Chapter

Remediation and Management of Sewage Sludge

Farzana Malik, Muhammad Yousuf, Zeeshan Umer, Wajid Malik, Abdul Majid and Sajid Iqbal

Abstract

In recent times, along with urbanization, the population of the city is also increasing rapidly. In this regard, the discharge of municipal sewage is increasing year by year, which is a worrying situation for living beings as well as the environment. In fact, wastewater is an important by-product of modern industry and contributes significantly to polluting the aquatic environment. Its sources are based on many industries and anthropogenic pollutants. The nature of wastewater is organic and inorganic. Many harmful pollutants especially heavy metals are present in sewage sludge and wastewater. Phytoremediation has become a significant experimental and practical strategy to use plants to remove heavy metals from sewage waters, sludges, spillage sites, and polluted places.

Keywords: sewage, sludge, contamination, phytoremediation, wastewater

1. Introduction

A vital requirement for human survival is water. However, this problem will only get worse over time because we are still far from fulfilling the world's standards for clean water. Due to declining water quality, global climate change, and population growth, there is a growing need for clean drinking water [10]. In recent times, the city's population has been increasing rapidly along with urbanization. In this regard, the discharge of municipal sewage is increasing year by year, which is a worrying situation for living organisms as well as for the environment [13]. High concentrations of microplastics (MP) have been observed in municipal sewage sludge. In various countries, it is used as a fertilizer for agricultural land. The application of microplastics to land can contaminate other uncontaminated areas, leading to uncontrolled pollution in those areas [14]. Municipal sewage is an accumulation of commercial water, domestic water of citizens, and municipal unit water. Municipal wastewater must be properly treated. Otherwise, it will be a serious threat to the ecological environment [13].

In fact, wastewater is an important by-product of modern industry and contributes significantly to polluting the aquatic environment. Based on the many industries and pollutants, there are different types of sewage sludge. Each industry sector releases its own unique set of contaminants. In general, there seem to be two types of wastewaters released from industries, chemical wastewater and biological wastewater [6].

2. Types and sources of wastewater

2.1 Chemical (inorganic) wastewater with sources

Among them, the electroplating sector is a significant source of pollution. Compounds containing chromium, cadmium, nickel, lead, iron, zinc, and titanium are discharged by the metal working industries. Solvent waste is produced by dry cleaning and auto repair industries, Silver is released by photo processing industries; ink and dye are released by printing industries. Petroleum products and phenolic compounds are widely discharged by the petrochemical industry. Additionally, pulp and paper mill effluents comprise suspended particles, organic wastes, and chloride organics and dioxins because the pulp and paper sectors extensively depend on chlorine-based compounds. Wastewater from factories that produce food atoms includes a significant number of suspended particles and organic matter (**Table 1**) [6].

2.2 Biological (organic) wastewater with sources

Biological industrial wastewater is the by-product of large-scale chemical plants and other industrial operations that primarily use organic materials for chemical reactions. The organic components in the wastewaters have diverse properties and originate from various sources. After the wastewater has undergone the proper pretreatment, these can only be eradicated through biological treatment. Numerous organic industrial wastewaters are produced by the following sectors and locations:

i. Factories that produce soap, synthetic detergents, insecticides, herbicides, cosmetics, organic dyes, glue, and adhesives

ii. Paper and cellulose manufacturing factories

iii. Fermentation and brewery and factories

Industries	Contaminants
Steel and iron	COD, BOD, oil, cyanide, phenols, metals, and acids
Refineries and petrochemicals	COD, BOD, mineral oils, chemicals COD, heavy metals, chromium, organic chemicals, phenols, and cyanide
Leather and textiles	Sulfates, solids and chromium, and BOD
Paper and pulp	Chlorinated organic compounds COD, solids, and BOD
Microelectronics	Organic chemicals and COD
Non-ferrous metals	SS and fluorine
Mining	Acids, SS, salts, and metals

Industrial wastewater contaminant.

Table 1.
Sources with contaminants.

iv. Oil refinery manufacturing industry

v. Leather and tanneries

vi. Textile industries [6].

3. Types of sewage contaminants

3.1 Organic sewage contaminants

Various sources, such as urban runoff, domestic wastewater, industrial discharges, and wet and dry atmospheric deposition, can contribute organic contaminants to wastewater. Sewage sludge typically contains large quantities of many kinds of organic contaminants because they tend to sorb on the suspended solids in wastewater. Sewage sludge contains more than 300 chemicals, representing several different chemical groups, according to the type of sewage that the household produces, whether it's municipal or industrial. The range of their concentrations is between pg. kg-1 and g kg-1. Phthalic acid esters (PAEs), organochlorinated pesticides, monocyclic aromatics, polychlorinated biphenyls (PCBs), phenols, polycyclic aromatic hydrocarbons (PAHs), chlorobenzenes (CBs), amines, nitrosamines, and polychlorinated dibenzo-p-dioxins and furans (PCDD/Fs) are the contaminants that are most frequently found [4].

3.2 Inorganic sewage contaminants

The dangerous inorganic chemicals found in sewage sludge are generally heavy metals, having concentrations ranging from cadmium 1–3410, arsenic 3–230, copper 80–2300, zinc 101–49,000, nickel 2–179, lead 13–465 to chromium 10–990,000. Environmental risks are not eliminated by thermal procedures, which often transport, and pollutants can build up in both solid and liquid states. Using sewage that has not been treated, which is a source of numerous hazardous and lethal substances, it may be particularly harmful [16].

4. Role of heavy metals in sewage pollution

There have been many harmful substances introduced into the agro-ecosystem, but heavy metals are particularly problematic because they do not degrade and are bio toxic. In addition to lowering crop yield and quality, heavy metals in soil can pose a hazard to the ecosystem's security and public health [9]. For the most part, because of their toxicity, bioaccumulation, and environmental endurance, heavy metals are well-known inorganic contaminants. Along with other contaminants, these inorganic ones slowly migrate to the nearby water and soil. Waterways can become contaminated by heavy metals in several ways. In places with such contamination, severe cases of diseases caused by heavy metals in living systems have been documented. In some countries, wastewater can be discharged into lakes, rivers, and other bodies of water. Such practices contaminate freshwater, harming the environment. Most the earth's natural species are severely affected by heavy metal contamination. The earth's crust contains heavy metals, but due to human

Source	Heavy metal	Affect
Use of fertilizers	As, Pb, Hg, Cu	water, soil, and crops
Use of pesticides	As, Cd, Cr, Pb, Ni, Hg	Water, soil, and crops
Reclamation of land	Cr, As, Cu, Cd	Agricultural soil
Dyeing and tanning	Zn, Wood preservation, As	Water and soil
Manufacturing of batteries	Hg	Water and soil
Coating and plating	Cr	Water and soil
Metal refining	Zn, Ni, Fe,	Water and soil
Mining activities	Cd, Ni, Cu, As, Hg, Pb, Zn	Water and soil
Smelting operations	Cd, Co, Cu, Cr, As, Ni, Sb, Hg, Pb	Water and Soil

Table 2.
Sewage sludge is one of the sources of heavy metals in water and soil.

activity, there are geochemical and biochemical imbalances involving naturally occurring compounds [12]. Because they may cause cancer and mutagenesis, heavy metal ions from the paper, leather, and textile industries are a severe issue. Some contaminants are poisonous, damaging, and carcinogenic to ecosystems and people. Impurities in some heavy metals are extremely hazardous. Arsenic has long been recognized as a deadly substance. The very poisonous heavy metals chromium, lead, copper, mercury, cadmium, zinc, and nickel, among others, can have detrimental toxic effects. Additionally, the following nitrates, fluoride, selenides, chlorides, phosphates, and chromates have a high-level dangerous effect (**Table 2**) [10].

5. Entrance of heavy metals into our food chain

Compared to other contaminants, heavy metals are considered to pose the main threats to food safety [9]. The natural ecosystem services are degraded by heavy metals being present in contaminated soils, which ultimately impact human health through the food chain. Due to their abundance of advantageous and necessary nutrients and minerals, vegetables are a significant component of the human diet. Unfortunately, plants can absorb and accumulate excessive amounts of heavy metals in both edible and inedible sections of their bodies. Heavy metal concentrations in vegetables (fruit, leafy vegetables, and root vegetables) have been found to be high in recent years. Finally, the accumulation of heavy metals in vegetables and edible crop components in sewage sludge-contaminated soils is a cause for considerable worry due to the negative and permanent consequences that metals have on both human and animal health overall through the food chain [8].

5.1 Sewage wastewater used in agriculture

Nitrogen and phosphorous are found in sewage sludge, particularly because of the nitrification and denitrification phases of the wastewater treatment process. As a result, sludge has special nutritional properties because it contains nutrients that are necessary for plant growth. Sludge may also contain other substances, therefore, that can be hazardous if they get into the human food chain [5].

6. Types of sewage and wastewater treatments

The accumulation of wastewater through urban wastewater treatment systems is a rising environmental problem. A crucial component of sewage management is manure sludge. Through the treatment of wastewater, sludge is created. Wastewater is made up of liquid or water-borne wastes that are separated from institutions, homes, industries, and organizations, as well as groundwater, stormwater, and surface water [1].

It is organic because it contains carbon compounds like paper, human waste, vegetable matter, and so on. It is composed of 99.9% water and 0.1% solids. In the area, there is industrial effluent in addition to sewage from the local communities. In the same manner that sewage is handled physically, chemically, and/or by microorganisms, many industrial wastes also have an organic nature. Using either physical–chemical processes or microorganisms, in order to treat sewage and wastewater, complex organic compounds must be broken down into less unstable, odorless substances. The contaminants in wastewater are removed by physical, chemical, and biological means [15].

In basic, advanced, and secondary wastewater treatment methods, sludge is produced. It is categorized as basic, advanced, and secondary sludge produced in innovative wastewater treatment, respectively. Secondary sludge is made up of biological solids as well as additional settable solids, while primary sludge is made up of settable solids transported in the untreated wastewater. Advanced wastewater can produce sludge that contains highly resilient viruses, heavy metals, nitrogen, or phosphorus.

6.1 Sludge disposal and treatment

i. Initial treatment (screening, comminuting)

ii. The first thickening (belt, centrifuges, gravity, flotation, drainage)

iii. Stabilizing liquid sludge (lime addition, aerobic digestion, anaerobic Digestion)

iv. Secondary thickening (gravity, flotation, drainage, belt, centrifuges)

v. Conditioning (elutriation, chemical, thermal)

vi. Dewatering (belt press, plate press, drying bed, centrifuge)

vii. Storage (dry sludge, compost, liquid sludge, ash)

viii. Transportation (pipeline, road, sea)

ix. Destination (agriculture/horticulture, landfill, reclaimed land forest, land building, other uses).

x. Final treatment (pyrolysis, wet oxidation, drying, incineration, composting, and line addition) [5].

6.2 Disposal of municipal sludge

Sewage sludge is now primarily disposed of via agricultural usage; 11% is burned, 40% is dumped, 37% of the produced sludge is used in agriculture, and 12% is used in other sectors, including forestry, silviculture, land restoration, and so on. Significant scientific interest has been produced by the most recent developments in management of sewage, including co-combustion of sewage sludge with other substances for future use as a source of energy, moist oxidation, decomposition, gasification, and combustion of sludge.

6.3 Incineration technique

The most attractive disposal technique is still incineration. In terms of procedure engineering, fuel efficiency, and plant efficiency, incineration technology has made significant progress in recent years. Advanced fluid bed incinerators are gaining popularity due to their lower capital and operating cost. Sludge volume is massively diminished; after combustion, it is only about 10% of what it was after mechanical dewatering.

i. Burning hazardous organic compounds to dust

ii. Since sewage sludge has roughly the same calorific value as brown coal, incineration presents the opportunity to recover that energy content.

iii. Reduction of odor production [5].

6.4 Thermal processing

To meet the ever-stricter regulations, sewage sludge is thermally processed, which makes use of the energy that has been stored in the sludge while also minimizing any negative environmental effects. Sludge is widely recognized for having high moisture levels. To decrease the amount of moisture, most of the energy released during thermal operations is used. Various contemporary technologies have recently been established, providing an alternate tendency to the disposal of sewage sludge, particularly with the declining availability and rising cost of land for landfilling. The primary representatives of the thermal processing are pyrolysis, gasification, moist oxidation, and combustion. These technologies can all be categorized under the heading of thermal exploitation of sewage sludge [5].

6.5 Combustion

For the warm air processing of sewage, several techniques have been developed and are available on the market. The most well-established method involves the one-track- and co-combustion of sewage sludge, with mono-burning (combustion) being considerably more prevalent. For the warm air processing of sewage sludge, various fluidized bed and hearth technologies have been developed. The extremely well-recognized ones include the one-track- and co-burning of sewage sludge, with being significantly more common. As opposed to single hearth furnaces, multiple hearth furnaces typically consume mechanically wet (dewatered) sludge. Whereas, fluidized bed furnaces may burn sludge with a dry matter composition of 41–65 wt% that is both wet and semi-dried. The release and combustion of volatiles, drying of sludge, and the burning of the extreme residue content left over as char are the dominant factors that might possibly alter the general combustion procedure of sewage sludge. According to the makeup of sewage sludge, burning of the sludge might be viewed as a cause of possible contaminants; thus, caution must be used while disposing of it.

i. Furans and dioxins, HCl, N2O, HF, SO2, as well as NOx, and Cx Hy emissions

ii. Processing solid waste products, such as bed and filter ash

iii. Metals that are released [5]

6.6 Pyrolysis

The process of pyrolysis involves the thermal decomposition of organic materials within an oxygen-off environment at temperatures between 300 and 900°C. To put it another way, pyrolysis is the process of heating sewage sludge within an inactive atmosphere to make available organic stuff that may then be recycled. This process focuses the heavy metals around a solid carbonaceous deposit, not necessarily as much as in debris from burning, which makes it look less polluted Compared to standard procedures (combustion, incineration).

i. The gaseous component of this non-condensable gas (NCG) is mostly composed of hydrogen, carbon monoxide, methane, and carbon dioxide, with negligible volumes of numerous additional gases.

ii. The liquid part of the stream is made up of tar and oil, which also includes acetic acid, acetone, and methanol.

iii. The portion of the solids is mostly made up of char, which is typically just uncontaminated carbon mixed along with trace volumes of inert substances [5].

Pyrolysis consists of the following steps:

i. Volatile compounds vaporizing

ii. Solid char is the primary byproduct of the breakdown of non-volatile components. In addition to the char, fumes and tar are also created.

iii. The char could go through a higher-level pyrolysis process. Many hydrocarbons and aromatic chemicals are present in this stage's final volatile phase [5].

6.7 Wet oxidation

The thermal process category includes the wet oxidation of sewage sludge. It utilizes pure or ambient oxygen and occurs in an aqueous phase, and its temperatures lie between 150 and 330°C and pressures of 1 to 22 MPa. The procedure requires a high temperature to avoid boiling at the necessary temperatures. The procedure involves heat degradation, hydrolysis, oxidation, and conversion of the organic substance in the sewage sludge to water, nitrogen, and carbon dioxide. Two separate regimes operate during the entire operation.

i. The initial happens at temperatures between higher than or below 374°C and 10 MPa of pressure.

ii. A pressure of 21.8 MPa and supercritical temperatures below 374°C for the second.

6.8 Gasification

Technologies that make it possible to use garbage as fuel are extremely important. Theoretically, nearly all biological wastes along with a humidity content of 5–30% are able to be successfully gasified, yet not all biofuels can do this. Gasification is known to be influenced by fuel characteristics like surface, size, and moisture in addition to shape, carbon content, and volatile matter. Sludge and other less-priced materials might be useful as the feedstock for gasification. Numerous variables, including the input fuel, reactor type, and others, affect the gasification process' ability to create gas with a given amount of energy. To produce a suitable gas for power production, essential research into the impacts of sludge on gasification is crucial. Gasification technology can be used to both alleviate the environmental issue and turn the sewage sludge into a usable energy source.

7. Phytoremediation of heavy metal polluted sewage and wastewater

Pesticides, oils, colors, phenol, cyanides, hazardous organics, phosphorus, suspended particles, and heavy metals can all be found in untreated industrial and home wastewater. Among these harmful compounds, heavy metals are easily collected in the environment. To reduce the risk to the environment and human health, it is crucial to remove harmful contaminants from the environment. The fact that heavy metals can take on various chemical forms makes it challenging to remove them from wastewater. Most metals are not biodegradable, and they can easily move between trophic levels to accumulate chronically in the biota. High pollutant concentrations in wastewater are extremely harmful to both human health and aquatic ecosystems.

The development of several heavy metals, including zinc, cadmium, lead, nickel, and so on, is a result of wastewater irrigation. Some of these metals, for instance Ni, Zn, Cd, Cu and Pb, are frequently noticed in the soil's subsurface when untreated wastewater is used to irrigate the soil. Long-term wastewater irrigation raises the level of hazardous heavy metal content in the soil [2].

Phytoremediation has become a significant experimental and practical strategy to use plants to remove heavy metals from sludges, sewage waters, spillage sites, and polluted places. When compared to other remediation methods, phytoremediation offers several benefits:

i. It can be carried out with little impact on the environment.

ii. It is applicable to an inclusive range of toxins, as well as many metals for which there are only some other possibilities.

iii. It may produce a lesser amount of resultant air and water wastes than conventional techniques.

iv. Organic contaminants can degrade to carbon dioxide and water, eliminating their environmental injuriousness.

v. For large quantities of water with low pollutant concentrations, it is economical; taking up contaminated groundwater by plants can stop migration off-site [3].

The idea of using metal accumulator plants in phytoremediation for the removal of heavy metals and several more-than toxins was originally proposed in 1983, but it has been around for 300 years. Numerous terms, including agro-remediation, green remediation, vegetative remediation, botanic remedy, and organic (green) technology, are used to refer to phytoremediation. For the elimination of potentially hazardous metals from the environment, phytoremediation is regarded as an efficient incredibly attractive, economically advantageous, and environmentally beneficial technology. In phytoremediation, plants collect pollutants through their roots and then move them to their aboveground parts of the body [2].

To degrade, remove, or immobilize the pollutants, phytoremediation uses a variety of mechanisms, including accumulation (phytoextraction, rhizofiltration,), degradation (rhizo-degradation, phytodegradation,), immobilization (Phyto stabilization and hydraulic control), and dissipation (phytovolatilization). Plants use a variety of these methods to lower the amounts of pollutants in soil and water, depending on the contaminants. For instance, plants absorb and store HMs in their tissues, and they breakdown organic contaminants to lessen their toxicity in the soil and water. Depending on the types, forms, and mediums of the contaminants, various plants use various strategies or combinations of them to remediate soil and water. Rhizo-filtration, phytodegradation, phytovolatilization, rhizo-degradation, and phytodegradation are all methods for cleaning up contaminated groundwater. Rhizo-filtration, phytodegradation, and rhizo-degradation are three treatment options for surface and wastewater contamination. Through phytodegradation, phytovolatilization, phytoextraction, and rhizo-degradation, contamination caused by soil, sediments, or sludge is remedied [7].

7.1 Phytoextraction

Phytoextraction can be used to eliminate heavy metals [7]. By translocation in the sections of roots that can be harvested, pollutants are retained in the shoot tissue [11]. One of the environmentally safe, long-lasting alternatives for soil cleanup is phytoextraction, which also offers the potential for reusing the metals that are extracted through phytomining. The hyperaccumulating plants' tolerance levels and development restrictions frequently place a limit on phytoextraction. Through the introduction of moderate stress cues that lead to acclimatization in the plant, priming can affect the tolerance of plants to stress. Utilizing various types of chemicals that are added exogenously to plant organs (such as roots, leaves, etc.), plant priming's capacity to increase abiotic stress tolerance has been thoroughly studied [8].

7.2 Phytodegradation

Enzymatic activity breaks down organic pollutants [11]. Organic substances can undergo phytodegradation either inside the plant or in the rhizosphere. This technique can be used to remove a wide variety of substances and classes of compounds from the environment, including as solvents in groundwater, aromatic compounds in soils, volatile compounds in the air, and petroleum [12]. Petroleum is a pollutant that can remain in the environment for a very long time before vegetation fully recovers, and its persistence can be attributed to the hydrocarbons' slow biodegradation. The effects of petroleum on plants might be direct when they encounter oil or indirect when biotic and abiotic changes related to plant development occur. Because of their potential to degrade contaminants, several species of Caesalpiniacae, Mimosaceae, Fabaceae, and Poaceae have been investigated. When compared to soils with no vegetation, the decomposition of petroleum and its derivatives in soils with Juncus roemerianus Scheele, Sorghum bicolor L. Moench, Vigna sinensis (L.) Endl. ex Hassk., Panicum maximum Jacq, Medicago sativa L., Brachiaria brizantha. Stapf., and Festuca arundinacea Vill. The Poaceae family of plants are most important as compared to other plant families because they encourage the removal of pollutants. By altering the physical and chemical properties of the soil, plants and their roots have a direct impact on the breakdown of contaminants [5].

7.3 Phytovolatilization

Gas exchange at stomata on leaf surfaces aids in pollutant removal. Microbiological processes connected to plant roots may enhance/speed up the transformation of organic pollutants like pesticides and hydrocarbons into harmless forms. By combining metal(loid)-immobilizing soil additives with plants that can withstand high levels [11].

7.4 Phyto stabilization

Contaminants are immobilized inside the root zone by an adsorption mechanism working in conjunction with the accumulation and precipitation phenomenon [11]. Microbiological processes connected to plant roots may enhance/speed up the transformation of organic pollutants like pesticides and hydrocarbons into harmless forms. By combining metal(loid)-immobilizing soil additives with plants that can withstand high levels, Phyto stabilization can be improved [5].

7.5 Rhizo-degradation

It is the microbial breakdown of pollutants in plant root zones [11]. Plants influence a site's water balance, alter the pH and redox potential of the soil, and promote microbial activity. These unintended effects could increase root zone destruction or lessen chemical leakage into groundwater. Upon entering plants, substances may be metabolized, retained, or volatilized into the atmosphere [15].

7.6 Rhizo-filtration

It is the storage of contaminants by plants following root absorption from an aqueous growth media [11]. Rhizo-filtration is a phytoremediation technology that can reduce groundwater contamination by using the root systems of plants to remove a variety of contaminants (both organic and inorganic). The chemicals from the polluted water are absorbed and deposited in the root systems of the plants. The bioavailability of pollutants in the food chain can be greatly reduced by the interaction between the roots of plants and pollutants in contaminated groundwater. The plants chosen for rhizo-filtration should be easy to cultivate, have a low maintenance cost, and produce few wastes when disposed of once the roots of the plant have become completely saturated with the pollutants. The effectiveness of rhizo-filtration was influenced by a variety of variables, including plant species, groundwater quality (pH and temperature), and the chemical properties of organic pollutants. The influencing elements placed a cap on how well the plants could execute rhizo-filtration. The elements could be considered to maximize rhizo-filtration's effectiveness, hence speeding up the removal of organic contaminants from groundwater [13].

7.7 Phyto desalination

Plant species primarily in saline soils remove salts [11]. Phytoremediation using halophytes is preferable since it can be carried out without these issues and is very simple to do. Different halophyte species, such as grasses, shrubs, and trees, can remove the salt from salt-affected problematic soils by salt excluding, excreting, or accumulating through their morphological, anatomical, and physiological adaptation at the organelle and cellular levels. Meeting the fundamental needs of people in salt-affected areas can also be accomplished by utilizing halophytes to reduce salinity [8].

8. Conclusion

Water is a vital requirement for living organisms. However, this problem will only get worse over time because we are still far from fulfilling the world's standards for clean water. The discharge of municipal sewage is increasing year by year, which is a worrying situation for living organisms as well as for the environment. Heavy metals in soil and water can pose a hazard to the ecosystem's security and public health. Most metals are not biodegradable, and they can easily move between trophic levels to accumulate chronically in the biota. High pollutant concentrations in wastewater are extremely harmful to both human health and aquatic ecosystems. To degrade, remove, or immobilize the pollutants, phytoremediation uses a variety of mechanisms, including degradation (phytodegradation, rhizo-degradation), accumulation (rhizo-filtration, phytoextraction), dissipation (phytovolatilization), and immobilization (hydraulic control and Phyto stabilization). Plants use a variety of these methods to lower the amounts of pollutants in soil and water, depending on the contaminants. Municipal sewage is an accumulation of commercial water, domestic water of citizens, and municipal unit water. Municipal wastewater must be properly treated. Otherwise, it will be a serious threat to the ecological environment.

Author details

Farzana Malik[1]*, Muhammad Yousuf[1], Zeeshan Umer[2], Wajid Malik[3], Abdul Majid[4] and Sajid Iqbal[5]

1 Department of Environmental Science, University of Agriculture, Faisalabad Pakistan

2 Department Society and Culture, University of Calabria, Italy

3 Department of Epidemiology and Public Health, University of Agriculture Faisalabad, Pakistan

4 Department of Textile Engineering, Hamdard University Karachi, Pakistan

5 Department of Livestock Management, University of Veterinary and Animal Sciences Lahore, Pakistan

*Address all correspondence to: farzanaawan0115@gmail.com

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