeing section was 50. Microfibers in wastewater has the highest value compared to textile units in Kasur district.

Regarding the textile units of Sheikhupura, 200 microfibers have been found from the sample of knitting. The high number of MFs was confirmed in knitting section in Sheikhupura district (Table 4).

Table 5 has shown the Faisalabad's textile units, where high numbers of microfibers were found in wastewater samples (150) whereas , dyeing unit has the lower value (20). The total number of microfibers detected from the drinkable water samples was 90, whereas from wastewater samples were 150 from the textile industry.

Table 4: MF composition in textile industries of Sheikhupura

Sites	Beads	Sheets	Fibers	Fragments	Foam	Total Microfibers
Knitting	0	30	160	5	5	200
Printing	0	10	80	5	5	100
Dyeing	0	10	40	5	5	60
Stitching	0	20	120	5	5	150
Drinking water	0	20	60	10	0	90
Wastewater	0	40	250	10	0	300

Table 5: Microfibers found in textile industries of Faisalabad

Sites	Fibers	Sheets	Fragments	Foam	Beads	Total MF
Knitting	60	20	0	0	0	80
Printing	40	10	0	0	0	50
Dyeing	10	5	0	5	0	20
Stitching	50	10	5	5	0	70
Drinking water	70	20	0	0	0	90
Wastewater	100	50	0	0	0	150

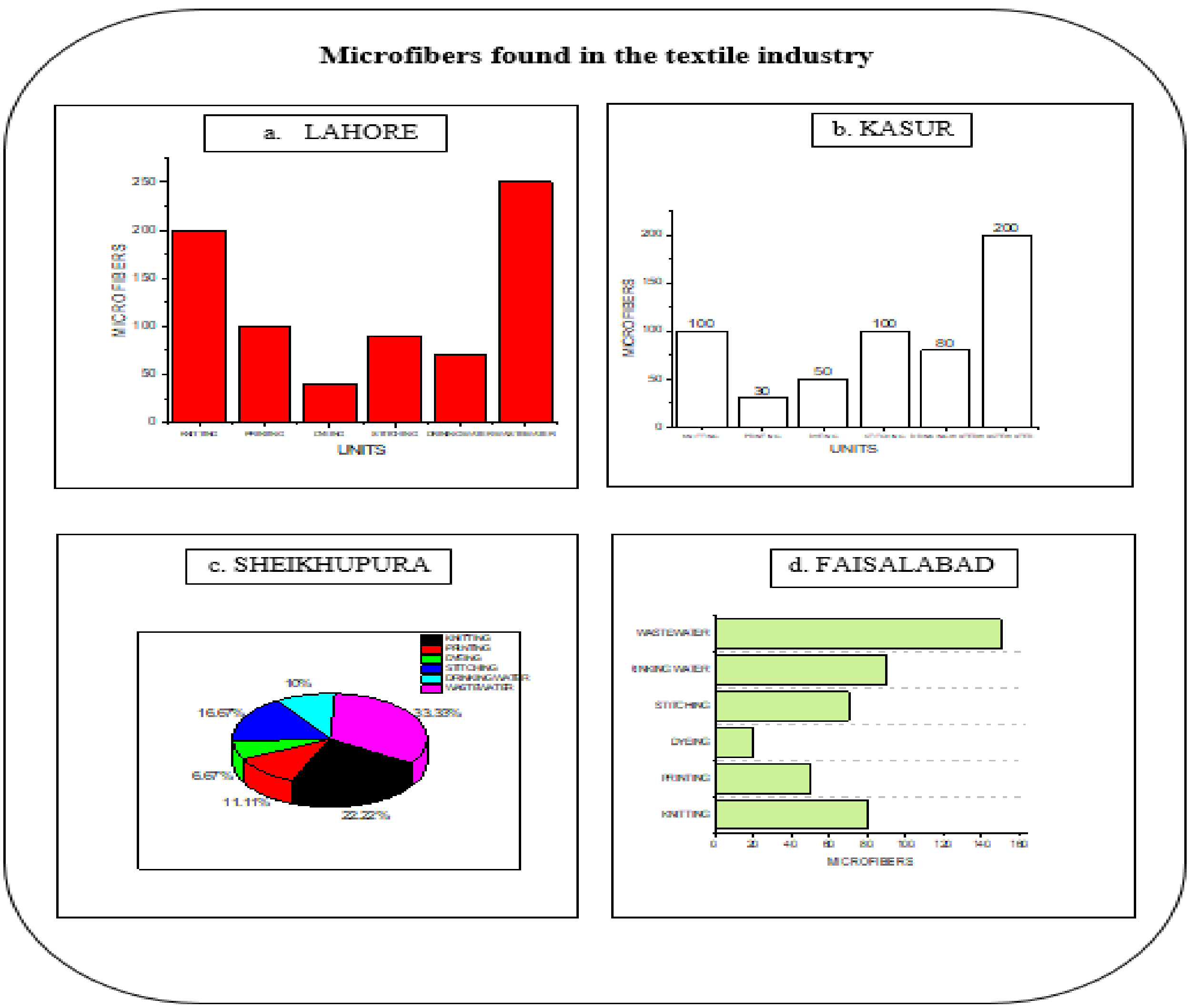
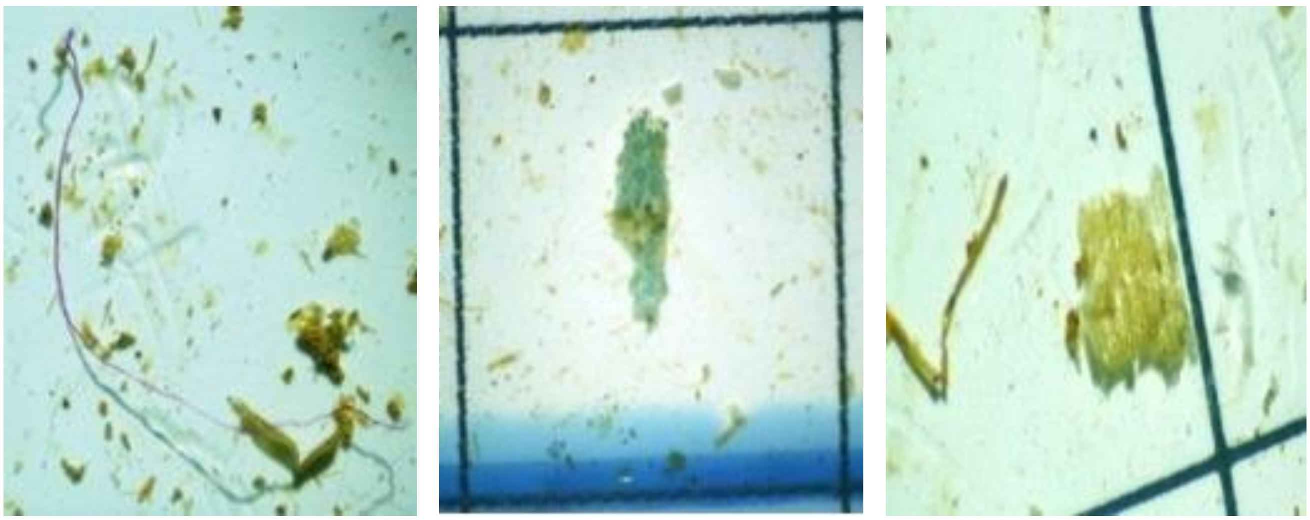


Figure 2: Graphical representation of microfibers detected in textile sectors of study sites

Comparison of microfibers abundance in selected study sites: Among all the samples collected from selected study sites, Sheikhupura's textile sectors showed the highest abundance of microfibers. Small – Medium scale industries are dominant in Sheikhupura hat typically lack advance filtration systems and have poor indoor air control, resulted in highest microfiber detection. The predominance of mechanical textile processing facilities, the extensive use of synthetic fibers, all of which promote fiber fragmentation and airborne accumulation. Moreover, less strict implementation of environmental regulations might also contribute to highest levels. After Sheikhupura, Lahore's textile sectors recorded the second highest contribution of microfibers while Kasur and Faisalabad showed comparatively lower levels.

Types of microfibers found in samples: Microfibers detected in samples were classified into three major categories: Fiber, Sheet and Foam (Figure 3).



1. Fiber **2. Sheet** **3. Foam**

Figure 3: Various types of MFs detected in FTIR

In a sample having MFs, FTIR indicates the presence of different types of plastics. Those which are identifiable using FTIR are Polybutylene Terephthalate, Polyisobutylene, and Polypropylene Standard PVC. The highest contributor was polyethylene terephthalate followed by polypropylene standard (Figure 4 and 5).

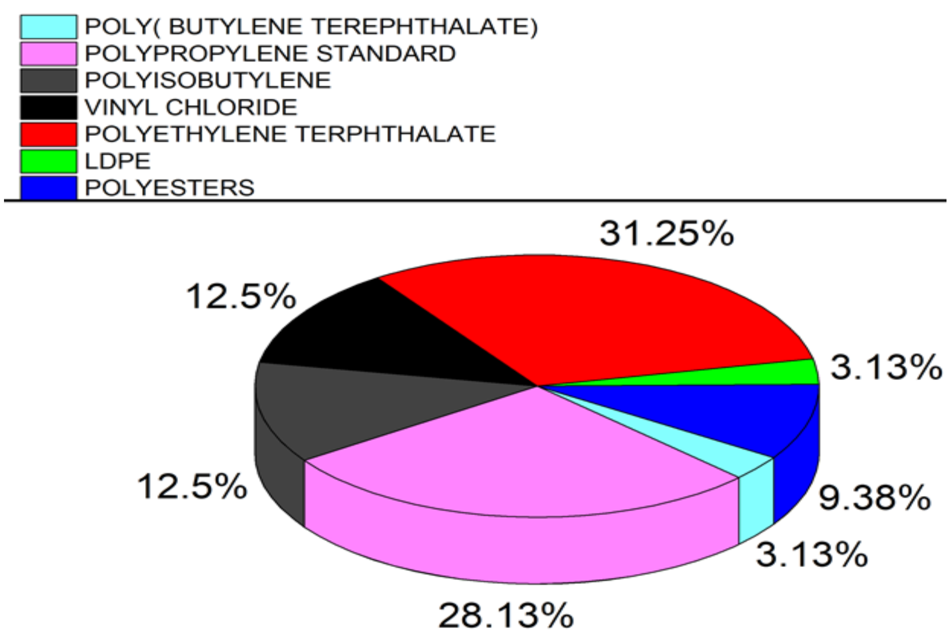


Figure 4: Composition of microfibers in FTIR

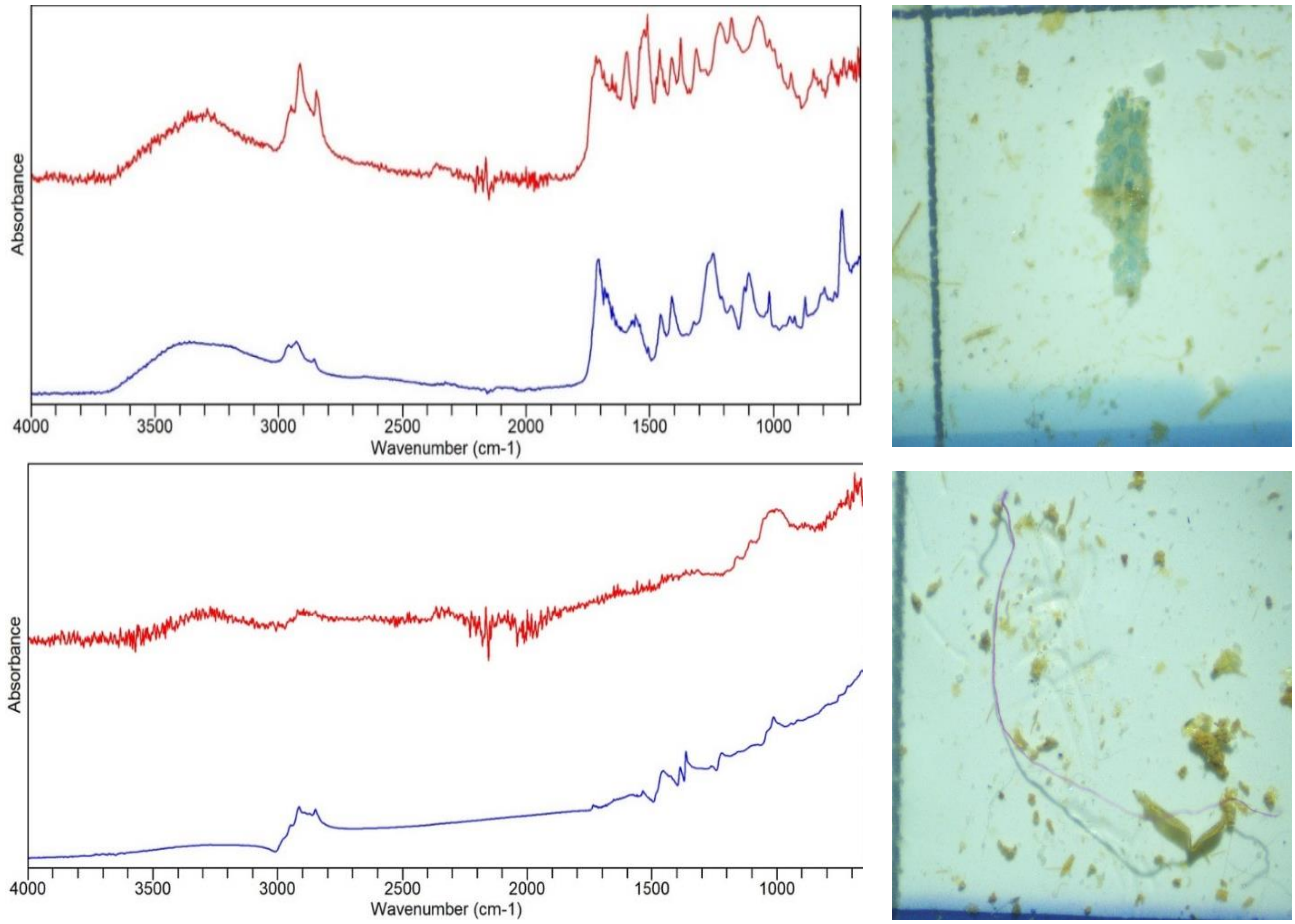


Figure 5: Chromatograms of different microfibers

Health risk of microfibers: The health risk calculation was represented as the Hazard index (HI) which reflects if it is less than 1 then it indicates a little to no health risk, a value greater than 1 indicates a health risk is present. The results revealed that MFs in the air samples in all units except knitting were at lower levels compared to those that have been proven to pose potentially harmful effects on health in human beings (Table 6).

Table 6: CDI and HI in air samples for microfibers exposure to the workers in the textile industry

Sites	MF	IR	EF	ED	CF	BW	AT	CDI	RFD	HI
Knitting	580	15.9	350	30	1E-06	70	10950	0.00013	0.0001	1.26
Printing	280	15.9	350	30	1E-06	70	10950	6.10E-05	0.0001	0.61
Dyeing	170	15.9	350	30	1E-06	70	10950	3.70E-05	0.0001	0.37
Stitching	410	15.9	350	30	1E-06	70	10950	8.93E-05	0.0001	0.89

Chronic daily intake (CDI) and HI for airborne microfiber exposure among textile workers are shown in Table 6. The inhalation rate falls between 15-20 m^3/day. Inhalation rate that is the volume of air inhaled per day (m^3/day) for knitting section is 15.9 and Hazard index is 1.26. CDI of exposure to microfibers in knitting section is 0.000126329 mg/kg/day. Hazard index of knitting is more than 1 which indicates that it has a high tendency to cause illness as it causes higher risk in workers and general public. While, other units including dyeing, printing, and stitching units have less than 1 which means low health risk of MFs.

Table 6: CDI and HI in wastewater and domestic water for microfibers exposure

Sites	MF	IR	EF	ED	CF	BW	AT	CDI	RFD	HI
Domestic water	330	2	350	30	1E-06	70	10950	9.04E-06	0.0001	0.09
Wastewater	900	2	350	30	1E-06	70	10950	2.47E-05	0.0001	0.25

Table 7 provides a description of health risk of microfibers associated with wastewater and domestic water. There are 330 microfibers in drinking water whereas 900 in wastewater. IR refers to the ingestion rate per day majorly computed at 2 m^3/day. The CDI of domestic water use is 9.04×10-6 mg/kg/day and its HI is 0.09 while of wastewater CDI and HI were 2.47×10-5 mg/kg/day and 0.25 respectively. Thus, values of HI indicate less than 1 which means lower health risk of microfibers from the selected processing units and their surroundings. Risk of exposure although risk is lower as far as exposure from drinking water is concerned, it is still tolerable in comparison to potential illnesses.

Conclusion: The study exposes the dangers to health related to working and environmental exposure to microfiber contamination in air, water and wastewater. The current study on microfibers in the textile industries of Punjab provides much-needed data on their effects across various sectors. The outcomes of the study proved the presence of microfibers in all district of Punjab due to textile processing. The results revealed that quantity of microfibers are greater in Sheikhupura region compared to other districts of the Punjab. Moreover, MFs can be integrated into all phases of textile production-from weaving and dyeing to final finishing and quality checking because of their fine and adaptable character. Some advantages and disadvantages are attached to its application. First, microfibers increase the qualities associated with softness, abrasion resistance, and water resistance in a fabric that should fulfill market requirements. The incorporation of microfibers into technical textiles is likely to result in new products of higher functionality and hence make the Punjab textile industry more competitive. On the downside, mass utilization of microfibers poses some environmental and operational risks. On the other hand, manipulation and processing of microfibers will require some controls to avoid operational inefficiencies as well as high-quality products. A balanced approach including efficient waste management practices, technological innovation, and industry restrictions will help maximize the positive impacts of microfibers while limiting the negative impacts. This dual approach would make it possible for Punjab's textile industry to be sustainable and competitive in achieving world-class standards and consumer expectations.

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