Innovative Protective Solutions for Manhole Cleaners in Pakistan: Material Analysis, Safety Gear Development, and Antimicrobial Advancements

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Abstract:
Workers who clean manholes in Pakistan encounter serious health hazards due to dangerous working environments, including exposure to poisonous gases, harmful pathogens, and chemicals present in sewage systems. A REACH documentary revealed that health-related issues linked to their occupation lead to 80% of manhole workers dying before they reach the age of 60. The risks are heightened in the absence of suitable protective gear, which can cause infections, respiratory ailments, and other serious illnesses. The World Health Organization (WHO) reports that over 3.4 million people die each year globally from water-related diseases, often resulting from exposure to contaminated water. This underscores the crucial need to protect sanitation workers. In 2021, the death of twelve workers in an explosion within Karachi's drainage system highlighted the severe dangers faced by these individuals. This research explores the potential of polyester fabric coated with PVC and embedded with silver as a durable solution. Comprehensive tests on the fabric demonstrated its antibacterial properties, chemical resistances, and waterproof capabilities, proving its suitability for the challenging environment of sewer cleaning. The results indicate that this material can significantly enhance productivity, reduce health risks, and improve the safety of workers. To sum up, polyester fabric treated with PVC and infused with silver presents a practical approach to bettering the working conditions and safety of sanitation workers in Pakistan, potentially benefiting both environmental and public health.

Keywords: Manhole cleaners, Pakistan, occupational health, PVC, silver-infused fabric, health risks, urban sanitation, sewage systems.

Introduction:
Many individuals strive diligently to enhance their quality of life, yet the nature of their occupations can often be perilous, particularly for manhole cleaners in Pakistan. The country’s deteriorating sewer system, primarily constructed over 60 years ago, often becomes clogged and creates hazardous working environments. A 2017 report by the Pakistan Water and Sanitation Program reveals that only a handful of cities, like Islamabad, have adequate wastewater treatment facilities. For instance, just one of the three treatment plants in the capital is operational, heightening health risks for the cleaners.
These workers face harsh job conditions with insufficient safety measures. They come into contact with toxic gases, harmful pathogens, and other dangerous substances in sewage systems, often lacking essential protective equipment. This absence of protective gear not only jeopardizes their health but also contributes to ongoing mental and physical strain, as noted by Khan et al. (2020). Given that their work can lead to serious accidents such as suffocation or drowning, many cleaners experience respiratory issues, infections, and potentially fatal injuries (Shah & Babar, 2019).
Moreover, the plight of these workers is exacerbated by society's indifference towards them. Due to a significant lack of awareness regarding their challenges and the dangers they face, both governmental and community efforts fall short of providing adequate assistance. As stated by Rehman (2021), the stigma surrounding sanitation work leads to low wages and precarious employment, further entrenching these individuals in poverty. Numerous studies have emphasized the undervaluation of their work, highlighting the urgent need for safer working conditions (Khan et al., 2020).
To safeguard the health and welfare of manhole cleaners in Pakistan, this article aims to underscore the critical issues they face and the pressing need for improved safety equipment.

Literature:
Manhole cleaners play a crucial role in maintaining urban sewer systems by performing important tasks such as cleaning, inspecting, and repairing. Their work is vital for ensuring the proper functioning of these systems, which is critical for environmental protection and public health. Nonetheless, the occupation poses significant risks, especially in developing countries like Pakistan, where workers frequently face hazardous working conditions. Manhole cleaners in Pakistan endure one of the most perilous jobs due to their exposure to harmful chemicals, diseases, and toxic gases (Khan et al., 2018). Despite the importance of their role, they are at a considerable risk of health issues stemming from a lack of infrastructure investment and inadequate personal protective equipment (PPE).

The age of the sewer infrastructure significantly influences the safety and efficiency of cleaning operations. In cities like Lahore, where sewer systems are over 60 years old, workers often find themselves in perilous situations. According to the Pakistan Institute of Labour Education and Research (PILER, 2019), manhole cleaners are more vulnerable to health risks as they typically do not have access to basic protective gear like masks and gloves. In contrast, sanitation workers in wealthier countries are provided with comprehensive protective equipment including full-body suits, helmets, and respiratory masks. Conversely, laborers in Pakistan commonly lack these essentials, resulting in increased vulnerability to infections, respiratory illnesses, and physical injuries due to the hazardous working environment (Ahmed et al., 2020).

The effectiveness and safety of cleaning operations are largely influenced by the age of the sewer systems. In cities such as Lahore, where sewer systems have exceeded 60 years of age, workers typically operate under dangerous conditions. The Pakistan Institute of Labour Education and Research (PILER, 2019) notes that manhole cleaners are prone to health hazards because they often lack access to even the most basic protective equipment, such as masks and gloves. In comparison, sanitation workers in developed nations are equipped with respiratory masks, gloves, full-body suits, and helmets, among other protective gear. Unfortunately, workers in Pakistan frequently work without these necessities, making them vulnerable to infections, respiratory problems, and physical injuries associated with unsafe working conditions.

Manhole cleaners face a heightened risk of health issues from toxic chemicals present in industrial waste, including heavy metals such as lead and mercury. These pollutants are commonly found in urban sewage systems and prolonged exposure can lead to serious health issues such as respiratory disorders and neurological damage (Ahmad & Farooq, 2020). Often, manhole cleaners are exposed to these dangerous substances without the necessary protective gear, further endangering their health. Pakistan is not unique in this issue; studies from other developing countries indicate that sanitation workers encounter significant health risks as a result of insufficient safety measures (Baloch et al., 2019).

For laborers, extreme temperatures inside manholes in major cities of Pakistan present a serious challenge. In summer, surface temperatures on roads can soar to between 35 and 45°C. Meanwhile, inside manholes, the heat generated by sewage and poor ventilation can elevate temperatures to as high as 55°C (Ali et al., 2020). The excessively high temperatures within sewers in cities like Hyderabad and Karachi complicate the maintenance efforts for those responsible for these systems. High internal temperatures can lead to dehydration and fatigue among workers (Shah et al., 2019).

The relatively warm temperatures inside manholes pose ongoing health risks, even in winter when road temperatures in cities like Lahore and Rawalpindi can fall between 5 and 15°C. To ensure the safety and health of manhole cleaners, it is crucial to use suitable protective gear and clothing that consider these environmental conditions. A study by Khan et al. (2020) indicates that uniforms made from advanced materials, such as polyester coated with PVC and infused with silver ions, can significantly reduce health hazards by providing durability in harsh conditions and offering antibacterial protection.

Province	Capital	Summer C	Winter C	Environment C	Road C	Sewer C	Reference
Punjab	Lahore	35-45	5 - 15	35	35	28	https://www.aiib.org/en/projects/proposed/2018/_download/lahore/LWWMP-Draft-ESIA-Report-Trunk-Sewer-12-October-2019.pdf
Punjab	Rawalpindi	35-40	5 - 10	30	30	26	
Sindh	Karachi	35-40	15 - 25	35	35	30	
Sindh	Hyderabad	40-45	10 - 20	38	38	32	
K.P.K	Peshawer	35-40	0 - 10	28	32	26	https://nwfc.pmd.gov.pk/new/press-releases.php hore/LWWMP-Draft-ESIA-Report-Trunk-Sewer-12-October-2019.pdf
K.P.K	Abbotabad	25-30	-5 - 5	20	25	18	
Balochistan	Quetta	25-35	-10 - 5	22	22	15	https://www.thenews.com.pk/latest/1084769-heavy-rains-disrupt-life-in-rawalpindi-islamabad
Balochistan	Gawadar	30-40	15 - 25	35	35	28	
Giligat-Baltistan	Gilgat	20-30	-5 - 5	20	20	15	
Giligat-Baltistan	Skardu	25-35	-10 - 0	22	22	18	
Capital	Islamabad	30-40	5 - 15	30	30	26	

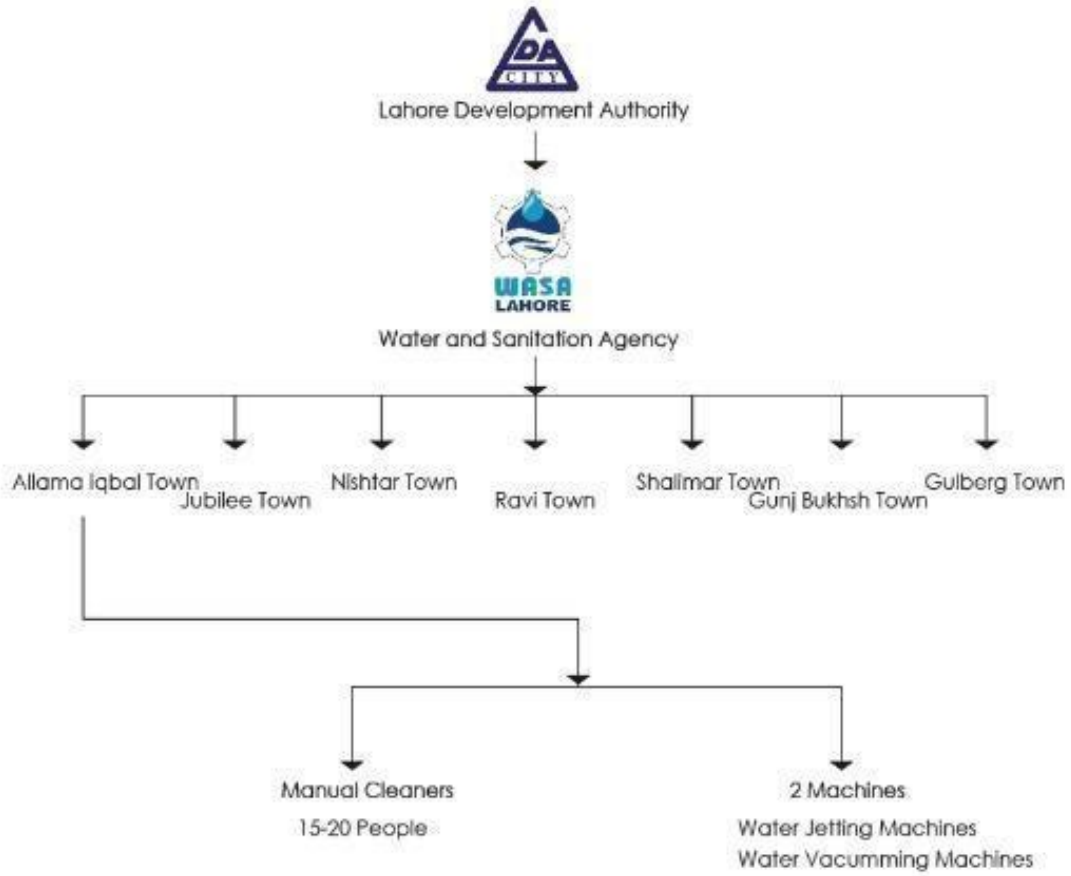


Table 1 Comparative Temperature Measurements in Manholes and External Environment Table 2 Operational Zones and Cleaning Methods of WASA Lahore

The Water and Sanitation Agency (WASA) Lahore oversees the city's sewer system, and although it has made strides in using vacuuming and water jetting equipment for cleaning, it struggles with insufficient resources and outdated infrastructure, making it challenging to ensure the health and safety of its workers (WASA Lahore, 2020). Despite attempts to organize Lahore into operational zones and allocate machines accordingly, worker safety remains compromised due to a lack of appropriate personal protective equipment (PPE) and inadequate safety protocols.

According to a flow graphic illustrating WASA's division of the city into different zones (Jamil & Khan, 2021), most of Lahore still relies on manual cleaning methods, which expose workers to greater risks. Systemic reform is critically needed to ensure that manhole cleaners receive the necessary safety equipment and working conditions that comply with international safety standards, as highlighted by this operational framework.

Therefore, the key research questions are:

1. *How do the working conditions of manhole cleaners in Pakistan impact their health and safety?*
2. *What specific dangers do infections and harmful gases in sewage systems pose to manhole cleaners?*
3. *How does the lack of personal protective equipment (PPE) influence the long-term health of manhole cleaners?*

Research Methodology:

This research utilized a mixed-methods approach, combining quantitative evidence with qualitative insights to thoroughly explore the experiences and challenges faced by manhole cleaners. The investigation involved distributing surveys, conducting interviews, and engaging in discussions with pertinent stakeholders to identify gaps in safety protocols and examine potential solutions.

Data Collection:

Surveys were executed with a tailored questionnaire designed to capture both numerical and descriptive data. These surveys were shared through Google Forms and administered during on-site visits to manhole cleaning locations across Lahore. The sample included 42 manhole cleaners—30 from public institutions and 12 from

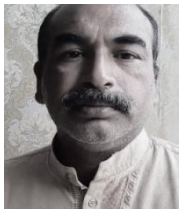
private companies. Furthermore, interviews were conducted with coordinators and supervisors from WASA to gather organizational perspectives on the obstacles encountered and available resources.
The majority of respondents were male, reflecting the gender composition of the workforce in this field. Over 70% of participants were aged over 35, and all acknowledged significant safety-related issues and a lack of adequate uniforms. Workers often reported being exposed to harmful gases, pathogens, and chemicals, a situation exacerbated by the unavailability of protective equipment. Notably, 78% of respondents indicated that access to better protective gear would boost both their confidence and work efficiency.

Data Analysis:
Quantitative data were analyzed using descriptive statistics to summarize key demographic characteristics and findings. For example:
- **Age distribution:** Most respondents were older than 35 years.
- **Safety concerns:** A large number reported experiencing respiratory issues and skin conditions due to hazardous working environments.
- **Impact of uniforms:** 78% of participants believed that upgraded uniforms would improve their productivity and self-assurance.

Statistical methods were utilized to calculate percentages and trends, revealing patterns regarding safety and health issues. Qualitative data derived from open-ended survey responses and interviews underwent thematic analysis.
This method uncovered recurring themes such as dissatisfaction with current safety measures, considerable health risks, and a strong demand for durable protective uniforms. Discussions with WASA supervisors highlighted their awareness of the inadequacy of safety gear and the urgent need for better protective solutions for workers.

Results:
The findings emphasized the significant impact of unsafe working conditions on the health and productivity of manhole cleaners. Respiratory issues, infections, and skin ailments were commonly reported challenges. Workers identified the lack of proper safety equipment, particularly protective uniforms, as a key concern. Supervisors agreed that enhanced uniforms could reduce health risks and improve job performance. The research validated the efficacy of silver-infused PVC-coated polyester fabric as a durable, antimicrobial, and chemical-resistant alternative. Testing of this material confirmed its suitability for demanding environments, showcasing attributes such as water resistance and high durability. The implementation of this fabric in uniforms can greatly enhance worker safety, minimize health hazards, and contribute to increased productivity within the sanitation sector.

User Persona:
In the research phase, a user persona named Malik Masai was developed to reflect the typical requirements and challenges faced by manhole cleaners. This persona facilitates a targeted strategy for designing solutions that cater to individuals like Malik Masai by encapsulating their experiences, preferences, and areas of difficulty.



Profile of Malik Masai
Name: Malik Masai
Age: 51 years
Religion: Christian
Experience: 20 years in manhole cleaning

Challenges and Pain points
1. Malik often encounters hazardous waste and toxic fumes, which can have a severe impact on his health. He constantly expresses concern about this exposure.
2. Malik believes that individuals feel overlooked and marginalized, as society fails to recognize the essential role of manhole cleaners.
3. The risk of injury and health complications significantly rises when appropriate personal protective equipment (PPE) is not utilized. Malik, with his extensive experience, advocates for enhanced safety protocols.

4. Years of physical demands from his job have taken a toll on Malik's health. While he has developed strategies to reduce physical strain, he acknowledges the importance of ergonomic tools and equipment.

Goals:

1. Prioritize Personal Safety: Malik desires to work in an environment where he has access to proper safety gear and is protected from hazardous materials.
2. Advocate for Workers' Rights: He is deeply passionate about highlighting the rights of manhole cleaners and believes that better working conditions and fair compensation are crucial.
3. Efficient Manhole Cleaning: Malik aims to enhance his efficiency by utilizing advanced equipment and techniques that can speed up the cleaning process while ensuring safety.

Insights and Implications:

Malik Masai's character provides an in-depth and human-focused viewpoint on the manhole cleaning industry, highlighting the urgent issues that need to be addressed. By comprehending Malik's journeys, this research aims to inform the development of strategies and solutions that prioritize safety, efficiency, and dignity. Gaining insight into the specific challenges faced by Malik and others in similar occupations can assist stakeholders in crafting targeted policies and initiatives to improve their working conditions and overall well-being. This user persona serves as a reference when formulating practical solutions and interventions, ensuring they align with the real-world needs and experiences of manhole cleaners.

Ergonomic Risk Factors in Manhole Cleaning:

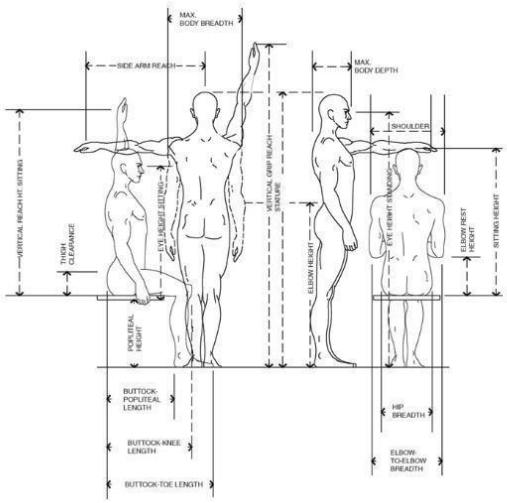
Certainly, here are some common awkward postures encountered in manhole cleaning:

Posture	Explanation	Image
Bending	In order to reach the manhole, workers frequently have to stoop or bend forward, which can put pressure on their hamstrings and lower back.	
Twisting the torso	Spinal tension and discomfort may result from rotating the upper body while keeping the torso bent to access various parts of the manhole.	
Reaching overhead	Shoulder and neck strain might result from lifting or manipulating equipment inside the manhole with the arms extended overhead.	
Kneeling or squatting	When operating within the manhole, a kneeling or squatting position may eventually cause hip and knee pain.	
Unsupported postures	Muscle fatigue and an elevated risk of injury might arise from prolonged work without adequate back, arm, or leg support.	

Size Charts and Anthropometry Data:

To establish the correct measurements for different costume elements, it is crucial to gather anthropometric data. Every aspect, including sleeve length, inseam, chest, and waist dimensions, is meticulously considered

to accommodate the diverse range of body shapes among male staff. By incorporating these principles into the design phase, costumes can be created to provide sufficient coverage and mobility. This approach will tackle ergonomic
concerns and promote a safer and more comfortable work environment.



Anthropometric Parameters[a]	Male			
	5th	50th	95th	Mean ± SD
Stature	164	177	186	176.5 ± 6.66
Sitting height	86	92	98.8	92.2 ± 38.2
Shoulder height (sitting)	57.15	64	68.5	63.3 ± 3.15
Elbow height (sitting)	18.65	25	29	24.9 ± 3.15
Popliteal height	36	41	44.5	40.9 ± 3.43
Knee height	47	51.75	62.85	51.7 ± 2.85
Shoulder breadth	34.09	37.42	42.39	37.8 ± 2.27
Hip width	32.37	36.5	40.6	36.5 ± 2.27
Elbow-fingertip length	44.13	47.2	51.18	47.4 ± 2.07
Buttock-popliteal length	46.15	50	58	50.4 ± 3.28
Buttock-knee length	57.15	61	69.7	62.2 ± 3.42
Abdominal depth	21	24	28	24.3 ± 2.15
Forearm width	6.8	8.05	9.49	8.1 ± 0.8
Thigh thickness	13	16	20.42	16.1 ± 2.34
Elbow to elbow width	35.76	43.46	53.93	43.7 ± 5.37
Weight	55	70	87.82	70.3 ± 9.6

[a] All dimensions are in cm.

Figure 1 Anthropometry Data

Consideration of Average Male Height:
The consideration of variations in average male height is crucial for ensuring that costumes fit well and are proportionate to the body types of individual workers. By taking height differences into account, designers can avoid problems like restricted movement or discomfort from poorly fitting clothing. This careful attention to detail not only improves the ergonomics of the costumes but also supports the overall health and satisfaction of manhole cleaners, enabling them to perform their tasks more comfortably and effectively. Furthermore, data from the Life Sciences Department at Nusrat Jahan College in Rabwah, Pakistan, dated June 21, 2016, provides insights into the height of males at the 5th and 95th percentiles. This information is valuable for understanding the height range within the male population, further guiding costume design choices to accommodate different height
variations.

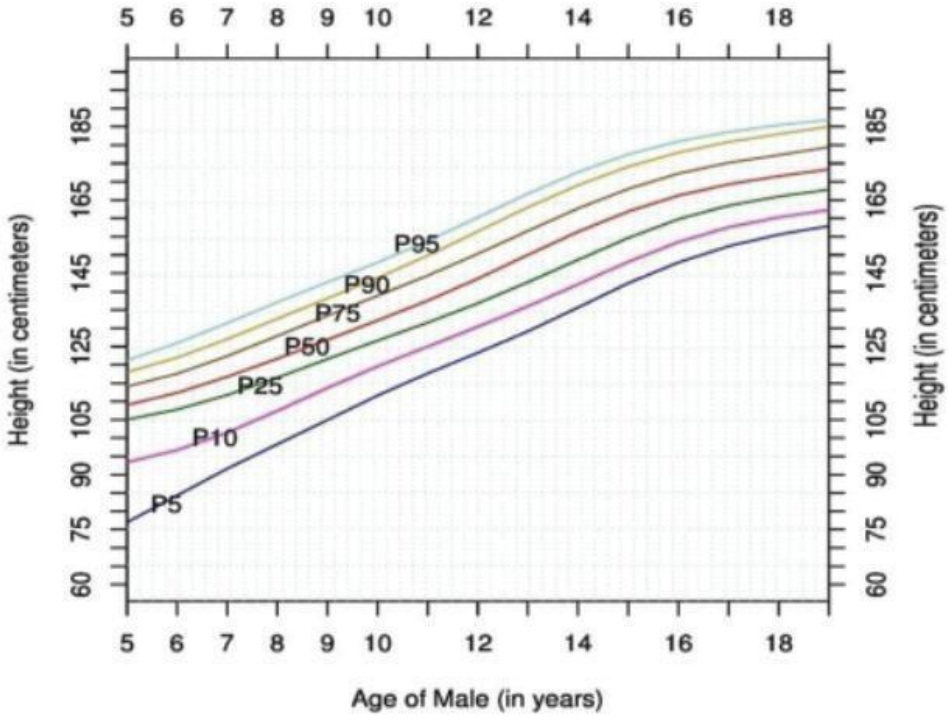


Figure 2 Average Male Height

Additionally, data from organizations like the National Sample Survey Office of India, UNICEF, the Survey of Pakistan, and the survey department of Sri Lanka offer important insights about the average height of Asian males aged 18. Including this information in costume design choices helps to ensure that clothing aligns with the unique needs and traits of the intended audience, which supports ergonomic and user-centered design principles.

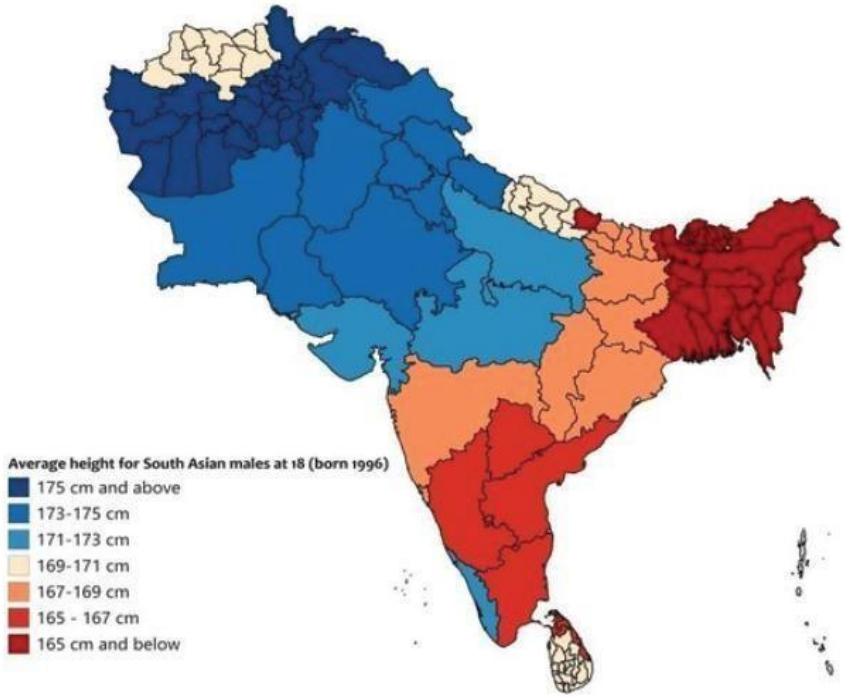


Figure 3 National Sample Survey Office of India, UNICEF, the Survey of Pakistan

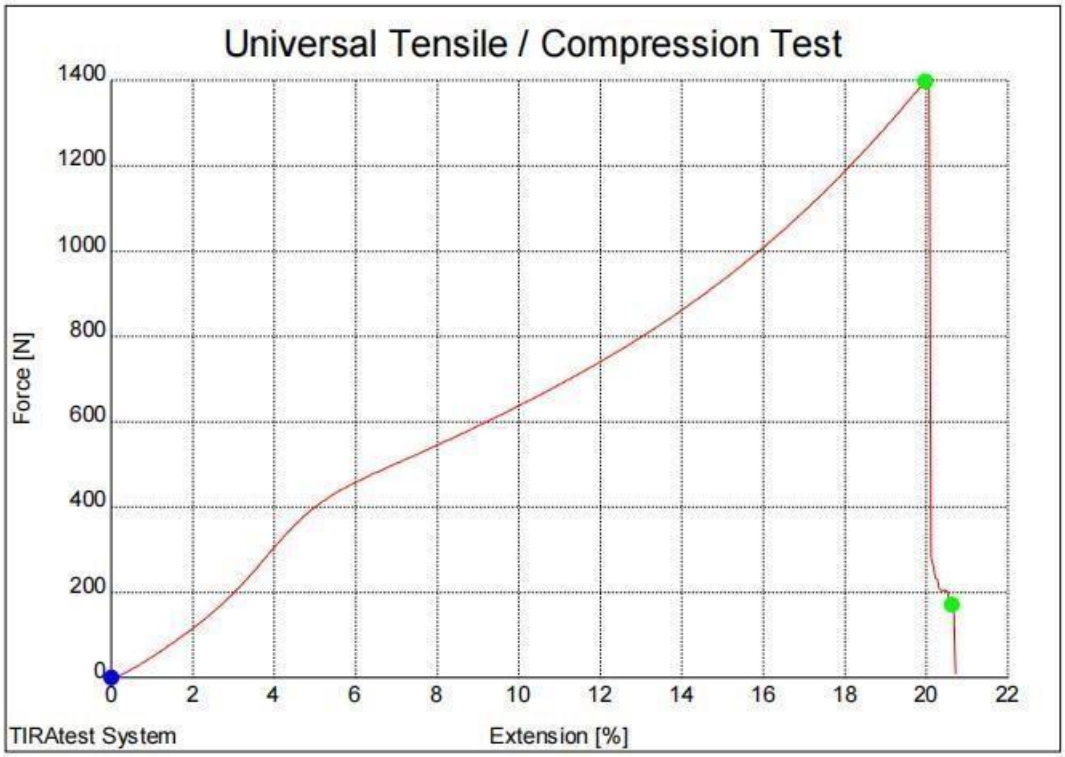
Material and Experimentation:
Selecting the right material is crucial in creating uniforms for workers in challenging settings, such as those involved in manhole cleaning. This section concentrates on assessing the appropriateness of PVC-coated material, recognized for its resilience, resistance to environmental factors, and adaptability, for manufacturing uniforms. By conducting a myriad of tests at the University of Engineering and Technology's laboratories—such as tensile strength evaluations in the mechanical testing lab of the Polymer Department and chemical resistance examinations in the Chemistry Department—we strive to comprehend the material's performance in harsh conditions. The main goal is to evaluate the tensile strength of the PVC-coated fabric, investigating its capacity to withstand stretching forces, and to execute chemical resistance tests against corrosive agents like NaOH, HCl, NaOCl, and NH4OH. In addition, we will analyze the structural stability of canvas fabric after being coated with PVC and explore the incorporation of silver ions into the PVC-coated fabric to boost its antimicrobial properties, ultimately aiding in the safety and longevity of uniforms worn by manhole cleaners.

Tensile Testing:
Tensile testing is a key mechanical evaluation conducted on materials to understand their behavior when subjected to tension. The purpose of this test is to ascertain the strength and elasticity of the material, especially its capacity to endure stretching or pulling forces prior to failing or deforming. In relation to the PVC-coated fabric utilized in uniform production, tensile testing aids in evaluating the material's durability and structural soundness, offering important information regarding its performance and suitability for diverse applications. A Universal Testing Machine (UTM) will be employed to carry out the tensile test.**Test**

Parameters:
*Test:*Universal Tensile / Compression Test
UTM type: TIRAtest 2810 E6
Load cell: 10kN

Extensometer: XHd.pos. *Clamping device:* -- 01 --
Test area: Lower test area
Sample dimensions: a = 0.65 mm; b = 50 mm
Length data: L0 = 150 mm
Test rates: V0 = 75 mm/min; V1 = 75 mm/min
Rate switch points: F0 = 0 N ***End of test criterions:*** F = 9000 N; dF = 95 %
PVC Polyester Fabric:

Graph:



		Comm.1	Comm.2	Date	Time	FH N	RH N/mm²	AH %	dLH mm
3	x			21.01.05	03:01	1397.44	43.00	19.97	29.95

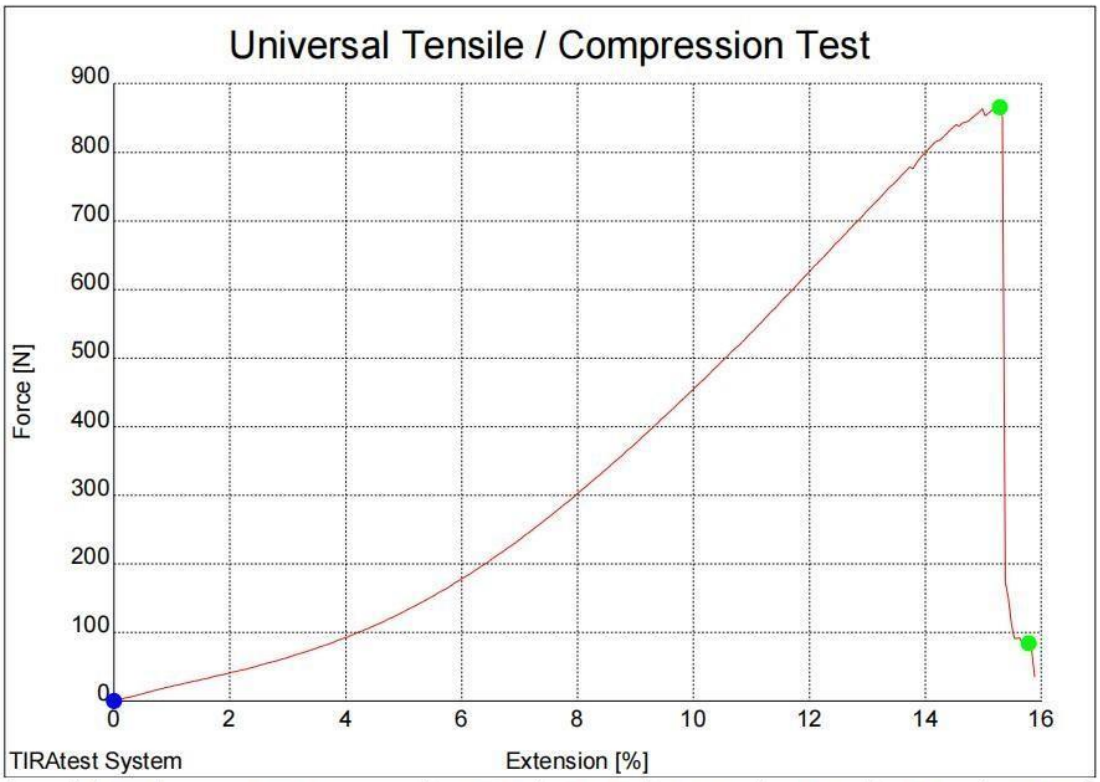
		FB N	RB N/mm²	AB %	dLB mm
3	x	170.88	5.26	20.62	30.93

Images:

Figure 90 PVC Polyester Fabric Testing

Calculation:
Breaking point = Stress = 43.00 N/mm2
Strain = 19.97%

PVC Canvas Fabric:



		Comm.1	Comm.2	Date	Time	FH N	RH N/mm²	AH %	dLH mm
2	x			21.01.05	02:58	865.37	26.63	15.28	22.93

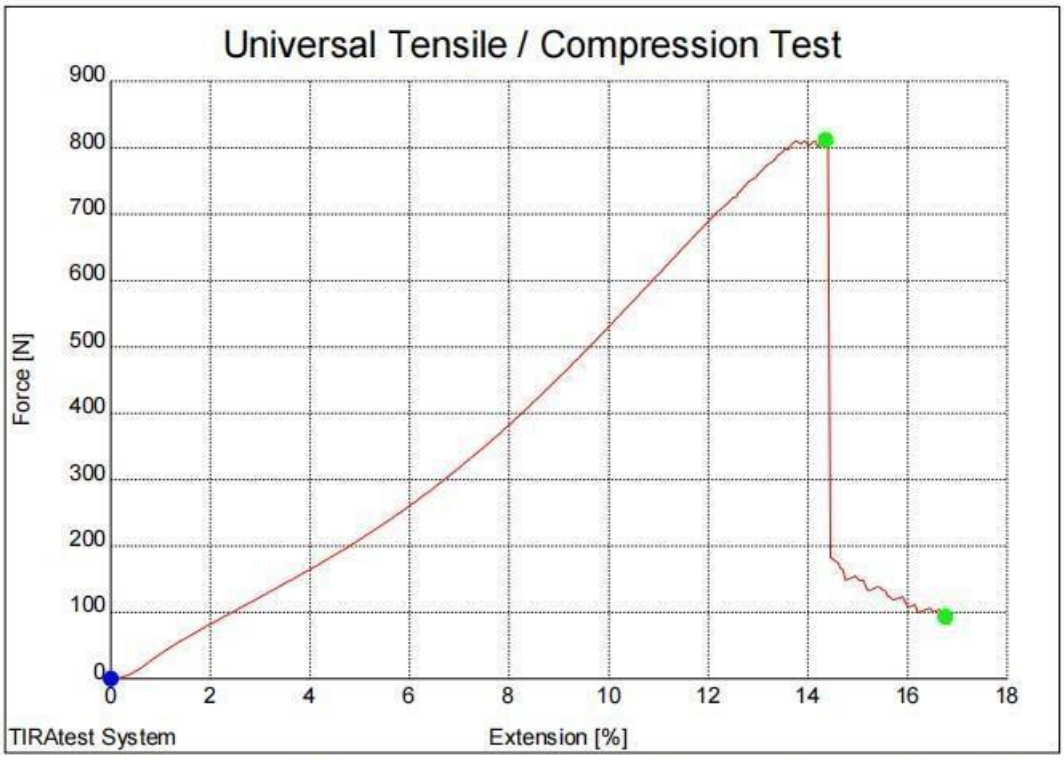
		FB N	RB N/mm²	AB %	dLB mm
2	x	83.71	2.58	15.78	23.68

Images:

Figure 91PVC Canvas Fabric Testing

Calculations:
Breaking point = Stress = 26.63 N/mm2 Strain = 15.28%

Canvas Fabric:



	Comm.1	Comm.2	Date	Time	FH N	RH N/mm²	AH %	dLH mm
1	x		21.01.05	02:55	811.99	24.98	14.35	21.53

		FB N	RB N/mm²	AB %	dLB mm
1	x	93.22	2.87	16.75	25.13

Images:

Figure 92 Canvas Fabric Testing

Calculations:

Breaking point = Stress = 24.98 N/mm2 Strain = 14.35%

This suggests that PVC-coated polyester fabric demonstrated better strength and resilience when subjected to tension compared to the other materials. Its outstanding performance implies that it could be the best option among the fabrics tested for applications that demand
high durability and strength, like protective clothing or covers for industrial
equipment.

	Canvas Fabric	PVC Coated Canvas Fabric	PVC Coated Polyester Fabric
Strain Value	14.35 %	15.28 %	19.97 %
Strength	Low	Medium	High
Durable	Low	Medium	High

Chemical Resistance Test:
Chemical resistance testing plays a vital role in evaluating the longevity and performance of materials designed for environments that frequently encounter various chemicals. This evaluation process entails exposing materials, such as PVC-coated fabrics, to a range of chemical solutions including sodium hydroxide (NaOH), hydrochloric acid (HCl), sodium hypochlorite (NaOCl), and ammonia (NH4OH). By investigating the material's response to these chemicals, we can ascertain its level of resistance and its appropriateness for use in sewer systems and manhole cleaning tasks.
For the chemical resistance testing, samples of PVC-coated polyester fabric were prepared by cutting them into 1-inch squares. The chemicals used for the testing included:

Hydrochloric Acid (HCl) Test:
1. Prepare diluted HCl to reach a concentration of 10%.
2. Apply the diluted HCl to a specific area of the fabric.
3. Allow it to remain in contact with the fabric for a period of 30 minutes.
4. Afterward, rinse the area with water and check for any signs of degradation, discoloration, or damage.

Sodium Hydroxide (NaOH) Test:
1. Prepare diluted NaOH to achieve a concentration of 5%.
2. Apply the diluted NaOH to a different section of the fabric.
3. Let it sit for 1 hour.
4. Rinse the area thoroughly with water and inspect for any negative effects.

Sodium Hypochlorite (NaOCl) Test:
1. Create a diluted NaOCl solution to form a 5% bleach concentration.
2. Apply the diluted NaOCl to another part of the fabric.
3. Allow it to stay in contact with the fabric for 20 minutes.
4. Rinse the fabric well with water and evaluate for any changes.

Ammonium Hydroxide (NH4OH) Test:
1. Dilute NH4OH to a 5% concentration.
2. Apply the diluted NH4OH to a separate area of the fabric.
3. Let it remain in place for 45 minutes.
4. Thoroughly rinse the fabric with water and check for any reactions.

After the designated times, no visible changes were observed on the samples of PVC-coated polyester fabric, suggesting a strong resistance to the chemicals tested.

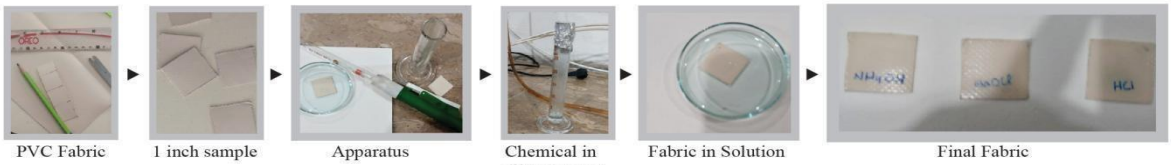


Figure 4 Chemical Resistance Test **Silver Ions Infusion:**

The technique of silver ion infusion entails embedding silver ions into a material to improve its antimicrobial features. This approach has garnered considerable interest across various sectors, including the textile industry, due to the strong antimicrobial effects of silver ions. By integrating silver ions into materials like fabrics, plastics, and coatings, producers seek to develop items that deter the proliferation of bacteria, viruses, and fungi, consequently lowering the risk of microbial contamination and the transmission of infections. In this chapter, we explore the silver ion infusion method and its role in boosting the antimicrobial properties of PVC-coated fabrics used in manhole cleaning uniforms.

Procedure for Silver Ion Infusion:

1. ***Formulate the Silver Salt Solution:*** Dissolve silver salt (for example, silver nitrate or silver acetate) in distilled water to create a silver ion solution. The concentration of this solution will depend on the desired efficacy and recommended application of the silver ions.
2. ***Fabric Treatment:*** Submerge or spray the fabric with the silver ion solution, making certain that the treatment is applied evenly to promote a uniform distribution of the silver ions.
3. ***Allow Absorption:*** Permit the fabric to absorb the silver ions by allowing it to remain in the solution for a designated timeframe. This step will ensure the ions penetrate into the fabric fibers.
4. ***Activation:*** Optionally, activate the silver ions by exposing the fabric to heat or UV light. This phase may enhance the efficacy of the silver ions in managing odor.
5. ***Rinse and Dry:*** After the absorption period, rinse the fabric thoroughly with water to eliminate any surplus silver ions that have not been taken up. Allow the fabric to air dry completely.
6. ***Testing:*** Once the fabric has dried, perform tests to evaluate its effectiveness in odor control. This can involve exposing the fabric to odor sources and assessing the decrease in odor intensity.

Result:

The fabric has been effectively infused with silver ions through the outlined process. Upon inspection, the fabric sample shows a distinct black mark, signifying the presence of silver ions embedded within the fabric fibers. This indicates successful infusion of silver ions, which is anticipated to improve the antimicrobial properties and odor control capabilities of the fabric.

Figure 5 Silver Ions Infusion

Design Development:

Costume Design:

In order to choose the ideal fabric for the uniforms of manhole cleaners, we have gathered information that contrasts different fabric materials based on essential characteristics. The table below illustrates the durability, water resistance, chemical resistance, odor management, and abrasion resistance of each fabric type. This evaluation seeks to determine the most suitable material capable of withstanding the tough requirements of this demanding job.

Fabric Selection Table

	Material name	Availability in Pakistan	Price	Anti odor	Properties					
					Chemical Resistent	Strength	Water Resistent	Breathable	Bacterial Free	Abrasion Resitant (Wear Resistent / Tear Resistent)
1	Heavy-duty nylon 	Online Ubuy Imported from USA store	PKR 4086 10 Yards 2 Inch Wide Black Nylon Heavy Duty Webbing Strap	MEDIUM	MEDIUM	HIGH	MEDIUM	LOW	LOW	HIGH
2	Reinforced polyester 	Khalis Fiber Private Limited (Lahore) 25 KM Raiwind Road Raiwind		LOW	MEDIUM / HIGH	HIGH	HIGH	LOW / MEDIUM	LOW	HIGH
3	PVC-coated fabric 	City Textiles (Pvt) Limited		LOW	MEDIUM	HIGH	HIGH	LOW	MEDIUM	HIGH
4	High-Density Polyethylene (HDPE) 	resin-impex-avenue (raw material)		MEDIUM	MEDIUM	HIGH	HIGH	LOW	MEDIUM	HIGH
5	Rubberized Fabric 	AL-HAMD TRADERS		MEDIUM	HIGH	HIGH	HIGH	LOW / MEDIUM	MEDIUM / HIGH	HIGH
6	Polyurethane (PU)-Coated Fabric 	BAHLOL Located in Sialkot, Pakistan		MEDIUM	MEDIUM	HIGH	HIGH	LOW / MEDIUM	MEDIUM	HIGH

PVC Coated Fabric:

PVC-coated fabric is the perfect option for manhole cleaners, providing outstanding durability, excellent water resistance, and strong chemical resistance to guarantee the safety of the wearer. Its efficient odor control and superior abrasion resistance also improve comfort and lifespan during prolonged use. Therefore, PVC-coated fabric delivers unparalleled performance for this challenging profession.

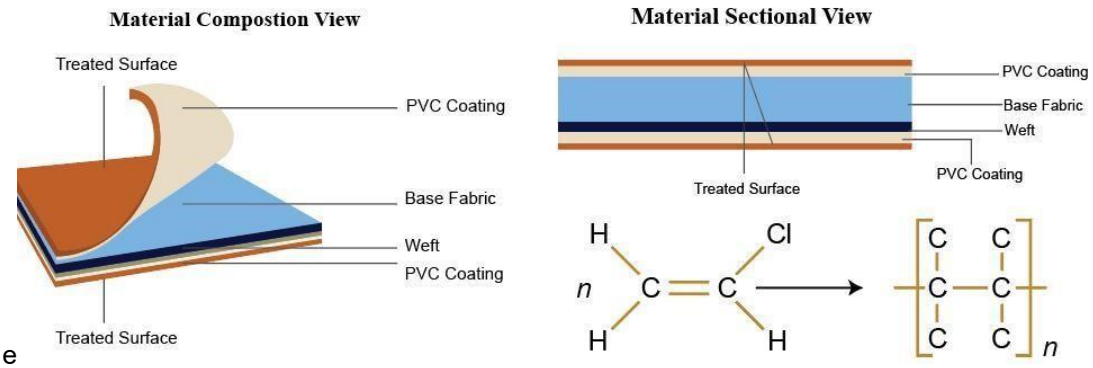


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Figure 6 Sectional View of the fabric

Figure 8 Fabric Manufacturing Process

Silver Infused Fabric:
In the previous chapter, we discussed the creation process of silver-infused fabric, which harnesses the antimicrobial properties of silver. By integrating silver into the fabric matrix, we not only enhance its durability but also enable it to resist microbial growth, promoting hygiene and ensuring longevity in various settings. This innovative fabric offers exceptional protection and performance due to its antimicrobial properties, making it an ideal choice for applications where cleanliness and durability are paramount.

Concept Development:
In developing the design for manhole cleaners' uniforms, we draw inspiration from current workwear and a range of materials. By analyzing the practicality of existing uniforms and investigating different fabrics, we seek to create inventive solutions specific to the distinct requirements of this job.

Figure 10 Costume Concept Development

Color Psychology:
Color psychology investigates the influence of various colors on human feelings, actions, and views. The colors you have selected can be interpreted in the following ways:

Orange: Often associated with warmth, enthusiasm, and energy, orange can evoke feelings of vitality and optimism. It's a vibrant color that can grab attention and stimulate creativity. In the context of a work uniform for manhole cleaners, orange could convey a sense of alertness and visibility, helping workers stand out in potentially hazardous environments.

Blue: Blue is commonly linked to feelings of calmness, stability, and trustworthiness. It's a soothing color that can promote a sense of security and reliability. Using blue in the costume, particularly in areas other than the head and shoulders, may create a balanced look while instilling a sense of professionalism and dependability.

Grey Reflective Strips: Grey is often associated with neutrality and balance. In combination with reflective strips, it adds a practical element to the costume, enhancing visibility and safety, especia lly in low-light conditions. The reflective nature of the strips ensures that the wearer remains visible and easily identifiable promoting safety in the workplace.

Size Chart:
The costume's size chart has been thoughtfully designed to suit a variety of male heights, specifically for those between 5 feet 7 inches and 6 feet tall. Available in small, medium, and large sizes, each option is customized to fit diverse body proportions, allowing wearers to choose the size that aligns with their height and physique.

Size		Small (S)	Medium (M)	Large (L)
A	Uppar Body Length	30”	32”	34”
B	Outseam	40”	42”	44”
C	Inseam	32”	34”	46”
D	Neck	15”	16”	17”
E	Chest Width	38”	40”	42”
F	Waist Width	34”	36”	38”
G	Hip Width	32”	34”	36”
H	Sleeves Width	13”	14”	15”
I	Sleeves End	06”	09”	10”
J	Sleeves Length	24”	26”	28”
K	Full Body Length	64”	66”	68”

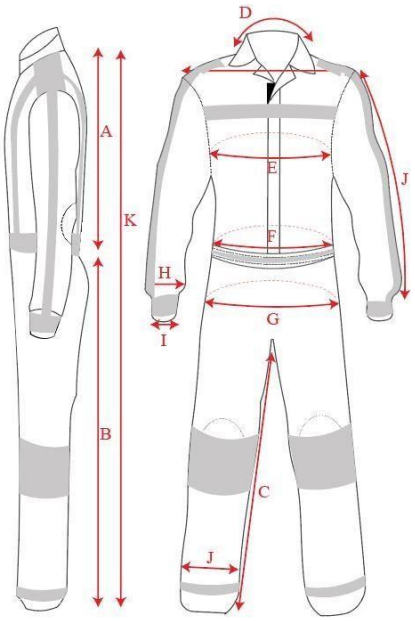

Table 3 Uniform Size Chart

Piece Part Drawing:
This detailed drawing of the components will aid in the careful stitching process by specifying the exact locations for button placement and outlining the necessary cuts needed for consistent assembly. It acts as an all-encompassing reference, promoting smooth production and guaranteeing accuracy in the creation of the final garment.

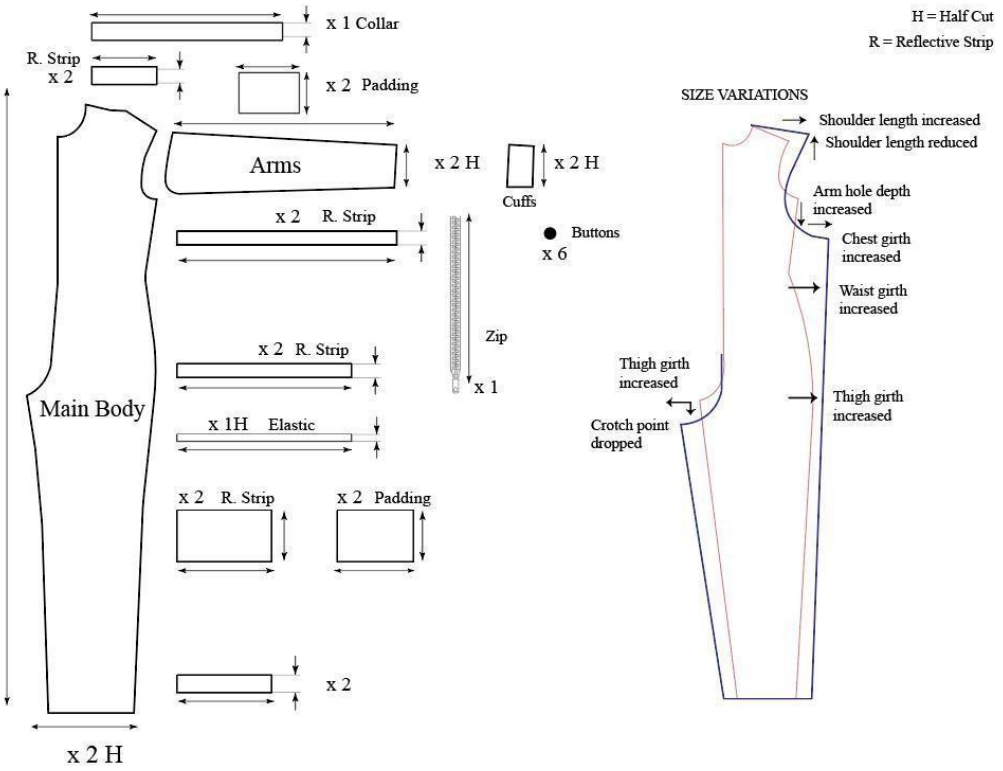

Figure 9 Piece Part Drawing

The Features of Costume are following:

Features	Description	Benefit
Durability	Made from high-quality materials designed to withstand tough everyday usage and challenging work conditions.	Guarantees enduring performance and worth.
Water Resistance	Designed to keep moisture at bay and ensure that workers remain dry, even in humid and damp environments.	Improves comfort and safety.
Chemical Resistance	Creates a safeguarding shield against hazardous substances frequently found in manhole conditions.	Protects against dangerous exposure.
Odor Control	Incorporated odor-eliminating technology ensures the clothing remains fresh even after extended wear.	Preserves cleanliness and fosters user trust.
Abrasion Resistance	Reinforced materials help resist damage, even during heavy and frequent usage.	Extends the longevity of the uniform.
Breathability	Enables adequate airflow to control temperature and minimize moisture accumulation.	Maintains a cool, dry, and comfortable environment for workers.
Lightweight Design	Using lightweight materials reduces tiredness during long periods of work.	Enhances mobility and effectiveness.
High Visibility	Reflective features enhance visibility in dim or dangerous situations.	Improves safety and lowers the likelihood of accidents.

Comfort Fit	Designed for comfort to enable free movement while still presenting a polished appearance.	Enhances productivity and adaptability.
Antimicrobial	Enhanced with antimicrobial treatments such as silver ions to inhibit the growth of bacteria and control odors.	Enhances cleanliness and decreases health hazards.
Available Sizes	Available in Small, Medium, and Large to accommodate different body shapes and preferences.	Guarantees an ideal and cozy fit.

Discussion:

The investigation into creating specialized uniforms for manhole cleaners sheds light on the significant challenges faced by these workers and underscores the necessity for resilient, protective solutions. Manhole cleaners encounter extreme working conditions, including dangerous chemicals, toxic gases, and pathogens. Despite their crucial function, a deficiency in adequate protective gear exposes them to serious health risks, including respiratory ailments and infections.

Material analysis identified PVC-coated polyester fabric as the ideal option, providing durability, resistance to water, and strong chemical resistance—key attributes vital for shielding workers in contaminated and wet environments. Furthermore, the antimicrobial properties of silver-infused fabric improve hygiene by reducing bacterial growth, a major concern in sanitation roles. These combined attributes not only physically safeguard the workers but also tackle comfort-related issues such as odor management and abrasion resistance, promoting sustained productivity during extended work hours.

Responses from worker surveys and interviews accentuated the significance of protective clothing. Around 78% of participants indicated that enhanced uniforms would bolster their confidence and elevate work efficiency. These insights highlight the psychological and operational advantages of customized workwear, which can boost workers' morale and performance. Additionally, conversations with WASA coordinators and supervisors revealed that, while machinery is accessible, the lack of adequate personal protective equipment (PPE) persists as a primary issue.

Nevertheless, the study has its limitations. The sample was confined to Lahore and included only male participants. Moreover, the results are based on laboratory assessments; further evaluations in real-world settings are necessary to confirm the fabric's long-term effectiveness in resisting chemicals, bacteria, and other contaminants.

Looking ahead, incorporating this material into a complete work kit, which includes masks, gloves, and tools, could considerably enhance worker safety. Additionally, collaboration between government and private sectors is essential to implement these solutions widely, ensuring that manhole cleaners throughout Pakistan have access to standardized protective apparel. Bridging these systemic gaps will not only enhance workers' safety and dignity but will also positively impact public health and urban sanitation.

Conclusion:

This research underscores the critical necessity for tailored protective equipment to enhance the working conditions of manhole cleaners in Pakistan. By recognizing silver-infused PVCcoated polyester fabric as a long-lasting and antimicrobial option, the study provides a viable solution to mitigate the considerable health and safety dangers encountered by these workers. The fabric's resistance to water, chemicals, and its antimicrobial features render it well-suited for challenging environments, ensuring both safety and comfort.

The results further highlight that enhanced uniforms can significantly boost workers' confidence, safety, and performance. Although the investigation was constrained by a limited sample size and laboratory assessments, future studies should concentrate on field experiments to confirm the fabric's efficacy in practical settings.

Implementing these solutions necessitates collaboration among government entities, private sectors, and policymakers to guarantee scalability and accessibility. By emphasizing the safety and dignity of manhole cleaners, this research aids in the enhancement of urban sanitation systems, public health, and the overall living standards for these vital workers.

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