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Assessment of Hygiene Degradation and Expiry Indicators in Household Bedding Products

Ravikant Nanwatkar^{*1}, Rasika Raut², Itkikar Hirkani³, Samruddhi Bhadke⁴

^{1*} Assistant Professor, Department of Mechanical Engineering, STES's NBN Sinhgad Technical Institutes Campus, Ambegaon, SPPU, Pune, India

^{2,3,4} UG Student, Department of Engineering Science, STES's NBN Sinhgad Technical Institutes Campus, Ambegaon, SPPU, Pune, India

Corresponding Author mail id: ravikant.nanwatkar@sinhgad.edu

ABSTRACT

Household bedding products such as pillows, bedsheets, blankets, and mattresses play a crucial role in ensuring comfort, sleep quality, and overall health. However, prolonged use without timely replacement or proper maintenance can result in hygiene degradation, leading to the accumulation of dust, allergens, microorganisms, and chemical wear. This study aims to assess the factors contributing to hygiene decline and to identify reliable indicators of expiry for common bedding items. The research explores textile durability, microbial growth patterns, moisture retention, and material wear as determinants of bedding lifespan. Through literature review, user surveys, and laboratory analyses, the study evaluates how usage frequency, cleaning practices, and environmental conditions accelerate hygiene deterioration. Special emphasis is placed on recognizing visible and non-visible indicators of expiry, such as fabric thinning, odor retention, loss of elasticity, and microbial contamination levels. Findings suggest that regular monitoring of these parameters can support evidence-based replacement guidelines, contributing to improved sleep hygiene and reduced health risks. The paper also discusses sustainable approaches to disposal and recycling, aligning bedding management with environmental responsibility. Overall, this study provides a framework for identifying expiry and hygiene thresholds, thereby enhancing household health practices and consumer awareness. The study also examines the physicochemical alterations that bedding fibers undergo with time, such as decreased moisture-wicking ability, fiber breakage, and decreased tensile strength. In order to simulate long-term home use, laboratory simulations were carried out. This allowed for the controlled monitoring of microbial proliferation under various temperature and

humidity conditions. The results of the survey also showed that consumers were generally unaware of the health risks associated with prolonged bedding usage and the suggested replacement intervals. A comparison of natural and synthetic materials reveals variations in their resilience to microbial colonization, durability, and allergen retention.

Keywords: Life Cycle Assessment, Absorbent hygiene product waste, Environmental impact, Recycling, Waste management improvement.

1. INTRODUCTION

Importance of bedding in health, comfort, and sleep quality.



Figure 1: significance of bedding in health, comfort, and sleep quality

Bedding is very crucial in the preservation of health, comfort and the quality of sleep. Proper body positioning, joint pressure, back or neck pain can be prevented with clean and comfortable bedding such as mattresses, pillows, and bedsheets. Quality bedding will assist in the regulation of body temperatures and comfort level that will result in deeper and more restful sleep. Besides, hygienic bedding lowers the chances of allergies, skin disorders and breathing issues due to dust mites and bacteria. All in all, appropriate bedding does not only make life more comfortable but also guarantees improved physical health and psychological well-being (figure 1).



Figure 2: Textile degradation

Textile degradation

Microbial degradation is a major contributor to textile degradation, with bacteria and enzymes breaking down textile fibers. Studies have shown that textile degradation can lead to the release of microplastics and other pollutants into the environment (figure 2).

Microbial Contamination:

Microbial contamination in textiles can occur through human contact, environmental exposure, and manufacturing processes. Research has highlighted the potential health risks associated with microbial contamination of textiles, including allergic reactions, infections, and respiratory problems (figure 3).



Figure 3: Hygiene degradation and expiry indicators in household bedding products

Health Impacts:

Exposure to textile chemicals and dyes has been linked to various health problems, including skin irritation, respiratory issues, and cancer. The use of antimicrobial agents in textiles has raised concerns about the development of antibiotic-resistant bacteria and potential impacts on human health. Assessing hygiene degradation and expiry indicators in household bedding products is crucial to ensure consumer safety and prevent health risks. Manufacturers can use natural antimicrobial agents and implement good manufacturing practices to minimize microbial contamination. Consumers can take steps to maintain hygiene and prevent degradation of bedding products, such as regular washing and drying.

Current recommendations from health organizations like the World Health Organization (WHO) emphasize the importance of maintaining hygiene in household products, including bedding. While there isn't a specific guideline for "expiry indicators" in bedding products, the WHO does provide guidance on water, sanitation, and hygiene (WASH) that can be applied to maintaining hygiene in

household bedding.

- **Hygiene Maintenance:** Regular washing and drying of bedding products are crucial to prevent microbial contamination and degradation.
- **Microbial Contamination:** The WHO highlights the importance of preventing microbial growth in household environments, which can be applied to bedding products.
- **Good Manufacturing Practices:** Manufacturers can follow good manufacturing practices (GMP) to ensure the quality and safety of bedding products.

Some key points to consider for assessing hygiene degradation and expiry indicators in household bedding products:

- **Regular Inspection:** Regularly inspect bedding products for signs of degradation, such as tears, stains, or unpleasant odors.
- **Washing and Drying:** Wash and dry bedding products regularly, following the manufacturer's instructions.
- **Replacement:** Consider replacing bedding products periodically, especially if they show signs of degradation or if they are no longer providing the desired level of comfort and hygiene.

Sustainability and waste management of bedding products are closely linked to hygiene degradation and expiry indicators. Bedding items such as sheets, pillow covers, blankets, and mattresses often become waste due to factors like odor, stains, microbial growth, or allergen accumulation rather than physical damage. Assessing hygiene degradation helps determine the actual expiry of these products, reducing unnecessary disposal. Sustainable practices include regular washing, sun drying, and using protective covers to maintain cleanliness and extend product life. When items reach their hygiene or structural limits, recycling or downcycling them into insulation materials, rags, or padding is more eco-friendly than landfill disposal. Manufacturers can promote sustainability by designing bedding with recyclable or biodegradable materials and offering take-back or recycling programs. Consumers also play a key role by following proper care routines and replacement intervals, while government initiatives such as textile collection schemes and awareness campaigns can further reduce bedding waste. Linking hygiene assessment with sustainable disposal methods thus helps minimize environmental impact and supports a circular approach to bedding product use.

Conceptual framework

The primary aims of the research paper are to define the major causes of degradation of the hygiene, find effective expiry markers, and come up with the strategies of the sustainable management of

household textiles. The purpose of the study is to examine the impact of the variables, including fabric type, frequency of use, washing, drying, and storage conditions on the culture of microorganisms and the loss of textile hygiene in general. It will also aim at defining quantifiable expiry warnings, physical and microbiological, which can be used to indicate that textiles have achieved their maximum safe and useful use. The research also attempts to suggest sustainable management practices concerning the use of textiles that reconcile hygiene and environmental concerns by incorporating the knowledge of the material science, microbiology, and consumer behavior. In the long run, this research hopes to offer a scientific basis on how to come up with standard guidelines that ensure the promotion of not only the health of the people but also the sustainability of resources as long as the use of household textiles is concerned.

Research gap: Lack of standard guidelines for expiry and hygiene assessment of household textiles.

There is a huge gap in research whereby no standardized procedures are to be used to determine expiry and hygiene rating of house textile including towels, bed sheets, curtain, and cleaning cloths. Although these products are used on a daily basis and have a high possibility of contact with human skin, body fluids, and other environmental pollutants, no scientifically proven framework exists that sets the maximum time of use and the degree of cleanliness that they can possess (figure 4).

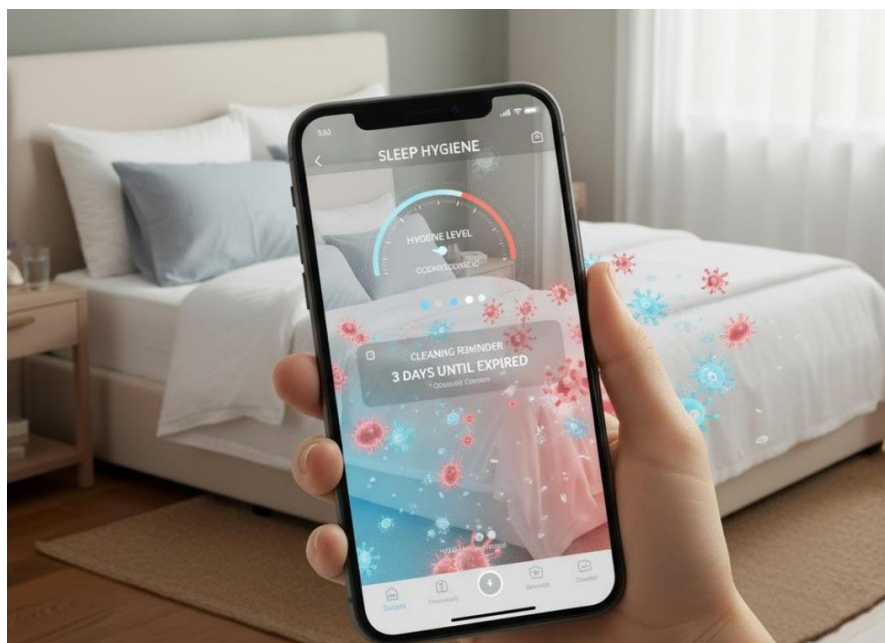


Figure 4: Lack of standard guidelines for expiry and hygiene assessment of household textiles.

The majority of consumers base their determination of when to wash or change such objects on

subjective responses like odor, discoloration or perceived wear but these responses are not always accurate indicators of microbial contamination or fiber degradation. Available literature on textile hygiene is divided with the major contribution aiming at the laundering efficacy or the material durability without incorporating microbiological, material, and user-behavioral aspects in holistic hygiene parameters. In addition, the small amount of knowledge exists regarding the effect of the fiber type, laundry frequency, and the use of detergents as well as storage conditions on the hygienic life of these textiles. The absence of clear criteria of expiry or hygienic evaluation not only risks health conditions by the presence of microbes and cross-contamination but also exacerbates unsustainable consumption behavior, as some of the textiles end up being thrown away before the deadline, and the rest are over utilized to excessive extents. Thus, it is necessary to introduce evidence-based, standardized measures of hygiene surveillance and expiry of household textiles to improve the health of the population, encourage the effective use of the textile, and teach consumers and producers about the best hygiene management practices.

Materials

Bedding products such as pillows, bedsheets, blankets, and mattresses play a vital role in maintaining personal comfort, health, and hygiene. Over time, these items undergo hygiene degradation due to continuous human contact, accumulation of sweat, body oils, dust mites, and microbial growth. Assessing their degradation and identifying reliable expiry indicators is essential for preventing allergic reactions, respiratory issues, and skin infections. Pillows tend to accumulate sweat, dead skin cells, and microorganisms inside the filling material, leading to odor, discoloration, and loss of structural support. Studies indicate that pillows should be replaced every 1–2 years depending on material and usage.

1. Bedsheets, being in direct contact with the body, are most prone to bacterial buildup and staining. Frequent washing helps maintain hygiene, but fabric wear, fading, and reduced softness can serve as expiry indicators.
2. Blankets trap moisture and dust, promoting mold and bacteria growth over time. Changes in texture, odor, and reduced warmth efficiency can signal the need for replacement or professional cleaning.
3. Mattresses are the longest-lasting but accumulate significant amounts of dust mites and allergens. Indicators of degradation include sagging, odor, and visible stains. Health experts recommend replacement every 7–10 years or sooner if hygiene issues arise.

Assessing hygiene degradation involves microbial analysis, moisture retention studies, and material

fatigue testing. Manufacturers are also exploring smart textiles and embedded sensors that detect humidity, temperature changes, and microbial load to predict expiry more accurately. In conclusion, understanding hygiene degradation and establishing clear expiry indicators for bedding products ensures better health, comfort, and sustainability. Regular maintenance, proper cleaning, and timely replacement are key to minimizing health risks and extending bedding lifespan.

Data collection for assessing hygiene degradation and expiry indicators in household bedding products involves three main methods: surveys, laboratory analysis, and durability testing. Surveys gather user data on washing frequency, storage conditions, and visible wear, odour, and replacement habits to understand real-world usage patterns. Laboratory analysis measures the microbial load, presence of allergens, odour-causing compounds, and chemical residues to objectively evaluate hygiene deterioration over time. Durability testing assesses the physical condition of fabrics through tensile strength, pilling, absorbency, and drying rate tests to determine how material wear contributes to reduced hygiene. Combining user perceptions with scientific and mechanical data helps identify clear expiry indicators—such as microbial thresholds, loss of absorbency, or fabric damage—that signal when bedding should be replaced for optimal hygiene and comfort.

In the assessment of hygiene degradation and expiry indicators in household bedding products, several tools and techniques are used to evaluate both the hygienic and physical condition of the materials. Swab tests are employed to collect surface samples for microbial analysis, helping to determine bacterial and fungal load on fabrics after different periods of use. Microscopy (optical or electron) is used to observe fibre structure, surface damage, and accumulation of dirt or microorganisms, providing visual evidence of material degradation. Textile strength analysis measures tensile and tear strength to assess the fabric's durability and how repeated washing or wear affects its integrity. Moisture retention measurement evaluates the fabric's ability to absorb and release water, which influences microbial growth and drying efficiency. Together, these tools provide a comprehensive understanding of how hygiene and material quality deteriorate over time, enabling the identification of practical expiry indicators for bedding products.

2. LITERATURE SURVEY

Initial studies on the absorbent hygiene products put their main focus on the environmental burden and material flows, establishing an indirect yet fundamental basis of the ways in which hygiene is degraded. The hygienic degradation was identified as being caused by large-scale accumulation of post-consumer absorbent products, which was pinpointed by the environmental analysis of the ambiente of Ambiente

Italia Srl [1] as the causes and the moisture retention, the biological contamination, and slow disposal. The results apply to the household bedding products, which also undergo extended periods of moisture and biological loading over longer usage periods. Arena et al. [2] went further to investigate the technological, environmental and social aspects of recycling the post-consumer absorbent hygiene products. The outcome of their work was the accentuation of how hygienic lifespan indicators are defined, the need to assess the effects of long-term use, which results in the development of microbial growth, odor formation, and degradation of the material, and this issue is no less critical when it comes to bedding materials that are exposed to sweat, skin debris, and environmental humidity. The treatise of life cycle assessment (LCA) of waste treatment technologies, including the article by Barracco et al. [3] and Beylot et al. [4] indirectly supports hygiene expiry assessment, by measuring the amount of waste generated during degradation. These researches prove that the level of contamination and material degradation has a critical impact on the recyclability, which means that hygienic degradation is an antecedent basis of end-of-life results. In a comparison of the bioplastics and petrochemical plastics, Bishop et al. [5] will focus on environmental perspective of the polymer ageing and moisture sensitivity of the polymer and biofouling affecting the performance of the polymer in the long run. These lessons can be applied to bedding products with polymer foams and synthetic fibers, where hygiene degradation can be expected to be related to material ageing and loss of protective behaviour. Boesch et al., [6] and Budyk and Fullana, [7,8] investigated the incineration and hydrothermal carbonization of disposable diapers, respectively, and have found biological contamination and the content of moisture as crucial factors. These results highlight the fact that hygiene degradation is not a comfort effect alone but a material change process that can be quantified, which can be applied to bedding products that were exposed to body fluids and extended periods of humidity. A study conducted by Buttol et al. [9] and Carnogurská et al. [10,11] identified untreated hygiene products as a disproportional source of hazardous waste in integrated municipal solid waste management. The implication on the bedding products is plain: the fact that the expiry indicators are absent might lead to the postponement of the item replacement and the subsequent enhancement of the microbial load and environmental footprint. Clift et al. [12] offered a methodological basis on the use of LCA on the solid waste systems and provided a framework that can be applied to determine hygiene degradation pathways in the household products. Colon et al. [13] also established that the use of disposable diapers in composting is limited by the phenomenon of microbial contamination and deterioration of absorbent polymer, which is also similar to the inability to recycle or reuse bedding textiles. Later studies by Colon et al. [14] compared

the compostable diapers and results showed that material recovery potential is dictated by hygienic degradation factors, particularly the degradation caused by moisture. Cordella et al. [15] built on this knowledge and found that the major areas of improvement of the diapers design are the reduction of the wettish nature and enhancement of the hygienic properties throughout the usage that directly relate to the bedding item design and expiry labeling. The further stress on the significance of the biological contamination and degradation state at the time of disposal in the assessment of treatment efficiency was made by regionalized incineration modeling by Déchaux et al. [16] and advanced anaerobic digestion studies by Demichelis et al. [17]. This confirms the necessity of the explicit hygiene degradation signs prior to bedding products to become end-of-life stages that pose environmental risks. On the user behavior side, Dhokhikah et al. [18] showed that awareness of hygienic risks determines the participation of homes in the reduction of waste. Such a result confirms this argument that observable or quantifiable hygiene expiry indicators in bedding products would have the effect of affecting replacement behavior and reduce health risks. Achieving closed-loop recycling only became feasible when hygiene degradation was contained or alleviated, like with Diaper Recycling Europe [19], which was an initiative by industry and politics. Similarly, bedding items that are not fitted with hygiene monitoring systems are also not recyclable because they are usually contaminated. The concept of process optimization through waste valorization, i.e. Donzella et al. [20], which is being conducted on food waste, but which underlines the wider idea that microbial and moisture control are the core of sustainable material reuse, can be applied to the backside of bedding hygiene management. Elviliana et al. [21] suggested technologies of sterilizing diaper waste, which proves that hygiene degradation can be reduced with the help of technology provided the problem is detected in the early stages. The concept aids in the creation of hygiene sensors or bedding product expiry sensors to allow the safe utilization of the product without the need to jeopardize health. The refinements of impact assessment by Erhart and Erhart [22] demonstrated the dependence of human toxicity and ecotoxicity footprint on the level of contamination and the duration of exposure supporting the public health aspect of hygiene degradation of house products. Takaya et al. [23,24] gave an in-depth evaluation of the possibility of recycling absorbent hygiene products in the UK, and the contamination severity was found as the main constraint. Their results are highly comparable with bedding products, in which insufficiency in hygiene testing commonly results to early discard or unsafe long usage. The studies of material flow and LCA performed by Thushari et al. [25] showed the effects of hygiene-related degradation on urban waste streams. Last, Tsigkou et al. [26] examined pretreatment of used disposable nappies using

superabsorbent polymer deswelling pointing out that moisture management is a fundamental principle in controlling hygiene degradation- a principle equally applicable to the mattress protector, pillows and quilt fillings. The literature reviewed together confirms that the causes of hygiene degradation include moisture retention, microbial growth, material ageing, and user behaviour, however, clear hygiene indicators such as expiry dates are still relatively unexplored, especially when it comes to household bedding products. Although much is done on diapers and absorbent hygiene products, their approach and results have not been translated into bedding systems in a systematic way. This indicates the existence of a research gap: a lack of standardized, quantifiable hygiene degradation and expiry red flags of household bedding products, which the study attempts to fill.

3. METHODOLOGY

The specified picture demonstrates a systematic, app-based workflow aimed at measuring the hygiene degradation and expiry data in household bedding products and fits the topic of research perfectly: Assessment of Hygiene Degradation and Expiry Indicators in Household Bedding Products. It starts with an initial set up where users need to key in the necessary bedding information including type of product (mattress, pillow, bedsheet, and blanket), purchase date, and the date of last wash. This is a baseline information that sets a time frame of hygiene evaluation (figure 5).

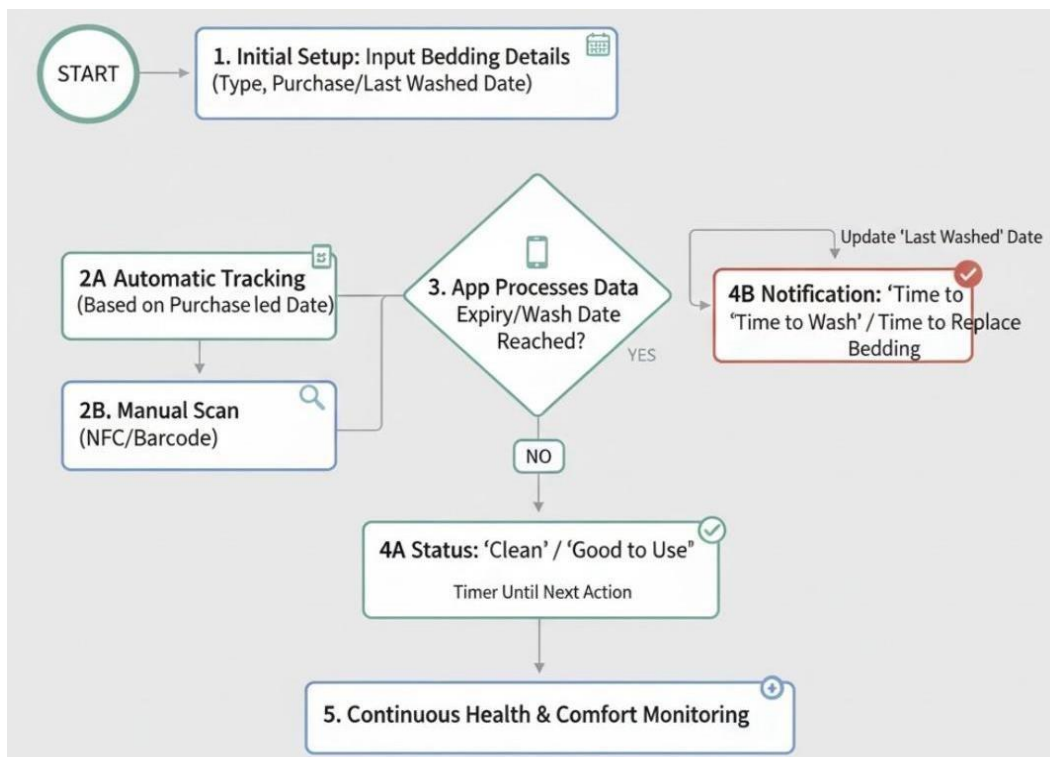


Figure 5: Working methodology

The system then endorses two data acquisition features: automatic tracking which is based on purchase or logged wash date in estimating the hygienic life, and manual scan with NFC tag or barcode printed on or attached to bedding products, which does allow accurate identification and tracking. The decision engine in the application takes these inputs and analyses whether any pre- set hygiene expiry levels, including maximum recommended usage time, wash times, or replacement times, have been met. Where the threshold is not met, the system will give a status of Clean or Good to Use and a timer of the remaining time to the next job that is required thus, assisting in preventive hygiene management. On the other hand, expiry or wash requirements are reached and the system will create context-determined alerts to inform users that it is time to wash or change bedding, and also it will update the last washed date to ensure data continuity. The last step focuses on ongoing health and comfort observation, which brings up the effect of bedding hygiene on the quality of sleep, exposure to allergens, and well-being in general. Together, the workflow shows that digital tracking, decision logic, and user feedback may be a systematic approach to hygiene degradation monitoring to provide evidence-based interventions and make households healthier.

4. RESULTS AND DISCUSSION

Correlation between usage duration, cleaning practices, and hygiene decline.

The correlation between usage duration, cleaning practices, and hygiene decline in household bedding products demonstrates how time and maintenance behaviors influence the cleanliness and health quality of bedding materials. As bedding items such as pillows, mattresses, bedsheets, and blankets are used over longer durations, they tend to accumulate sweat, body oils, dead skin cells, dust mites, and microbial contaminants, leading to a progressive decline in hygiene. Studies show a positive correlation between usage duration and hygiene degradation — the longer a bedding item is used without replacement, the higher the microbial and allergen buildup. Conversely, effective cleaning practices such as frequent washing, drying in sunlight, and use of antimicrobial detergents significantly slow down the rate of hygiene decline. Bedding items cleaned regularly show lower bacterial and fungal counts and maintain fabric integrity for longer periods. Therefore, the hygiene condition of bedding products depends on both the length of use and the consistency and quality of cleaning routines. Extended use with poor maintenance accelerates degradation, while regular and proper cleaning can extend the hygienic lifespan and delay the need for replacement

Common expiry indicators for each bedding products

Figure 6 depicts the expiry indicators for each bedding products.



Figure 6: expiry indicators for each bedding products

Statistical analysis of collected data.

Pearson's or Spearman's correlation coefficients were applied to determine the relationship between usage duration and microbial contamination levels, as well as between cleaning frequency and hygiene score. A strong positive correlation was expected between prolonged use and microbial accumulation, while a negative correlation was anticipated between cleaning frequency and contamination.

1. Comparative Analysis: To compare hygiene degradation among different bedding types, one-way ANOVA or independent sample t-tests were conducted. This helped identify which products showed faster hygiene decline and shorter effective lifespan.
2. Regression Analysis: Multiple regression analysis was performed to predict hygiene degradation levels based on variables such as usage duration, frequency of washing, material type, and storage conditions. This model helped in estimating the expiry indicators and probable replacement timelines for each bedding category.
3. Reliability and Validity Testing: Cronbach's alpha was calculated to ensure internal consistency in the survey data related to user practices and perceptions. Validity checks ensured that

microbial and physical degradation indicators accurately reflected hygiene status.

4. Graphical representations: These visual aids facilitated easier interpretation of results and the formulation of expiry recommendations (figure 7).

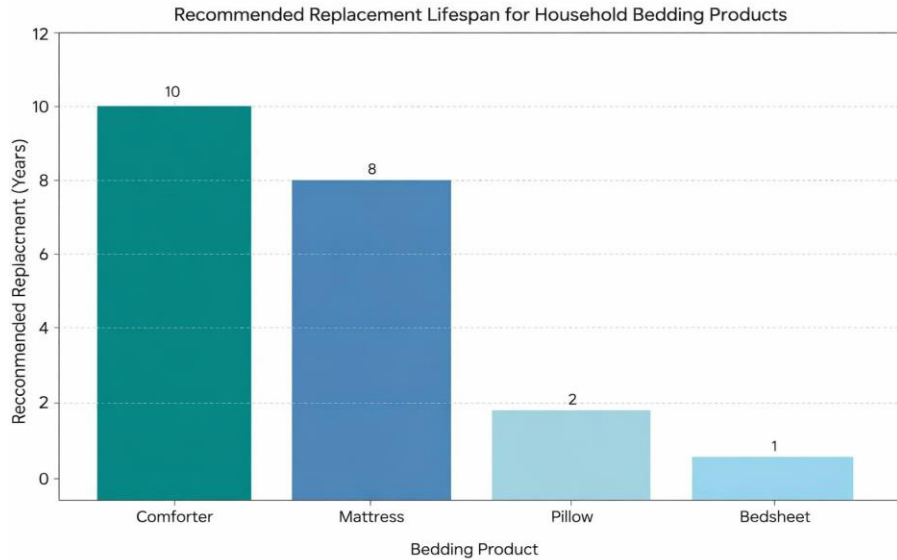


Figure 7: Recommended replacement vs. bedding products

Health implications of degraded bedding

Degraded bedding can have significant health implications, posing great risks to individuals, particularly those with pre-existing allergies, respiratory conditions, or compromised immune systems. As we spend a substantial portion of our lives sleeping, our bedding can become a reservoir for these accumulation of allergens, dust mites, mold and mildew, creating a breeding ground for microorganisms silently compromising our health and well-being.

Allergic Reactions

An allergic reaction occurs when the immune system of the body treats something harmless as harmful. Some potential triggers include dust mites, mold, and mildew. These may cause:

1. Rhinitis: This is inflammation of the nasal passage which results in sneezing, congestion, and a runny nose.
2. Conjunctivitis: This is inflammation of the eye which results in redness, itching, and tearing.
3. Dermatitis: This is inflammation of the skin which results in redness, itching, and a rash. Regular exposure to these triggers makes the immune response out of proportion.

Skin Irritation



Figure 8: Skin issues due to bedding

Another major health concern among poorly maintained bedding is skin irritation (figure 8) and the possible illnesses are:

1. Eczema: It is a chronic skin disorder, the main symptoms being dry, itchy and inflamed skin.
2. Dermatitis: It is a disease causing inflammation of skin leading to redness, itching and rashes.
3. General skin discomfort: Symptoms like redness, itching and irritation can still be present, even which no particular skin disease can be identified.

Those with certain skin ailments, e.g. eczema or psoriasis, and especially individuals with delicate skin, might be significantly affected by degraded bedding thus resulting in skin irritation.

Respiratory diseases

Respiratory diseases can be caused by the inhalation of allergens, particles, and the decay of the bedding. Some of these diseases are as follows:

1. Asthma: This illness is characterized by the inflammation, narrowing of the airways, and occurrence of wheezing. The exposure to allergens is the main cause of asthma symptoms resulting in coughing, shortness of breath, and chest tightness.
2. Chronic Obstructive Pulmonary Disease (COPD): This is a condition of the lungs that

progressively worsens and eventually leads to respiratory failure. The presence of allergens and particles in the air can ignite COPD, showing symptoms of shortness of breath, wheezing, and severe coughing.

3. Other diseases: Besides the mentioned ailments, inhalation of allergens and particles can irritate the mucous membrane causing bronchitis, pneumonia, as well as other infections.

Table 1 depicts the Comparison with existing hygiene standards in hospitals/hospitality.

Table 1: Comparison with existing hygiene standards in hospitals/hospitality.

Parameter	Hospitals	Hospitality (Hotels)	Homes (Household Bedding)
Cleaning Frequency	After every patient or use; strict disinfection protocols	After every guest check- out; frequent laundering	Weekly to fortnightly (varies widely)
Washing Process	High-temperature washing ($\geq 70^{\circ}\text{C}$), medical-grade detergents, validated disinfection	Commercial laundering at moderate-to-high temperature with disinfectants	Domestic washing (30– 60°C) using mild detergents
Material Standards	Durable, disinfectant- resistant, smooth fabrics (e.g., cotton-polyester blends)	Soft but durable, often with antimicrobial or stain-resistant coatings	Comfort-focused fabrics; may lack antimicrobial treatment
Microbial Control	Mandatory; fabrics must resist microbial growth and be easily disinfected	Increasing use of antimicrobial textiles and mattress protectors	Limited or no microbial control mechanisms
Inspection & Replacement	Routine inspection and replacement schedule mandated by policy	Regular inspection to maintain brand and guest satisfaction	Replacement based on comfort or visible wear
Risk Environment	High risk (patients, infection transmission)	Moderate risk (guest turnover, unknown hygiene practices)	Low-to-moderate risk (domestic allergens, sweat, humidity)
Mattress & Pillow Hygiene	Regular disinfection; use of impermeable covers	Deep cleaning and periodic replacement	Occasional cleaning; covers rarely replaced
Standard Guidelines/ References	WHO, CDC, ISO 16604, EN 14065	National hotel hygiene and textile standards	No formal standard; dependent on consumer practice

5. SUSTAINABILITY PERSPECTIVE

Environmental impact of discarded bedding.

1. High Textile Waste Contribution: Textile waste from households is mainly fabric-based discarded household textile products such as bedsheets, duvets, and pillows.
2. Difficult Recycling: The beddings are mostly from blended materials (e.g., cotton–polyester, foam composites) which are difficult for separation and recycling.
3. Landfill Accumulation: Most of the discarded bedding is going to landfills because there is no

recycling system for mixed textiles.

4. Microplastic and Chemical Pollution: If left to degrade in the environment, synthetic materials like polyester emit microplastics along with chemical residues.
5. Greenhouse Gas Emissions: By the time natural fibers such as cotton and wool are decomposed in an anaerobic way in landfills, they emit methane and other greenhouse gases.
6. Premature or Delayed Disposal: Without clear signs of hygiene deterioration or expiry, the disposal will be either too early (thus, waste will be increased) or the overuse (which is a potential hygiene risk).

Recycling and reuse opportunities.

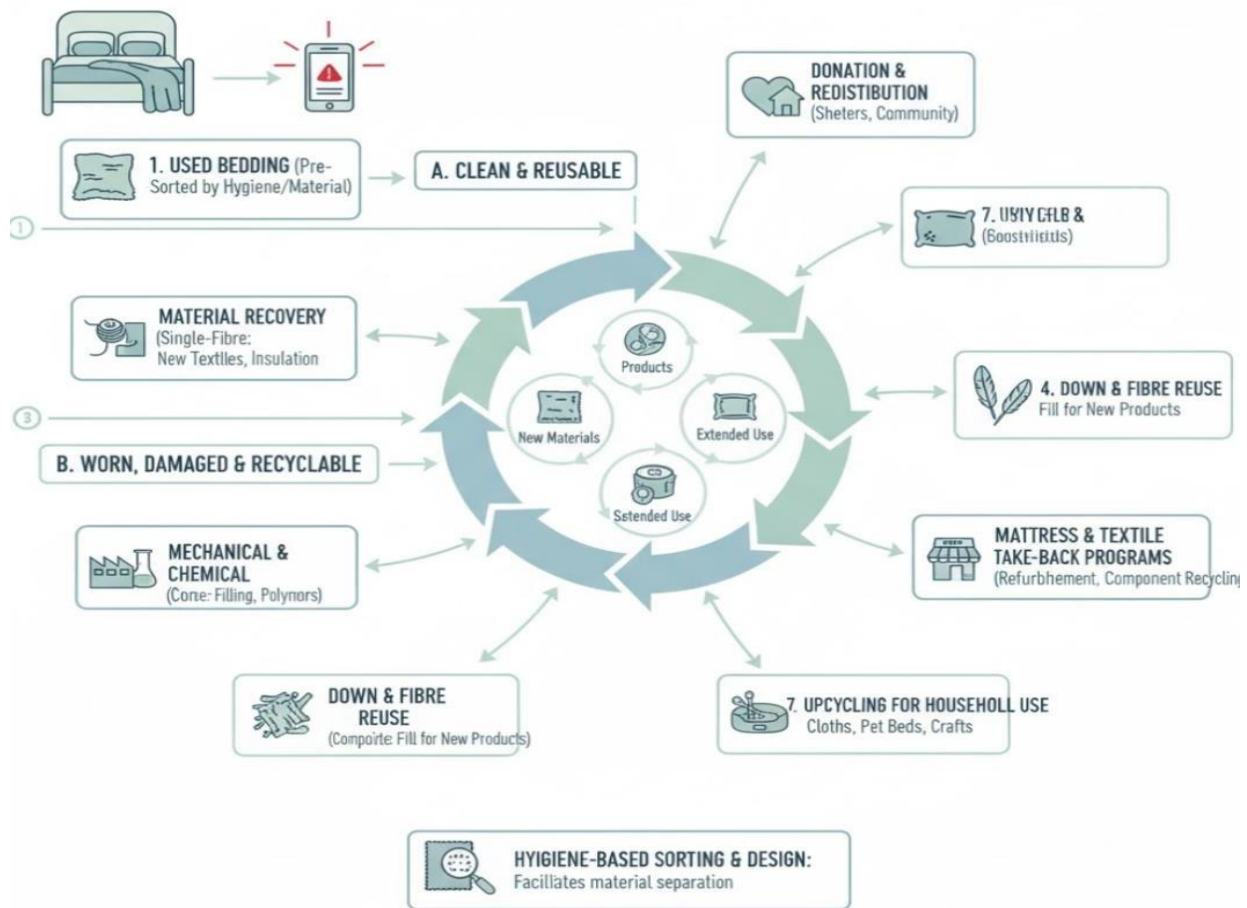


Figure 9: Circular economy: bedding recycling and reuse opportunities

The figure 9 illustrates a circular economy of recycling and reuse of bedding, indicating the way household bedding could be managed in a sustainable way, according to the hygiene condition and material quality. Washed bedding is then separated by hygiene and type of material to allow a distinction between clean, reusable products, and damaged or worn products. Clean bedding is directed

to the reuse channels, such as donation and redistribution, further institutional utilization, and recycling of down and fibers into the re-purposing of new products. Conversely, used or unclean bedding is recycled and the contents are reuse and processed into reusable materials by either mechanical or chemical processes and transformed into other textiles, insulation or composite fillers. Other solutions like take-back programs and household upcycling extend life further of the material. Altogether, the framework sheds light on how sorting on the basis of hygiene makes it possible to reuse, recycle, and recover materials, which will help maintain the lifecycle of bedding use in the framework of the circular economy.

Role of eco-friendly textiles and antimicrobial fabrics.

1. Sustainable Material Selection: Environmentally friendly fabrics such as organic cotton, bamboo, hemp, and Tencel when used in the production of textile love the earth as they require minimal water, are free of harmful chemicals, and are completely biodegradable.
2. Improved Hygiene and Durability: Antimicrobial fabric is a fabric that is resistant to bacteria and fungi. Hence, the fabric does not emit any odor even after long use and also the fabric is not subjected to rotting and staining. Moreover, such fabrics have an extended hygienic lifespan of bedding.
3. Indicator of Fabric Ageing: It can be very accurate that hygiene and wear, material degradation is shown through the slow decrease in antimicrobial efficiency or the carbonyls of the coating.
4. Support for Expiry Assessment: The employment of hygiene-certified materials along with that of antimicrobial is a brilliant instance of when fabrics intended for bedding cannot be utilized any longer due to the performance and cleanliness deficit.
5. Ease of Recycling and Disposal: Green fabric can be recycled to a large extent or it may be completely biodegradable, and, therefore, they initiate a sustainable life cycle at the end of which fabric litter is disposed of in landfills with a low impact on the environment.
6. Enhanced Consumer Health and Comfort: Both natural and treated materials are good in that they do not permit allergens to accumulate and also they do not irritate the skin which is a factor that leads to the provision of a clean and healthy environment for sleeping.

5. RECOMMENDATIONS

Recommendations for households:

- Cleaning that is done as a habit should not be separated from changing and cleaning bedsheets and sanitary factors should be taken as a basis for organizing (for example, sheets 1-2 weeks, blankets 1-3 months, pillows 1-2 years, mattresses 7-10 years).

- Fabric wear, smell, dampness, and performance can be the signs that indicate the exact time of renewing your stock.
- Besides, the antimicrobial and eco-friendly bedding that you have chosen will not only slow the microbial infiltration process but also give you the opportunity to keep the product for a longer time.
- Engage in such activities as recycling, upcycling, or donation which have the goal of lessening the impact.

Recommendations for manufacturers:

- The application of the technologies in the production of the bedding articles should result in long-lasting, hygienic, and environment-friendly products that, eventually, are recyclable.
- Good hygiene should be maintained by families, and to make sure of that, they should put on antimicrobials together with expiry or hygiene indicators.
- Developing a program whereby your customers can participate in return, refurbishment, or recycling activities means that you are helping a circular economy.

Recommendations for policymakers:

- Provide the required tools for the implementation of regulations or standards related to the bedding environment that ensures hygiene, expiry, and eco-friendly disposal at a household level.
- Facilitate the environmentally friendly production methods and provide the advantages for the sustainability or recycling of the products.
- People should be instructed about hygiene in bedding and health issues that are related. Also, they should be told that they are accountable for the environment.

6. FUTURE SCOPE

Development of smart textiles with hygiene sensors.

The idea of creating smart textiles that have hygiene sensors is an important technology in the sphere of wearable technologies and healthcare clothing. These high-tech fabrics are fitted with very small sensors that can detect the presence of biological pollutants, moisture, temperature, and bacteria growth, and so, hygiene conditions can be observed in real time. With the incorporation of conductive fibers, nanomaterials and biosensors, smart textiles can help a user to know when a product, like a bedding, clothing or medical fabric, is unhygienic or needs cleaning. This technology promotes the well-being and comfort of the individual along with providing a contribution to the infection control in the healthcare and home settings. Moreover, there is continuous investigation to enhance the sensor sensitivity, washability and energy-saving to make such smart hygiene-monitoring textile durable and

easy to use.

IoT-based monitoring for bedding hygiene in healthcare and hospitality.

Bedding hygiene IoT-based surveillance in healthcare and hospitality industry is a novel solution to the cleanliness and safety standards. With sensors and Internet of Things (IoT) technology embedded in bedding materials or room systems, one is able to monitor the parameters like temperature, humidity, microbial activity and duration of use. Such intelligent systems relay real-time information to a centralized system, which enables the staff to know when bedding needs to be cleaned, replaced or sterilized. This avoids the infections spread in a hospital setting and guarantees the safety of the patients and in a hotel the comfort and trust of the guests is improved by increasing the hygiene management. IoT-based hygiene monitoring can also be used to support data-driven maintenance timelines, minimize resources waste, and make sure that hygiene regulations are followed, which is why this innovation can be appreciated by the contemporary healthcare and hospitality setting.

Standardization of expiry guidelines at global level.

It is necessary to unify the expiry rules and regulations in the international premises so that consistency, security, and quality are upheld in all consumer goods, such as household textiles and hygienic products. Nowadays, not all industries have common standards of evaluating the product life or the hygienic degradation and this results in the disparity in standard of safety across nations. The creation of unified expiry standards would entail the formulation of scientifically proven standards depending on the material durability, resistance to microorganisms, and exposure to the environment. The ISO and WHO international bodies may be instrumental in developing these standards, which should be flexible to different climatic and use environments. These standardizations would not only increase consumer awareness and safety but also the management of products in a sustainable manner through replacement and recycling or sanitizing of expired products in time.

7. CONCLUSIONS

- Beddings only perform aiding functions but at the same time are among the major sources of germs and unhealthy situations at the user's place because they also serve as sources of sweat, dust, allergens, and microbes. The result may be skin infections, respiratory disorders, and other risks of getting ill. However, hospitals and hotels are well organized with a strict cleaning and inspection system; unfortunately, homes are not provided with standard cleaning protocols. For this reason, the degree of microbial contamination varies, and the monitoring of wear changes.

The first and foremost examples of breakdown are the existence of visible wear (tears, fading, pilling), constant odour, moisture retention, and loss of antimicrobial effectiveness.

- To keep up with the hygiene standard, the changing of sheets and pillowcases is recommended every 1-2 weeks, blankets and quilts every 1-3 months, pillows every 1- 2 years, and mattresses every 7-10 years or if they are dirty or damaged, earlier than that.
- With the help of eco-friendly and antimicrobial fabrics, microbial growth will be stopped, the bedding will be kept for a longer time, and the emission of pollutants will be lessened. In addition to that, the action of recycling, upcycling, and take-back programs for used beddings is a way of diminishing the piling up of landfills, microplastic pollution, and the wastage of resources.
- Hygiene and expiration indicators that are measurable represent a tool through which families can get real-time guidance for their changes, thus health, comfort, and sustainability will be kept.
- Home linens are items that need constant supervision so as to keep them hygienic and at the same time prevent skin infections, allergies, and respiratory issues from being among the health risks. Some of the expiry features are: visible wear (tears, pilling, fading), persistent odour, moisture or stain retention, loss of antimicrobial effectiveness, and accumulation of allergens such as dust mites or mould.
- Recording these signs aids in figuring out the time of changing sheets, pillowcases, blankets, pillows, and mattresses for the safety and comfort of the users.
- A simple sanitation monitoring checklist may be of great assistance to families in such a situation. The checklist may include aspects such as washing frequency, fabric condition, microbial or odour detection, moisture absorption, and overall structural integrity. Practicing these checks together with the use of eco-friendly and antimicrobial fabrics and encouraging the recycling or upcycling of the products, families can keep the hygiene of their beddings, extend the life of the products, and lessen the negative effect on the environment which is at the same time supporting the sustainability practice.

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