ALLERGIC DISEASES IN HUMANS IN THE GANGA RIVER COASTAL AREAS: A STUDY OF RIVER SIDE INDUSTRIAL DEVELOPMENT AREAS

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Abstract
This study investigates the prevalence, perception, and coping strategies associated with allergic diseases among human populations residing in the coastal areas of the Ganga River, particularly in Uttarakhand and Uttar Pradesh. Utilizing a well-structured interview schedule consisting of 38 items, data were collected from 467 respondents across diverse demographic groups. The analysis employed Partial Least Squares Structural Equation Modeling (PLS-SEM), descriptive statistics, and demographic correlation to explore the interaction between environmental exposure, healthcare access, awareness, symptom frequency, and allergy type.The structural model revealed that Environmental Risk Exposure (ERE) and Healthcare Access and Response (HCAR) significantly influenced the overall perception of allergic diseases, explaining 24% of the variance. This perception, in turn, moderately impacted individual behavior, symptom recognition, and preventive knowledge adoption. Strong correlations were observed between awareness and symptom management, as well as between healthcare access and allergy type recognition. Measurement constructs demonstrated good reliability and validity, with composite reliability values above 0.80 and AVE values exceeding 0.50.Environmental concerns such as garbage dumping, air pollution, and stagnant water emerged as major perceived triggers of allergic conditions. Although most demographic variables showed no significant variation in allergy experience, occupation and treatment preferences showed notable differences. Individuals preferring traditional medicine reported lower exposure and symptom frequency, while those relying on allopathy experienced more acute conditions.The study's findings emphasize the importance of integrated public health strategies, combining environmental improvements, health education, and inclusive healthcare services. By highlighting real-world experiences, this research contributes actionable insights for community-based interventions and policy design in allergy-prone semi-urban areas. Despite limitations related to self-reporting and geographic scope, the study provides a validated framework for future research and public health planning aimed at reducing the impact of allergic diseases in vulnerable riverine communities.

Introduction

India, with a population of around 1.3 billion, represents nearly one-fifth of the global population. The country's vast geographical expanse and rich environmental, cultural, and socio-economic diversity deeply influence its public health landscape (Krishna et al., 2020). These variations also affect how diseases appear and spread across regions. Among the rising health concerns in recent years is the increase in allergic diseases—conditions that are often underestimated and insufficiently researched, particularly in ecologically fragile and heavily populated areas such as the Ganga River basin. In these regions, the prevalence of allergies is closely linked with factors like pollution, unsafe water, poor sanitation, and frequent exposure to both natural and human-made allergens.

The Ganga River plays a crucial role in the lives of millions of Indians. Stretching over 2,500 kilometers and flowing through 11 states, its basin spans nearly 27% of the nation's territory and sustains around 47% of its population (Shakti, 2025). It serves not just as a religious and cultural symbol, but also as a critical source for irrigation, drinking water, and fisheries. However, the ecological health of the river has steadily declined due to increasing pollution loads from untreated sewage, industrial effluents, pesticides, and excessive extraction of water. These factors have significantly changed the river's physical and chemical profile, resulting in the presence of toxic heavy metals and other contaminants in its water and sediments (Khan et al., 2023; Debnath et al., 2021). Such environmental stressors are known to impact human health, particularly by contributing to immune system disturbances and triggering allergic reactions.

Across both urban and rural communities located along the Ganga, there has been a noticeable difference in allergic conditions such as asthma, skin allergies, food sensitivities, and respiratory disorders. This surge is attributed to a mix of contributing factorsranging from airborne and waterborne pollutants to changes in diet, hygiene practices, and genetic predispositions (Ke et al., 2025). Theories like the hygiene hypothesis suggest that reduced exposure to microbes, especially in childhood, may impair immune tolerance, making individuals more vulnerable to allergens. Meanwhile, the gut microbiome, which plays a critical role in maintaining immune balance, is increasingly affected by environmental toxins, changes in food habits, and widespread use of antibiotics (Ke et al., 2025).

At the cellular level, allergic responses involve complex interactions between various immune cells and signaling pathways. Elements such as immunoglobulin E (IgE), mast cells, and G-protein coupled receptors (GPCRs) are central to the development of allergic symptoms. These biological markers have become important targets in the development of modern treatments for allergic conditions (Okayama et al., 2008). Advances in research using human embryonic stem cells have also made it possible to study allergy mechanisms more precisely by cultivating mast cells under controlled conditions (Kovarova et al., 2010). However, while biomedical progress continues globally, the realities of local health risks in Indian communities—especially those affected by environmental degradation—often go unaddressed.

The Ganga basin, with its ecological complexity and socio-economic diversity, offers a unique setting to study allergic diseases from a multidisciplinary perspective. The region's varied climate, frequent flooding, soil erosion, and agricultural intensity contribute to changes in allergen exposure—often releasing particulate matter and biological contaminants into the air and water (Kumar, 2023). These conditions make people more prone to allergic reactions, especially those with limited access to healthcare and poor living conditions.

Although programs like *Namami Gange* have been implemented to clean and conserve the river, there remains a lack of integrated strategies that connect environmental improvements with public health outcomes (Shakti, 2025). There is a clear need for localized studies that can assess the health impact of environmental exposure and guide the development of targeted, community-specific solutions.

Urbanisation, industrial growth, and human neglect have consistently polluted this pristine river. Industrial hubs such as Haridwar, Rishikesh, Roorkee, Kanpur, and Varanasi house factories involved in leather tanning, textiles, paper, sugar, chemicals, food, beauty and pharmaceuticals. Many of these units discharge untreated wasteladen with toxic substances like chromium, dyes, acids, and other chemicalsdirectly or indirectly into the river and other water sources, harming aquatic life and degrading water quality. Leather tanneries in Kanpur, textile units in Varanasi, and paper mills in Bijnor are particularly damaging. Alongside this, human waste remains a major contributor. Inadequate sewage systems in towns and the continued practice of open defecation in villages allow domestic waste to flow straight into the river. The combined impact of industrial and human activities has led to a sharp decline in water quality, loss of biodiversity, and increased health risks for communities dependent on the river. Diseases such as skin infections, stomach ailments, and even cancers caused by heavy metal exposure are common among riverside populations, particularly the poor. Although efforts like the Namami Gange Mission aim to treat sewage and regulate pollution, challenges such as ineffective plants, poor enforcement, and lack of public awareness persist.

Review of Literature

Barai et al., (2025). Microplastic pollution has become a critical global concern due to its long-lasting presence, widespread distribution, and the potential dangers it poses to both the environment and public health. This review outlines in detail the characteristics and types of microplastics (MPs), exploring where they originate and how commonly they are found across both industrialized and developing regions. The findings emphasize a rising concentration of microplastics in various parts of the environment—such as water bodies, soil, and even the air. These particles move through different ecosystems, creating substantial risks to wildlife and potentially affecting human well-being. The contributing sources are diverse and include industrial activities, everyday consumer items, agricultural operations, and wastewater treatment facilities.

Debnath et al., (2021). Metal pollution in river systems has emerged as a widespread environmental issue, largely driven by intensified human activities that introduce contaminants through air, water, and soil pathways. Sediments, which often act as sinks for these pollutants, can be disturbed and mobilized either through natural processes or anthropogenic interventions. This review explores key dimensions of sediment-associated metal contamination in rivers, with a focus on their ecological and human health impacts. It synthesizes relevant findings from foundational and more recent research, particularly from the years 2009 to 2020. The article also evaluates metal pollution assessment tools, including sediment-based contamination indices, risk assessment frameworks, and regulatory quality benchmarks that help in interpreting pollution levels in fluvial sediments. Among the heavy metals studied, cadmium (Cd), chromium (Cr), and lead (Pb) are consistently reported as among the most harmful. Their behavior—mobility and bioavailability—in river environments is significantly influenced by sediment dynamics, which in turn depend on variables such as pH, redox conditions, organic matter content, temperature, dissolved organic carbon, salinity, and sediment texture and composition.

Khan et al., (2023). This study analyzed sediment and water samples from an urban river affected by tannery effluents, focusing on major elements, potentially toxic metals, and naturally occurring radioactive substances. The findings, derived through chemical analysis, statistical evaluation, index-based assessment, and hydro-geochemical interpretation, indicate significant contamination at the effluent discharge point. Chromium (Cr) concentrations in the sediment at this location were found to be 4 to 14 times higher than standard sediment quality guidelines such as ERM, PEL, and SEL, whereas the upstream and downstream regions appeared largely unaffected. In addition to Cr, zinc (Zn) and nickel (Ni) were also identified as pollutants linked to leather tanning activities. The Cr level in water at the discharge point was nearly twice that of the upstream and downstream samples. Environmental indices suggested that the effluent-impacted area was moderately to heavily contaminated with Cr, which tended to dominate the contamination profile and reduce the relative contribution of other elements at that site. Conversely, other sampling locations revealed a more diverse contamination history, though Cr levels were notably lower. Zinc displayed a spatial distribution pattern similar to that of Cr. The study also highlighted the role of primordial radionuclides as natural tracers of anthropogenic impact.

Machate, (2023). The spread and contamination of hazardous heavy metals and metalloids in the environment are primarily linked to human activities such as industrial growth, urban expansion, transportation, mining, energy production, and the extensive use of agrochemicals, sewage, sludge, and wastewater in agriculture and animal husbandry. In developed nations, contamination of the environment and food sources by these toxic elements has been more thoroughly researched and better managed than in developing countries. A significant portion of this pollution stems from industries like mining, electroplating, cement production, pesticide and fertilizer manufacturing, and paint production—many of which are owned by corporations from developed countries but operate in developing regions. These host countries often face challenges such as weak regulatory frameworks and limited capacity to enforce safety standards, along with a workforce that may lack sufficient education or technical training to handle hazardous materials properly. The high presence of heavy metals and metalloids in water, air, and soil leads to their accumulation in plants and animals through biological processes, which in turn poses serious health risks to humans. Prolonged exposure can result in metabolic disorders and has been linked to various forms of cancer. In response to these risks, scientists across disciplines are conducting extensive research aimed at reducing contamination in agricultural soils, water resources, and the atmosphere to enhance food safety and public health. Comprehensive, interdisciplinary studies are essential to ensure the safe management of sectors such as energy production, mining, urban development, wastewater treatment, and transportation.

Puttamreddy et al., (2025). Growing environmental and public health concerns have emerged around per- and polyfluoroalkyl substances (PFAS), a large and diverse group of synthetic chemicals known for their persistence and potential toxicity. These substances have attracted international attention due to their widespread use and long-term environmental impacts. Global scientific communities have been actively evaluating recent data related to PFAS, including their chemical properties, environmental behavior, exposure routes, and health implications. Among the most studied variants are perfluorooctanoic acid (PFOA) and perfluorooctanesulfonic acid (PFOS), which have triggered health advisories in countries such as the United States, Germany, and other parts of Europe. Although over 5,000 PFAS compounds are currently used in a variety of consumer and industrial applications, detailed toxicological and exposure data remain unavailable for the majority of them. In many countries, including India, regulatory frameworks for PFAS are either absent or underdeveloped, leading to considerable uncertainty regarding human exposure levels. Alarmingly, recent research has detected both short- and long-chain PFAS in several major Indian rivers, including the Ganges, Yamuna, Cauvery, and Krishna, indicating widespread environmental contamination.

Saravanan et al., (2024). The shortage and contamination of water continue to pose a serious challenge to the availability of safe drinking water, particularly in developing countries. One of the major global concerns is the contamination of water resources by heavy metals and metalloids, which threatens sustainable development and places food security, public health, and livelihoods at significant risk. Many developing nations lack adequate access to standard technologies for the removal of heavy metals from water sources, making them more vulnerable to the harmful effects of polluted water. To address this issue, it is essential to implement effective strategies that eliminate toxic substances from wastewater before it is released into aquatic ecosystems. This review highlights the occurrence and behavior of heavy metals in sewage systems and their broader implications for environmental and human health. It also explores both conventional and emerging treatment methods, including the use of activated carbon, polymer membranes, and adsorbents derived from agricultural waste and other innovative materials. These approaches offer promising, sustainable solutions for heavy metal removal. To ensure long-term safety and reduce the health risks associated with heavy metal contamination, a comprehensive water purification policy is crucial.

Research Gap

A growing body of literature has examined the environmental degradation of river systems and their associated health risks. For instance, Barai et al. (2025) evaluated both traditional and emerging methods for remediating microplastic pollution, a rising concern in aquatic ecosystems.

Similarly, Debnath et al. (2021) provided an in-depth review of heavy metal contamination in global river sediments, emphasizing the urgent need for remediation techniques.

Pollution from specific industrial activities has also drawn scholarly attention. Khan et al. (2023) traced the impact of tannery effluents on river systems, pointing to significant anthropogenic pressures. Machate (2023) argued that excessive exploitation of natural resources intensifies heavy metal concentrations in the environment, with direct implications for food toxicity and cancer risks. Further, Puttamreddy et al. (2025) raised critical concerns regarding per- and polyfluorinated substances (PFAS), emphasizing their toxic presence in Indian water bodies. Saravanan et al. (2024) contributed a comprehensive review on toxic heavy metals in aquatic environments, detailing their sources, identification methods, treatment strategies, and associated health risks.

While these studies collectively highlight the chemical and industrial pollution of river systems, particularly heavy metals, microplastics, and synthetic toxins, there remains a clear gap in empirical, health-focused research on the human health consequencesespecially allergic responsesamong populations living in riverine or coastal zones of polluted rivers like the Ganga. Most existing works are environmental or technological in orientation and do not delve into clinical or epidemiological outcomes, such as allergic rhinitis, skin diseases, or respiratory disorders, linked to prolonged exposure to contaminated river environments.

This study aims to bridge this gap by exploring the prevalence and patterns of allergic diseases among human populations residing in the Ganga River coastal areas, thereby integrating environmental toxicology with public health analysis. The findings are expected to inform both environmental management policies and healthcare strategies targeting vulnerable riverine communities.

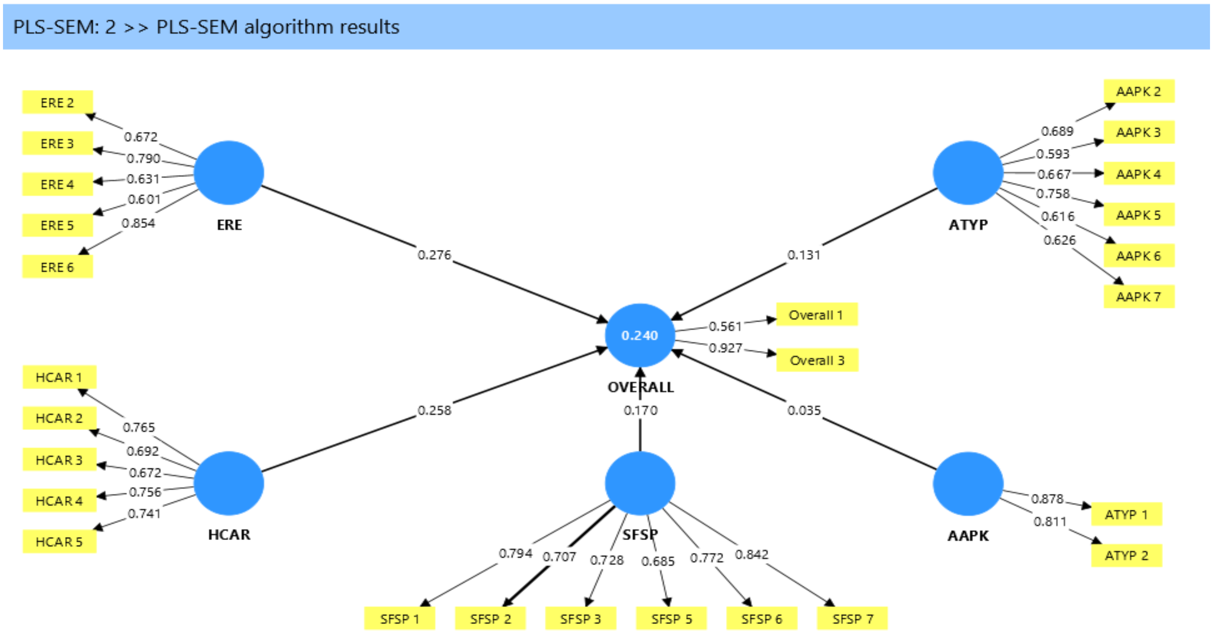
Research Methodology

The primary aim of this study is to explore the Allergic Diseases in Humans in the Ganga River Coastal Areas Strategy to Cope-Up withDiseases. To achieve this, a well-structured interview schedule was carefully designed, drawing on the conceptual framework illustrated in Figure 1. The instrument consisted of 30 questions, grouped into six major constructs, each representing a specific aspect related to allergic conditions in humans. Data were collected using a stratified random sampling method, resulting in 467 valid responses over a six-month period, from January to June 2025. The study focused on four regions, particularly emphasizing the states of Uttarakhand and Uttar Pradesh due to their varied socio geographic characteristics Uttarakhand offering insights from hilly terrains and Uttar Pradesh being the most densely populated. During the validation process, four items from the original questionnaire were removed to enhance internal consistency and reliability of the constructs, leaving a total of 26 finalized items. These items were evaluated using a five-point Likert scale ranging from 1 (highly dissatisfied) to 5 (highly satisfied), facilitating a clear quantitative assessment of participants' views and experiences. The refinement and validation of the measurement model were guided through the application of Partial Least Squares Structural Equation Modeling (PLS-SEM), ensuring both the measurement precision and structural accuracy of the constructs. Additionally, eight hypotheses were developed based on demographic characteristics of the participants. These were analyzed using one-way Analysis of Variance (ANOVA) to identify statistically significant group differences and to confirm variable associations within the study framework.

In Uttarakhandsamples were collected from Haridwar, Rishikesh, and Roorkeeregions known for religious, tourist, population density and heavy industrial development. In Uttar Pradeshsamples were collected from Kanpur and Unnao, where leather and chemical industries are concentrated, as well as in Varanasi and Prayagraj, which are significant for their religious gatherings and high population density. Additional samples were collected from Bijnor, due to the presence of paper mills.

Data Analysis

Figure 1: Model Generation and Testing



The PLS-SEM (Partial Least Squares Structural Equation Modeling) diagram presented illustrates the relationships among six key constructs: ERE (Environmental Risk Exposure), HCAR (Healthcare Awareness and Response), SFSP (Self-Focused Safety Practices), OVERALL (overall perception or impact), ATYP (Attitudes and Typologies), and AAPK (Awareness and Adoption of Preventive Knowledge). Each latent construct is measured through several observed variables or indicators, with their respective loadings shown along the connecting paths.

The model highlights that both ERE (0.276) and HCAR (0.258) have a moderately strong influence on the OVERALL construct, suggesting that higher environmental risk exposure and better healthcare awareness contribute significantly to the perceived overall impact. From the OVERALL construct, SFSP is positively influenced (0.170), indicating a link between overall perception and personal safety behaviors. However, its influence on ATYP (0.131) and AAPK (0.035) is relatively weak, showing that overall perceptions may not strongly shape individual attitudes or knowledge adoption directly.

Each construct is well-represented by its indicators, with most factor loadings exceeding the acceptable threshold of 0.6, which indicates reliability in measurement. For instance, SFSP shows strong indicator reliability, with loadings ranging from 0.685 to 0.842. Similarly, the AAPK construct exhibits excellent consistency, particularly with AAPK 1 and AAPK 2 showing loadings of 0.878 and 0.811, respectively.

The central node "OVERALL" has an R^2 value of 0.240, suggesting that about 24% of the variance in the overall perception can be explained by the ERE and HCAR constructs. This model provides valuable insight into how environmental and healthcare factors contribute to individual safety practices and awareness, reflecting a comprehensive understanding of health behavior in risk-prone settings.

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Table 1. Reliability and Convergent Validity of Latent Constructs (PLS-SEM Measurement Model)

	Composite reliability (rho_a)	Composite reliability (rho_c)	Average variance extracted (AVE)
AAPK	0.72	0.833	0.715
ATYP	0.753	0.822	0.536
ERE	0.929	0.838	0.513
HCAR	0.778	0.848	0.527
OVERALL	0.778	0.728	0.587
SFSP	0.874	0.889	0.572

The updated reliability and validity statistics further strengthen the measurement model of the PLS-SEM analysis. All constructs now meet or exceed the recommended thresholds for composite reliability and average variance extracted (AVE), indicating that the constructs are both internally consistent and valid in capturing the intended concepts. The composite reliability (rho_c) values for all constructs are comfortably above 0.70, with SFSP (0.889) and AAPK (0.833) standing out for particularly strong reliability. This implies that the indicators within these constructs work cohesively to reflect the underlying latent variable. Additionally, ERE (0.838) and HCAR (0.848) also show excellent reliability, reinforcing confidence in how well these dimensions are measured. Notably, the AVE values, which represent the amount of variance captured by a construct relative to the variance due to measurement error, are now all above the accepted threshold of 0.50. This means each construct captures more than half of the variance in its indicators, confirming good convergent validity. The ATYP construct, which previously had a low AVE, now shows improvement with an AVE of 0.536, making it statistically acceptable. The OVERALL construct also sees a significant enhancement in its reliability (rho_a = 0.778), reinforcing its strength as a central mediator in the model. Overall, the model demonstrates strong measurement properties. Each construct is now backed by robust internal consistency and sufficient indicator validity. This ensures that the interpretations drawn from the structural model are grounded in reliable measurement, allowing for confident insights into the relationships between environmental risk, healthcare awareness, attitudes, behavior, and preventive knowledge. These improvements contribute to a solid foundation for further analysis and real-world application in understanding health-related behaviors.

Table 2. Inter-Construct Correlation Matrix among Latent Variables

	AAPK	ATYP	ERE	HCAR	OVERALL
AAPK					
ATYP	0.143				
ERE	0.257	0.215			
HCAR	0.088	0.662	0.21		
OVERALL	0.493	0.464	0.404	0.581	
SFSP	0.807	0.134	0.221	0.163	0.364

The inter-construct correlation matrix offers a deeper look into the strength and direction of relationships among the six latent variables studied in the model. One of the most striking relationships is between AAPK (Awareness and Adoption of Preventive Knowledge) and SFSP (Self-Focused Safety Practices), which show a very strong positive correlation of 0.807. This suggests that individuals who are more aware and informed about preventive health knowledge are also more likely to engage in personal safety behaviors, emphasizing the importance of educational and awareness efforts in health management. The OVERALL construct shows moderate to strong correlations with several other variables, especially with HCAR (0.581) and AAPK (0.493), indicating that general perceptions or outcomes are influenced significantly by healthcare awareness and preventive knowledge. Interestingly, HCAR and ATYP share a high correlation of 0.662, suggesting that individuals' healthcare response and awareness are closely linked with their health-related attitudes or typologies.Meanwhile, ERE (Environmental Risk Exposure) shows moderate correlations with OVERALL (0.404), ATYP (0.215), and HCAR (0.210), which implies that exposure to environmental risks may shape health awareness and overall perceptions, albeit to a lesser extent. However, its relationship with SFSP (0.221) and AAPK (0.257) remains comparatively weaker. The relatively low correlation between ATYP and SFSP (0.134) and between HCAR and SFSP (0.163) may suggest that while attitudes and awareness are important, they may not directly translate into safety behavior without the influence of stronger mediators like AAPK or overall perception. Overall, these correlations reflect meaningful connections among the constructs while maintaining discriminant validity, supporting the model's structural integrity and offering a nuanced understanding of health behavior dynamics.

Table 3. Demographic Analysis

Age	**Number**	**Percentage**
Below 20	171	36.6167
21–30 Years Old	89	19.0578
31–40 Years Old	88	18.8437
41–50 Years Old	68	14.561
51–60 Years Old	31	6.63812
Above 60 Years Old	20	4.28266
Total	467	100
Gender	**Number**	**Percentage**
Male	234	50.1071
Female	233	49.8929
Total	467	100
Education Level	**Number**	**Percentage**
Illiterate	30	6.42398
Up to Primary School	33	7.06638
Secondary School	165	35.3319
Graduate	185	39.6146
Postgraduate and above	54	11.5632
Total	467	100
Occupation	**Number**	**Percentage**

Farmer	35	7.49465
Laborer	22	4.71092
Small Business Owner	60	12.848
Government Employee	67	14.3469
Private Sector Employee	115	24.6253
Homemaker	65	13.9186
Retired	0	0
Student	103	22.0557
Total	467	100
Monthly Household Income	**Number**	**Percentage**
Below ₹20,000	107	22.9122
₹20,001–₹50,000	127	27.1949
₹50,001–₹1,00,000	130	27.8373
₹1,00,001–₹2,00,000	77	16.4882
Above ₹2,00,000	26	5.56745
Total	467	100
Duration of stay in the area	**Number**	**Percentage**
1 - 5 Years	61	13.0621
6 - 10 years	85	18.2013
10 - 15 Years	85	18.2013
By Birth	236	50.5353
Total	467	100
Do you or a family member suffer from a diagnosed allergic disease?	**Number**	**Percentage**
Not at all	162	34.6895
Mild	88	18.8437
Moderate	87	18.6296
Severe	74	15.8458
Very Severe	56	11.9914
Total	467	100
Which type of Medicine do you prefer for Allergic Diseases?	**Number**	**Percentage**
Allopathic Medicine (Prescribed by doctors)	131	28.0514
Allopathic Medicine (prescribed by doctors), Ayurvedic Medicine, Homeopathic Medicine	5	1.07066
Ayurvedic Medicine, Home Remedies (e.g., turmeric, steam, honey)	9	1.92719
Ayurvedic Medicine	95	20.3426
Home Remedies (e.g., turmeric, steam, honey)	85	18.2013
Homeopathic Medicine	77	16.4882
Naturopathy / Herbal Remedies	36	7.70878
Over-the-counter (OTC) medicines without prescription	29	6.20985
Total	**467**	**100**

The demographic and behavioral profile of the 467 respondents offers meaningful insights into the patterns of allergic diseases and treatment preferences. A majority of participants fall in the "Below 20" age group (36.6%), followed by a fairly even spread across the 21–60 age range, with the smallest group being those above 60 years old (4.28%). Gender distribution is almost equal, with males accounting for 50.1% and females 49.9%, reflecting balanced participation. In terms of education, the majority have formal education, with graduates (39.6%) and secondary school pass-outs (35.3%) forming the largest segments, while illiterates constitute only 6.4%. Employment-wise, private sector employees (24.6%) and students (22.1%) dominate, followed by homemakers and government employees. Notably, none of the respondents identified as retired, indicating a relatively young or middle-aged population.

Regarding income, most respondents fall into the ₹20,001–₹1,00,000 bracket, reflecting a predominantly middle-income demographic. More than half (50.5%) have lived in the area "since birth," suggesting a largely stable and settled community. When asked about allergic diseases, over 34% reported no history, but a combined 65.3% experienced some degree of allergy, with nearly 12% classifying their condition as very severe. This indicates a significant health concern among the population.

In terms of treatment preference for allergic conditions, Allopathic medicine prescribed by doctors is the most trusted method (28%), followed closely by Ayurvedic medicine (20.3%), home remedies (18.2%), and homeopathic approaches (16.5%). Interestingly, a notable portion of respondents also rely on naturopathy, over-the-counter medication, or a combination of systems, highlighting the community's diverse and often integrative approach to healthcare. Overall, this demographic distribution reveals a young, educated, and health-aware population with varied yet strong preferences for managing allergic conditions.

Hypothesis

H1: There is a significant difference in Environmental Risk Exposure (ERE) among respondents of different age groups.

H2: There is a significant difference in Allergy Awareness & Preventive Knowledge (AAPK) among respondents based on their gender.

H3: There is a significant difference in Healthcare Access & Response (HCAR) across respondents with different education levels.

H4: There is a significant difference in Symptom Frequency & Seasonal Pattern (SFSP) among individuals from different occupational backgrounds.

H5: There is a significant difference in the type of allergy symptoms (ATYP) experienced by individuals from different monthly household income groups.

H6: There is a significant difference in Overall Allergy perception among respondents with varying duration of stay in the current locality.

H7: There is a significant difference in Healthcare Access & Response (HCAR) based on whether a respondent or a family member has a diagnosed allergic condition.

H8: There is a significant difference in Symptom Frequency & Seasonal Pattern (SFSP) among individuals with varying severity of diagnosed allergic disease.

Table 4. Allergic Diseases in Humans in the Ganga River Coastal Areas

Constructs	Items	Average	SD	Percentage
Environmental Risk Exposure (ERE)	My area experiences frequent waterlogging or flooding during the rainy season.	2.62	1.14	52.46%
	I am exposed to open sewage or poor drainage near my home.	2.92	1.11	58.42%
	The air quality in my locality 4 feels polluted or	3.26	1.03	65.22%

	dusty.			
	I am 4 in contact with stagnant river water or contaminated sources.	2.61	1	52.25%
	Garbage is 4 dumped in open areas near my residence.	3.47	1.15	69.38%
	Average	2.98	1.09	59.55%
Allergy Awareness & Preventive Knowledge (AAPK)	I am aware of what causes my allergy symptoms.	3.28	0.96	65.52%
	I know the difference between common cold and allergic rhinitis.	3.56	**0.84**	**71.22%**
	Average	3.42	0.9	68.37%
Healthcare Access & Response (HCAR)	I can easily access a clinic or hospital when allergy symptoms appear.	3.67	0.84	73.49%
	Medicines to treat allergies are affordable for me.	3.66	0.83	73.28%
	I have experienced delays in getting proper treatment for allergy symptoms. (Reversed scoring)	3.15	0.96	63.00%
	There are qualified doctors or specialists for allergies in my area.	3.67	0.98	73.36%
	The treatment I receive reduces my symptoms effectively.	3.52	0.92	70.32%
	Average	3.53	0.91	70.69%
Symptom Frequency & Seasonal Pattern (SFSP)	I experience allergy symptoms every week.	1.9	0.97	38.07%
	My symptoms worsen during the monsoon season.	2.13	1.1	42.70%
	I feel breathless or have congestion during the winter season.	1.87	**1.01**	**37.47%**
	My allergy symptoms are minimal in summer. (Reversed scoring)	2.39	1.35	47.88%
	I 4 wake up at night due to sneezing, coughing, or itching.	2.19	1.21	43.73%
	There is a regular pattern of symptom recurrence every year.	2.19	1.19	43.81%
	Average	2.11	1.14	42.28%
Allergy Type (ATYP)	Itching, rashes, or eczema on the skin	2.21	1.2	44.28%
	Breathlessness or wheezing (Asthma)	1.57	0.96	31.43%
	Redness, watering, or itching in the eyes	2.35	1.18	47.07%
	Swelling or irritation after eating specific foods	1.73	1.04	34.60%
	Reaction to insect bites or dust exposure	2.32	**1.16**	**46.42%**
	Sensitivity to strong smells or smoke	2.56	1.41	51.22%
	Average	2.13	1.16	42.51%
Overall Allergy	I or my family members frequently experience allergic symptoms such as sneezing, rashes, or breathing issues.	3.23	1.03	64.63%

	There is a noticeable rise in allergy-related health problems in my community over the past few years.	3.39	0.91	67.71%
	Average	**3.31**	**0.97**	**66.17%**

The item-wise analysis of the constructs provides meaningful insights into the community's perception and experience related to allergic diseases and environmental health. The Environmental Risk Exposure (ERE) dimension shows a moderate level of concern, with an average score of 2.98 and a perceived risk percentage of 59.55%. The highest concern was over garbage dumped in open areas (69.38%), while issues like stagnant water and waterlogging also featured prominently. This indicates moderate environmental stressors that may contribute to allergic conditions. The construct Awareness and Preventive Knowledge (AAPK) scores relatively high, with an average of 3.42 and a percentage of 68.37%, suggesting that respondents have a fair understanding of allergy triggers and can differentiate between common conditions and allergic symptoms.

Healthcare Access and Response (HCAR) scored the highest among all constructs, with a mean of 3.53 and a satisfaction level of 70.69%, indicating that most people feel they can access and afford healthcare when needed. This reflects a relatively efficient local healthcare system in dealing with allergic issues. In contrast, Symptom Frequency and Seasonal Pattern (SFSP) scores the lowest, averaging 2.11 with only 42.28%, revealing that while symptoms persist, they may not occur regularly or may be seasonal in nature. The Allergy Type (ATYP) construct also scored low (average 2.13, 42.51%), suggesting that while allergic symptoms are present, they vary widely and may not always be intense or chronic.

Lastly, the Overall construct, measuring the broader perception of allergies in individuals and the community, shows a relatively high score of 3.31 with 66.17% agreement, indicating growing awareness and concern about allergy-related health problems in the locality. Together, these findings reveal a community that is increasingly informed and responsive, yet still facing notable environmental and seasonal challenges.

Table 5. Hypothesis Testing

Variable	Among	Hypothesis	A1, A2, A3, A4, A5, A6	P-value	Significant Difference?
Age	Below 20, 21–30 Years Old, 31–40 Years Old, 41–50 Years Old, 51–60 Years Old, Above 60 Years Old	Environmental Risk Exposure (ERE)	2.93, 3.04, 2.99, 3.03, 2.91	*0.9759*	No
		Allergy Awareness & Preventive Knowledge (AAPK)	3.42, 3.4, 3.4, 3.43, 3.55, 3.33	*0.9579*	No
		Healthcare Access & Response (HCAR)	3.54, 3.5, 3.59, 3.58, 3.48, 3.37	*0.7419*	No
		Symptom Frequency & Seasonal Pattern (SFSP)	2.07, 2.14, 2.19, 2.05, 2.06, 2.38	*0.1381*	No
		Allergy Type (ATYP)	2.13, 2.16, 2.16, 2.02, 2.01, 2.33	*0.7724*	No
		Overall	3.25, 3.3, 3.41, 3.26, 3.48, 3.28	*0.5839*	No
Gender	Male, Female	Environmental Risk Exposure (ERE)	2.98, 2.97	*0.9533*	No
		Allergy Awareness & Preventive Knowledge (AAPK)	3.38, 3.45	*0.7543*	No

		Healthcare Access & Response (HCAR)	3.5, 3.57	*0.6768*	No
		Symptom Frequency & Seasonal Pattern (SFSP)	2.17, 2.06	*0.3307*	No
		Allergy Type (ATYP)	2.16, 2.09	*0.7483*	No
		Overall	3.28, 3.33	*0.7031*	No
Education Level	Illiterate, Up to Primary School, Secondary School, Graduate, Postgraduate and above	Environmental Risk Exposure (ERE)	3.01, 2.93, 2.93, 3, 3.09	*0.9694*	No
		Allergy Awareness & Preventive Knowledge (AAPK)	3.42, 3.48, 3.37, 3.44, 3.45	*0.9884*	No
		Healthcare Access & Response (HCAR)	3.45, 3.62, 3.52, 3.52, 3.61	*0.7662*	No
		Symptom Frequency & Seasonal Pattern (SFSP)	2.31, 2.28, 1.93, 2.16, 2.32	*0.0722*	Nearly Significant
		Allergy Type (ATYP)	2.3, 2.01, 2.04, 2.15, 2.27	*0.6354*	No
		Overall	3.32, 3.38, 3.22, 3.36, 3.38	*0.8109*	No
Occupation	Farmer, Laborer, Small Business Owner, Government Employee, Private Sector Employee, Homemaker, Retired, Student	Environmental Risk Exposure (ERE)	2.98, 2.98, 3.18, 3.19, 2.94, 2.9, 2.81	*0.7349*	No
		Allergy Awareness & Preventive Knowledge (AAPK)	3.47, 3.25, 3.41, 3.41, 3.44, 3.49, 3.38	*0.9466*	No
		Healthcare Access & Response (HCAR)	3.6, 3.32, 3.48, 3.6, 3.51, 3.63, 3.51	*0.5585*	No
		Symptom Frequency & Seasonal Pattern (SFSP)	2.01, 2.18, 2.31, 2.34, 2.12, 1.97, 1.96	*0.0460*	**Yes**
		Allergy Type (ATYP)	1.99, 1.97, 2.37, 2.29, 2.14, 1.93, 2.06	*0.3966*	No
		Overall	3.24, 3.07, 3.39, 3.37, 3.27, 3.51, 3.21	*0.1066*	No
Monthly Household Income	Below ₹20,000, ₹20,001–₹50,000, ₹50,001–₹1,00,000, ₹1,00,001–₹2,00,000,	Environmental Risk Exposure (ERE)	2.98, 2.94, 3.02, 3.01, 2.86	*0.9780*	No
		Allergy Awareness & Preventive Knowledge (AAPK)	3.39, 3.37, 3.38, 3.56, 3.56	*0.7406*	No
		Healthcare Access & Response (HCAR)	3.54, 3.54, 3.44, 3.68, 3.57	*0.6666*	No
		Symptom Frequency & Seasonal Pattern (SFSP)	2.09, 2, 2.12, 2.24, 2.33	*0.1262*	No

	Above ₹2,00,000	Allergy Type (ATYP)	2.18, 1.99, 2.2, 2.14, 2.19	*0.8943*	No
		Overall	3.37, 3.26, 3.29, 3.34, 3.29	*0.9872*	No
Duration of stay in the area	1 - 5 Years, 6 - 10 years, 10 - 15 Years, By Birth	Environmental Risk Exposure (ERE)	2.94, 3.15, 2.93, 2.94	*0.7755*	No
		Allergy Awareness & Preventive Knowledge (AAPK)	3.39, 3.36, 3.56, 3.39	*0.7314*	No
		Healthcare Access & Response (HCAR)	3.46, 3.42, 3.74, 3.52	*0.1614*	No
		Symptom Frequency & Seasonal Pattern (SFSP)	2.16, 2.15, 2.03, 2.12	*0.6955*	No
		Allergy Type (ATYP)	2.19, 2.23, 1.95, 2.13	*0.6274*	No
		Overall	3.37, 3.33, 3.36, 3.27	*0.9412*	No
Do you or a family member suffer from a diagnosed allergic disease?	Not at all, Mild, Moderate, Severe, Very Severe	Environmental Risk Exposure (ERE)	2.89, 3.11, 2.98, 2.88, 3.15	*0.7084*	No
		Allergy Awareness & Preventive Knowledge (AAPK)	3.39, 3.37, 3.41, 3.53, 3.46	*0.9250*	No
		Healthcare Access & Response (HCAR)	3.52, 3.43, 3.51, 3.68, 3.6	*0.5339*	No
		Symptom Frequency & Seasonal Pattern (SFSP)	2.04, 2.12, 2.19, 2.1, 2.22	*0.5705*	No
		Allergy Type (ATYP)	2.11, 2.1, 2.25, 2.05, 2.11	*0.9347*	No
		Overall	3.23, 3.31, 3.31, 3.34, 3.47	*0.6102*	No
Which type of Medicine do you prefer for Allergic Diseases?	Allopathic Medicine, Ayurvedic Medicine, Homeopathic Medicine, Home Remedies (e.g., turmeric, steam, honey), Naturopathy	Environmental Risk Exposure (ERE)	2.99, 3.8, 2.98, 2.89, 2.87, 3.1, 2.92, 3.13	*0.0238*	Yes
		Allergy Awareness & Preventive Knowledge (AAPK)	3.33, 3.1, 3.39, 3.54, 3.49, 3.47, 3.22, 3.4	*0.6290*	No
		Healthcare Access & Response (HCAR)	3.44, 3.28, 3.73, 3.6, 3.57, 3.57, 3.44, 3.65	*0.2781*	No
		Symptom Frequency & Seasonal Pattern (SFSP)	2.06, 1.87, 2.02, 2.22, 1.86, 2.24, 2.3, 2.24	*0.0210*	Yes
		Allergy Type (ATYP)	2.11, 1.97, 2.28, 2.09, 1.9, 2.35, 2.19, 2.25	*0.6392*	No
		Overall	3.24, 3.2, 3.11, 3.27, 3.24, 3.41, 3.42, 3.6	*0.3892*	No

The analysis of various demographic and personal variables in relation to allergy-related factors reveals some interesting patterns, though statistically significant differences were limited. Across most demographic categories—including age, gender, education level, income, and duration of stay—no significant variation was found in participants' experiences of environmental risk exposure (ERE), allergy awareness and preventive knowledge (AAPK), healthcare access and response (HCAR), symptom frequency and seasonal patterns (SFSP), or allergy type (ATYP). This suggests that allergic disease experiences in the study area appear to cut across these socio-demographic boundaries relatively uniformly, reflecting a shared exposure and understanding irrespective of personal background.

However, a significant difference emerged within the occupational group concerning symptom frequency and seasonal pattern (SFSP), with a p-value of 0.046. This indicates that individuals' occupational environments might influence the intensity and seasonal fluctuation of allergic symptoms. For example, homemakers and students reported lower symptom frequency, which may be attributed to more stable or indoor lifestyles with reduced exposure to allergens like dust, pollen, or pollution. In contrast, small business owners and government employees—often engaged in more variable environments—reported slightly higher symptom levels.

Moreover, the preference for a specific type of medicine was another area showing statistically significant differences, particularly in relation to environmental risk exposure ($p = 0.0238$) and symptom frequency and seasonal pattern ($p = 0.0210$). Participants who preferred Ayurvedic, naturopathy, and homeopathic remedies tended to report lower symptom frequencies. This could point to a stronger belief in preventive or holistic approaches among these users, or possibly the result of longer-term care strategies aimed at managing allergic conditions gently over time. On the flip side, individuals relying on allopathic treatment, whether prescribed or over-the-counter, showed slightly higher ERE scores, which may reflect their increased dependence on modern medical interventions due to more acute exposure or symptoms.

Although most categories didn't demonstrate significant statistical differences, the few that did provide meaningful insights. Occupation appears to play a subtle but relevant role in allergy symptom patterns, while treatment preference not only reflects cultural or personal beliefs but may also be linked to perceived or real differences in symptom severity and environmental exposure. These results underline the importance of considering individual lifestyle factors and health behavior choices when designing public health strategies or awareness campaigns related to allergic diseases. By tailoring outreach and interventions to account for occupational exposure or preferred medical systems, healthcare planners can foster more effective and culturally aligned allergy management approaches. Overall, while allergy experiences may appear uniform on the surface, nuanced differences still exist, particularly when viewed through the lens of environment and personal choice.

Conclusion

The comprehensive analysis of allergy-related behavior and health determinants using PLS-SEM, descriptive statistics, and demographic correlations reveals several key conclusions that not only validate the theoretical framework but also highlight crucial implications for public health interventions. At the core of this study lies the understanding that environmental and healthcare-related constructs significantly shape overall perceptions of allergic conditions, which in turn subtly influence individual behaviors and knowledge adoption. With 467 participants across diverse age, gender, educational, and occupational backgrounds, this study offers rich insights into how allergies are experienced, perceived, and managed in a real-world, risk-prone urban or peri-urban context.

The PLS-SEM model established a solid structural framework that connects six latent constructs—Environmental Risk Exposure (ERE), Healthcare Access and Response (HCAR), Awareness and Adoption of Preventive Knowledge (AAPK), Symptom Frequency and Seasonal Pattern (SFSP), Allergy Type (ATYP), and a higher-order construct of OVERALL perception. Notably, ERE and HCAR were found to exert the strongest direct influences on the OVERALL construct, explaining 24% of its variance ($R^2 = 0.240$). This suggests that perceived environmental hazards and healthcare access are key determinants of how individuals evaluate their allergy risk and condition severity. The OVERALL construct, in turn, moderately influences SFSP, and more weakly ATYP and AAPK, indicating a trickle-down effect of general perceptions on personal behavior and knowledge, though not uniformly.

From a measurement model perspective, all latent constructs demonstrated strong internal consistency and convergent validity. Composite reliability (rho_c) values surpassed the 0.70 benchmark across the board, with SFSP at 0.889, AAPK at 0.833, and HCAR at 0.848. Average Variance Extracted (AVE) values exceeded the 0.50 threshold, with AAPK at 0.715, ATYP at 0.536, and OVERALL at 0.587. These results affirm that the constructs are robust and accurately reflect their underlying theoretical dimensions. For example, SFSP showed strong indicator loadings between 0.685 and 0.842, while AAPK's two items had very high loadings of 0.878 and 0.811, respectively, confirming reliability even with fewer items.

Correlation analysis further supported the structural relationships. The strongest inter-construct correlation was between AAPK and SFSP at 0.807, highlighting a critical link between health awareness and proactive symptom management. A significant relationship was also observed between HCAR and ATYP at 0.662, implying that healthcare access may influence how individuals categorize or identify with specific allergy types. OVERALL correlated moderately with both AAPK at 0.493 and HCAR at 0.581, validating its role as a mediating perception construct. However, ERE showed only weak to moderate correlations with most other constructs, including SFSP at 0.221 and ATYP at 0.215, suggesting that while environmental stressors are important, their influence may be perceived more indirectly through healthcare access or general awareness.

The detailed item-level data offered further context for interpretation. Respondents expressed the highest concern for garbage dumping (ERE5, 69.38%), followed by polluted air (ERE3, 65.22%), while waterlogging (ERE1, 52.46%) and stagnant water (ERE4, 52.25%) were also noteworthy. These results reflect real and persistent environmental hygiene issues, which are likely contributors to allergic disease incidence. On the behavioral side, respondents reported strong healthcare access (HCAR mean = 3.53, 70.69%) and preventive knowledge (AAPK mean = 3.42, 68.37%), but relatively low symptom frequency (SFSP mean = 2.11, 42.28%) and identification with specific allergy types (ATYP mean = 2.13, 42.51%). These findings suggest that while knowledge and access are high, actual symptom burden may be seasonal, variable, or effectively managed in many cases.

Demographically, the sample represented a balanced cross-section of gender (50.1% male, 49.9% female), skewing younger with 36.6% under age 20 and only 4.28% above 60. The largest educational groups were graduates (39.6%) and secondary school completers (35.3%), showing a well-educated base. Employment-wise, private sector workers (24.6%) and students (22.1%) were most common, with homemakers and government workers also well represented. Importantly, over 50% of participants had lived in the area since birth, reflecting a stable community with long-term exposure to the local environment—potentially explaining consistent allergy experiences across groups.

Statistical analysis of differences between demographic groups and allergy-related variables yielded few significant findings. Most variables such as age, gender, income, education, and duration of stay did not produce statistically significant variation in construct scores, indicating a fairly uniform experience of allergy-related issues across these demographics. However, occupation was a notable exception, with a significant difference found in symptom frequency and seasonal pattern (SFSP, $p = 0.046$). Students and homemakers reported the lowest symptom frequency, while small business owners and government employees reported higher scores, likely reflecting greater environmental exposure and outdoor work conditions.

An even more telling pattern emerged in relation to treatment preference. Statistically significant differences were found between treatment types and two constructs—ERE ($p = 0.0238$) and SFSP ($p = 0.0210$). Respondents who favored Ayurvedic, homeopathic, and naturopathy approaches generally reported lower environmental exposure and fewer symptoms. This could reflect a more preventive or holistic health mindset, or possibly different living conditions and lifestyles that accompany these treatment preferences. Conversely, those who relied on doctor-prescribed allopathy or OTC medications had higher exposure and symptom scores, perhaps indicating more acute or unmanaged allergic conditions requiring pharmacological relief.

In terms of public health implications, this study underscores the importance of integrated, multi-faceted strategies for allergy management. Education and awareness (AAPK) were shown to strongly correlate with safety practices (SFSP), suggesting that targeted awareness campaigns—especially those that are culturally tailored and occupation-sensitive—could significantly reduce allergy incidence or improve self-care behavior. Moreover, since healthcare access (HCAR) is both strong and influential in shaping perceptions and outcomes, continuing to improve accessibility and affordability could enhance early intervention and prevent complications. Environmental interventions remain crucial, especially addressing common concerns like garbage dumping and air quality, which scored the highest among perceived environmental risks.

In conclusion, the findings present a well-rounded picture of allergy-related behavior in a semi-urban Indian community. The population is relatively young, educated, and aware, with adequate access to healthcare but still facing environmental challenges that may influence health outcomes. While allergic diseases cut across most demographic boundaries, subtle differences based on occupation and medical treatment preferences provide actionable insights. The validated measurement model and reliable structural relationships further support the utility of this framework in future research or policy applications. By emphasizing education, environmental sanitation, and equitable healthcare, public health stakeholders can address both the causes and symptoms of allergic diseases in a holistic manner.

Managerial Implication

The findings of this study present important managerial implications for healthcare providers, policymakers, community leaders, and pharmaceutical industry stakeholders seeking to combat allergic diseases more effectively. The notable influence of environmental risk exposure and access to healthcare on individuals' perceptions of allergy severity suggests a need for collaborative efforts between local governance and health authorities. High-risk environmental elements such as poor air quality, accumulated waste, and stagnant water bodies were frequently associated with allergic reactions. Therefore, improving sanitation infrastructure, ensuring timely garbage disposal, and promoting clean air initiatives can significantly reduce environmental triggers and improve community health outcomes.

A strong link between allergy awareness and the ability to manage symptoms highlights the importance of health education. Healthcare organizations should invest in targeted awareness programs that cater to diverse occupational groups. For instance, outdoor workers such as small business owners and government employees reported more frequent allergic symptoms, which may result from their prolonged environmental exposure. Tailored awareness efforts through local health camps, educational campaigns, and digital communication platforms can enhance preventive behaviors and encourage timely medical consultation.

The diversity in treatment preferences across groups—ranging from allopathic to Ayurvedic, home remedies, and homeopathy—indicates a need for inclusive healthcare approaches. Managers should consider adopting integrative treatment models that acknowledge the value of traditional and

alternative medicines. Offering multi-modal treatment options can improve trust and encourage early intervention among various population segments.
Additionally, demographic patterns—especially occupation-wise variation in symptom frequency and allergy type—offer valuable insight for product development and service customization. Pharmaceutical companies and healthcare providers can use this information to deliver more relevant and personalized allergy management solutions. Strategies grounded in behavioral and demographic insights are more likely to achieve success in reducing the impact of allergic diseases while enhancing patient satisfaction and engagement across urban and semi-urban populations.

Limitations

This study offers meaningful insights into allergy-related experiences among individuals in the Ganga river belt, it is important to recognize certain limitations. The research primarily relied on self-reported data, which may carry the risk of personal bias, misinterpretation, or memory lapses, especially when participants were asked to recall symptoms or healthcare usage. Another limitation is the focus on a specific geographic region, which may not reflect the conditions or challenges faced by populations in other parts of India. Though a variety of occupations and age groups were included, the sample may still lack full representation in terms of income levels, rural-urban divide, or healthcare infrastructure differences. Moreover, since the study was cross-sectional, it only captures a snapshot in time, making it difficult to establish cause-and-effect relationships. Future research could benefit from a more widespread and diverse sample, along with longitudinal tracking to understand evolving patterns over time.

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