



Pollen allergy: Developing multi-sectorial strategies for its prevention and control in lower and middle-income countries

Khaiwal Ravindra^{a,*}, Akshi Goyal^b, Suman Mor^{b,**}

^a Department of Community Medicine and School of Public Health, Post Graduate Institute of Medical Education and Research (PGIMER), Chandigarh, 160012, India

^b Department of Environment Studies, Panjab University, Chandigarh, 160014, India

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ABSTRACT

Pollen allergy is considered a major public health problem that causes morbidity and subsequently affects a patient's quality of life. Pollen due to their large size cannot enter the thoracic regions of the respiratory tract but can affect the nasopharyngeal mucous membrane. At the same time, the submicronic-pollen particles can act as respirable particles reaching deeper into the upper airways leading to exacerbation of asthma, chronic obstructive pulmonary disease (COPD) and other allergic reactions. Based on the existing literature, expanding evidence shows that climate change and air pollutants could affect the pollen number, morphology, season, allergen content, and distribution pattern. Hence, this will influence the prevalence and occurrence of allergies linked to pollen exposure. Being a part of biogenic pollutants, pollen allergens are not expected to diminish in the foreseeable future. Therefore, it is imperative that steps need to be strengthened to improve and optimize preventive/adaptive strategies. This paper aims to review the major causes of widespread allergy, identify the major gaps, and suggest key preventive/adaptive measures to address the onset and exacerbation of pollen-related allergic diseases with a major focus on lower and middle-income countries. The study also discusses how-to implement the prevention and control measures at the individual, health care communities and organizations, Local Governments, National/International Governments levels to decrease the risk of illnesses associated with pollen allergy.

1. Introduction

Green spaces are considered critical components in providing ecosystem services by minimizing pollution, air temperature, noise, and soil erosion. Despite their undeniable benefits for humans, they could be associated with many concerns if not appropriately managed (Sousa-Silva et al., 2020). The most severe challenge related to the plants is the human allergic responses to pollen grains released during pollination.

Over the past few decades, the prevalence of pollen allergy has increased. This trend is projected to rise due to urbanization, air pollution, and climate change, particularly in urban areas (Pawankar et al., 2013; Aerts et al., 2021). The noticeable negative impact of pollen has been seen in the sensitive population. Pollen cannot enter the thoracic regions of the respiratory system due to their large size (10–80 µm), but they can impact the nasal and nasopharyngeal mucosal membranes. Also, submicronic-pollen particles can act as respirable allergens, which can reach deeper into the upper airways leading to various respiratory

diseases. Exposure to allergic pollen from specific trees, grasses and weeds leads to a wide range of health effects. Though, a non-linear relationship has been described between different airborne pollen species with certain respiratory illnesses (Jones et al., 2021).

Pollen are also considered the primary cause of allergic rhinitis (AR). The prevalence of allergic rhinitis has increased in developed countries and affects about 10%–30% of adults and 20%–25% of children worldwide, posing severe repercussions on the quality of life (Hellings et al., 2017; Meng et al., 2020). However, several studies have found that pollen are also associated with the increasing problem of wheezing, atopic dermatitis (eczema) and exacerbation of asthma and chronic obstructive pulmonary diseases (COPD) in susceptible individuals (Cecchi et al., 2010; Singh and Mathur, 2021).

An extensive epidemiological study was conducted by ISAAC (International Study of Asthma and Allergies in Childhood) to determine the prevalence of asthma, allergic rhinitis, and atopic eczema in children and adolescents. The prevalence of current wheeze was found to be 7%

* Corresponding author.

** Corresponding author.

E-mail addresses: khaiwal@yahoo.com, khaiwal.ravindra@pgimer.edu.in (K. Ravindra), sumanmor@yahoo.com (S. Mor).

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in Indian children aged 6–7 years and 13–14 years (Krishna et al., 2020). In contrast, the overall prevalence of nasal symptoms and rhino-conjunctivitis is 12.5% and 3.3% among Indian children aged 6–7 years, respectively, and 18.6% and 5.6% among Indian children 13–14 years respectively (Chandrika, 2017; Kondraju and Sudhakar, 2019). However, around 20–30% of the population suffers from allergic rhinitis in Europe and the USA (Wang et al., 2021). Numerous other studies were also conducted to determine the prevalence of allergic rhinitis, atopic dermatitis (AD), eczema and wheezing in children and adolescents (as shown in Table 1).

Several international organizations, namely, American College of Allergy, Asthma, and Immunology (ACAAI), American Society for Microbiology (ASM), European Aerobiology Society (EAS), Indian Aerobiology Society (IAS), Nordic Aerobiology Society (NAF), The Palynological Society (AASP), etc. are actively working in the field of aerobiology to address the various issues related to pollen allergy (<https://sites.google.com/site/aerobiologyinternational/links>).

Table 1
Prevalence (%) of allergic rhinitis (AR), atopic dermatitis (AD), eczema and wheezing.

Diseases	Prevalence (%)	Study Area	Year	References
Allergic rhinitis	12.9–22.5	Denmark	1990–1998	Linneberg et al. (2000)
	23	Europe	2001	Bauchau and Durham (2004)
	32.2	United Kingdom	2001	Shamssain (2007)
	28.5	Pakistan	2007	Hasnain et al. (2009)
	11.1	China	2005	Zhang et al. (2009)
	23.1	Turkey	2008–2009	Cingi et al. (2010)
	28	Sweden	2007	Eriksson et al. (2012)
	5.8–13.7	Japan	2006	Honda et al. (2013)
	14.9	Beijing	2012	Zhang et al. (2013)
	19.9	United States	2001–2013	Hill et al. (2016)
	17.6	China	2011	Wang et al. (2016)
	28.3	Tehran	2013–2016	Shoormasti et al. (2018)
	24.4	India	2001–2003	Singh et al. (2018)
	22.2	Japan	2013–2017	Nakamura et al. (2019)
	17.1	Korea	2008–2017	Ha et al. (2020)
Atopic Dermatitis	17.8	Stockholm	1992–1994	Kihlström et al. (2002)
	3.9	Tehran	2013–2016	Shoormasti et al. (2018)
	21.2	Japan	2013–2017	Nakamura et al. (2019)
	3.9	Korea	2008–2017	Ha et al. (2020)
	4.65	French	2016	Richard et al. (2021)
Eczema	24.2	United Kingdom	2001	Shamssain (2007)
	21.8	Pakistan	2007	Hasnain et al. (2009)
	8.7–13.5	Japan	2005–2006	Honda et al. (2013)
	6.7	United States	2001–2013	Hill et al. (2016)
Wheezing	3.7	India	2001–2003	Singh et al. (2018)
	16.1	Bangladesh	2001	Zaman et al. (2007)
	11.7	Pakistan	2007	Hasnain et al. (2009)
	18.3	Thailand	2002	Bunnag et al. (2009)

ps://sites.google.com/site/aerobiologyinternational/links). Apart from this, the Global Initiative for Asthma (GINA), European Academy of Allergy and Clinical Immunology (EAACI), American Academy of Allergy, Asthma & Immunology (AAAAI), Allergic Rhinitis and its Impact on Asthma (ARIA) are some of the leading organizations that have proposed guidelines and recommendations covering the risk factors, development of disease, proper diagnosis, healthcare pathway and treatment involved with allergic rhinitis, allergic diseases, seasonal allergic asthma and immunology (Agache et al., 2018; Boulet et al., 2019; Bousquet et al., 2008; Cingi et al., 2017; Horak et al., 2016). As majority of these guidelines and recommendations are not directly focusing on pollen allergy, therefore, to address these gaps, there is a need for appropriate policies and framework related to pollen allergy covering various aspects (types of allergic species, their allergenic potential, peak pollen seasons) for the prevention and control measures at individual and public level to decrease the risk of illnesses associated with pollen allergy.

In order to alleviate the effects of climate change and air pollution, the establishment and growth of green spaces and urban forests are encouraged to improve the quality of life. However, an increase in the green spaces may also enhance allergic pollen levels. Therefore, knowing pollen will always persist in the environment, developing and strengthening pollen allergy prevention and treatment strategies are needed. The core purpose of the current review is to critically examine the implementation gaps and barriers to address the issue of pollen allergy and to prevent pollen allergy to avoid new exacerbations and their potential strategic interventions. Not many diverse studies are available that highlight the unmet needs and barriers to preventing and controlling pollen allergies. Therefore, this study examined the scientific literature to understand or assess the gaps and barriers and recommended the key measures required in order to prevent and control pollen allergies with a major focus on lower and middle-income countries.

2. Methodology

This comprehensive literature review explores and discusses the implementation gaps and measures to pollen allergy prevention and control from simple, basic, to more complex levels. The inclusion criteria for screening the relevant studies were: 1) recent publication in an international peer-reviewed journal available on PubMed, Google Scholar, Web of Science, Scopus, Science Direct, etc. database (in or after the year 2000). The latter was justified as the knowledge and clinical studies have been substantially evolved over time and the earlier studies do not provide much relevant data for current policies; 2) emphasis on articles that review hypersensitivity to pollen, related mechanism of action, clinical manifestations of allergic rhinitis and asthma, diagnostic test, cases of sensitivity to different pollen species and subsequent management; 3) published in English 4) both in-vivo and in-vitro studies were also considered. The exclusion criteria include 1) thesis, dissertations, case report, conference proceedings, letters to the editor and editorials; 2) language except for English. The literature review is not meant to be exhaustive but rather, it is intended to identify allergy severity, incidences, and complexity for developing integrated management strategies. The keywords were beginning with “pollen”, “pollen allergy”, “allergic rhinitis”, followed by the search words and their combinations: “allergies”, “pollinosis”, “hay fever”, “eczema”, “asthma”, “COPD patients”. The search was performed for articles published in English using Boolean logic searching methods (AND/OR/NOT/(/“ ”). Many of these articles were outside inclusion criteria and duplicated, and those were excluded. Additionally, a manual search for relevant articles was also carried out in each article’s bibliography section.

3. From where did the pollen allergy start?

Pollen grains are male biological entities produced by higher plant

cells that are essential for sexual reproduction. Pollen themselves are immobile and dispersion is aided by agents such as water, insects, birds and wind. Hence, they are considered as aeroplanktons (floating in the air) surrounding human beings. The first physician, John Elliotson, identified pollen grain allergy in 1831, whereas John Bostock first reported 'Hay Fever' in 1819. The detailed experiment was conducted by Phoebus (1862) and Charles Blackley (1873) (Cresti and Linskens, 2000; Xie et al., 2019). In 1873, Charles Blackley, in his book "Catarrhus aestivus" revealed the connection between pollen and pollinosis based on skin and provocation tests which leads to confirmation in the field of etiology. In 1908, Doctor A. Carini from Sao Paulo published the first paper on pollinosis, where the existence of hay fever was questioned in Brazil (Taketomi et al., 2006). Since then, pollen has received attention as an allergic agent by most physicians, botanists and aerobiologists. Further studies also show significantly higher pollinosis incidences in atopic individuals responding to grass and tree pollen (Frei and Leuschner et al., 2000; Jutel et al., 2005; Kailaivasan and Davies, 2018).

Numerous time-series studies correlate pollen seasons with hospital emergency room (ER) visits due to asthma and chronic obstructive pulmonary disease (COPD) (Jariwala et al., 2011; Darrow et al., 2012; Simunovic et al., 2020). Patients also show ocular pruritus with coryza, sneezing, nasal pruritus, nasal obstruction, rhinorrhea, angioedema and conjunctival hyperemia in any combination (Taketomi et al., 2006; Greiner et al., 2011). Two major symptoms, i.e., conjunctival hyperemia and nasal pruritus, differentiate pollinosis (hay fever) from the common cold. Clinically, allergic rhinitis (pollinosis or hay fever) is characterized by four major symptoms, i.e., sneezing, rhinorrhea, nasal itching and nasal congestion. Pollen are considered primary potential triggers of asthma and COPD; even though their size is large, they affect the upper airways of mucosa when inhaled. Each pollen grain is a double-walled structure (except in some cases) that contains different metabolites like proteins, carbohydrates, hormones, organic acids, pigments, minerals, etc. The proteins present inside pollen grains can activate strong immunological responses in the sensitized peoples known as Type-I hypersensitivity reactions. Thus, releasing the allergen from the pollen grain is a prerequisite for evoking allergic responses in sensitized individuals (Taketomi et al., 2006). There are two prerequisite mechanisms required for allergenic particles to be expelled from pollen grains: (i) allergens readily diffuses coming in direct contact with mucosal surfaces such as conjunctiva and nose, (ii) humidity and rain leads to rapid hydration of pollen to expel cytoplasmic inhalable material, capable of evoking IgE antibody-mediated allergic reactions, reaches lower airways due to small size and induces asthma (D'Amato et al., 2007b; Reid and Gamble, 2009; Stone et al., 2021).

These mechanisms reflect the probability of inducing epidemics (Ravindra et al., 2021a), like thunderstorm-related asthma and their linkage with the rise in hospital admission within a few hours of storm passage (Villeneuve et al., 2005; Losappio et al., 2011; Thien et al., 2018). It is not easy to evaluate the weather pattern on the prevalence of airborne pollen distribution patterns. However, the global rise in temperature and severe weather events studies indicate that they contribute to the dissemination of pollen grains and may further affect the sensitive and vulnerable population.

4. Environmental factors affecting airborne pollen

Pollen allergy is often considered a trivial disease. However, it is a major respiratory illness that causes morbidity and subsequently affects a patient's quality of life (Mridula et al., 2011; Greiner et al., 2011; Muzalyova et al., 2019). Due to the ubiquitous nature of pollen grains, it is estimated that a high percentage of humans are sensitive to these kinds of allergens. In contrast to some countries where the prevalence of allergic rhinitis (hay fever) has been stabilized or decreased, morbidity statistics are still rising in others (Pawankar et al., 2013; Guilbert et al., 2016). For example, it is established by European Community Respiratory Health Survey that the prevalence of allergic rhinitis has increased

from 4% to 32% in Europe (Pawankar et al., 2013). There are many human-driven factors responsible for the increase of pollen allergens in the atmosphere, such as:

- (i) Climate change and increase in global surface temperature in the atmosphere have a significant impact on plant life-cycle events (photosynthesis and plant growth) and their physiological parameters (such as pollen production, morphology and pollen season) (Ziello et al., 2012; Damialis et al., 2019; Poole et al., 2019). Hence, the overall relationship between climatic factors, meteorological conditions and pollen concentrations can be complex and multi-dimensional. CO₂ is considered the sole supplier of carbon to plants, which affects photosynthesis, plant growth, and pollen production (Ziska and Caulfield, 2000; Levettin and Van de Water, 2008). An increase in temperature and CO₂ influences pollen concentration, season timelines, strength and duration, and possibly increased allergenic content, which does not remain consistent and is found to be variable between various pollen emitting species in the atmosphere (Wan et al., 2002; Damialis et al., 2007; Cecchi et al., 2010; Cuinica et al., 2014; Beggs, 2015; Ziska et al., 2019). Therefore, these changing events affect the pattern of pollen that could affect pollinosis and exacerbate other allergic diseases.
- (ii) Another contributing aspect in the magnitude and concentration of pollen is the change in meteorological conditions (Gross et al., 2019) and geographic distribution (Wjst et al., 2005; Skjøth et al., 2013). The pollen concentration at a particular site reflects the distribution of pollen sources within a few kilometers of the site (Ravindra et al., 2021c). Changes in meteorological factors, especially wind speed and direction, will directly impact aerobiological pollen activities such as emission, dispersal, trans-mission, and deposition. This will affect the prevalence and occurrence of pollen-related allergies (Mandal et al., 2008b; Poole et al., 2019). Some evidence supports that sensitive populations respond to abrupt weather changes in the environment, for example, thunderstorm events (Losappio et al., 2011; D'Amato et al., 2016; Hew et al., 2019; Sabih et al., 2020). Numerous studies reported the long-distance transport of pollen from their release sites. Pollen grains disperse and travel from one location to another due to changing weather conditions, exposing humans to new and novel allergens (Yang et al., 2019).
- (iii) Rapid unplanned urbanization with high vehicular emissions was reported to be linked with rising incidences of pollen-induced respiratory allergies (Ghiani et al., 2012). Consistent studies support that people living in urban areas are more likely to suffer pollen allergies than people in rural areas (Wan et al., 2002; D'Amato et al., 2007a; Sénéchal et al., 2015; Charalampopoulos et al., 2021). Further, air pollutants and pollen are known to have a synergistic effect on human health (Beck et al., 2013). Air pollutants can attach to the surface of pollen grains and can modify morphology (change in diameter, thinning in exine, exine rupture) of these antigen carrying agents and alter the allergenic potential (Motta et al., 2006; Suárez-Cervera et al., 2008; Azzazy, 2016; Oduber et al., 2019). Acute and chronic exposure to various pollutants such as nitrogen dioxide (NO₂), sulfur dioxide (SO₂), ozone and particulate matter intensifies airway responsiveness to pollen in atopic individuals (Zhao et al., 2016).

These observations show a clear association between changing temperature, meteorological parameters, air pollution and ambient pollen number/concentration. The relationship between the climatic factors and airborne pollen production could have a manifold multi-factorial system, as shown in Fig. 1. However, determining anticipated changes that are contributed by increased pollen allergy will require an extensive network of research.

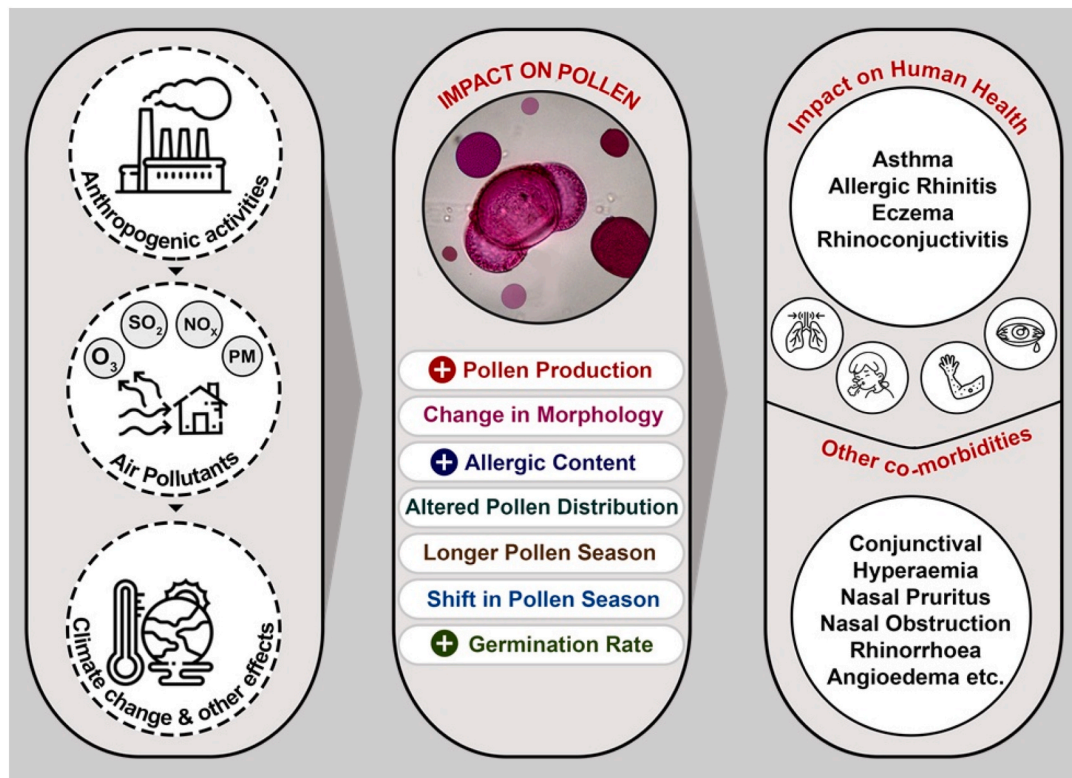


Fig. 1. Depicting impact of climate change on airborne pollen and human health.

5. What are the unmet needs and research gaps identified?

The prevalence of pollen allergy severity, incidences and complexity have dramatically increased over two decades (Damialis et al., 2007; Poole et al., 2019; Ziska et al., 2019; Simunovic et al., 2020). If not treated at early age, it can lead to “multi-system allergic diseases” in later life, which is life-threatening and may cause fatal reactions. There are various significant research gaps and challenges involved with increasing incidences of pollen allergies:

1. A high abundance of pollen has been associated with exacerbating various allergic responses and respiratory diseases (Singh and Mathur, 2021). The severity of allergic rhinitis due to the intricate interaction of genetic and environmental factors considerably increased within the last decade. Therefore, a growing requirement is to estimate accurate pollen concentration globally (D'Amato et al., 2015). Palynologists and botanists are always interested in measuring pollen concentration in the atmosphere. Various samplers have already been installed for the proper monitoring of airborne pollen allergens. Real-time measurements, which potentially offer immediate warning alerts to sensitized individuals, have been established at some places (Sofiev, 2019; Schaefer et al., 2021). However, a fully-reliable, operational, automated real-time aero-allergen monitoring program with global networking is necessary to collect and disseminate the obtained pollen data to develop long-time series data.
2. Several physicians, allergists and scientists have used aerobiology data in the medical community to properly diagnose and treat pollen allergic patients (Levetin and Van de Water, 2008). Most of the research has been done in Europe and the USA, providing better insights into pollen allergies. Hence, more research is needed in various lower- and middle-income countries, which are considered rich in floral diversity.
3. Studies from around the last three decades have shown that pollen allergens-based respiratory disease has increased in parallel to pollen

production of some plant species (D'Amato et al., 2001; Reid and Gamble, 2009; Osborne et al., 2017; Guilbert et al., 2018). In addition, changes over a period of time, potentially linked to climate change or globalization, can be used to explain and predict trends in the incidence of pollen allergies are missing. Therefore, the impacts of climate change on pollen and respiratory allergies caused need much more elucidation (Beggs, 2015).

4. In addition, there is a shortage of pollen allergy specialists/trainees who can provide the essential guidance and treatment, as well as lead the search for solutions to control allergies (Cecchi et al., 2010).
5. Among the ongoing studies related to plants and pollen allergens, research gaps have been found concerning the production and dissemination of allergens and specified proteins as well as their linkage with land use patterns, industrialization, environmental pollutants and extreme weather conditions (Ziska and Beggs, 2012).
6. Although various immunological and genetic studies also have been looking for different risk factors for allergic rhinitis and allergic asthma, focusing on identifying appropriate central genes to substantiate preventive measures (Papadopoulos et al., 2012). Meanwhile, some epidemiological studies have supported the famous “hygiene hypothesis” where early childhood exposure to microbes could protect against allergic diseases by providing the development of the immune system (Liu and Murphy, 2003; Mutius, 2007). To date, there is not sufficient evidence for the hygiene hypothesis, as complexities between the gene-environment relationships/interactions are apparent.
7. Pollen allergy is often considered a self-managed condition that enables atopic individuals to be at risk of missing health checkups and proper treatment (Medek et al., 2019). There is a lack of awareness among the people regarding pollen allergy, majorly in low-middle income countries. The symptoms of pollen allergy are somewhat similar to common flu and cold. Therefore, even if they have an allergy, itchy throat, or running nose, they try to treat it with home remedies. So, the dissemination of proper knowledge regarding

pollen allergy, allergen avoidance, their symptoms and management is needed to better address the pollen allergy ailment.

8. Longitudinal studies in children and adults, with and without treatments, are needed to better understand illness progression and treatment options.
9. Most European countries possess long-time pollen series data and forecasting models such as SILAM models, numerical forecasting and others (Sofiev et al., 2006; Muzalyova et al., 2021). But globally, data on airborne pollen concentration are limited; mainly, long-term time series are rarely available, especially for lower and middle-income countries. Major future challenges involve the collection of databases and applying these data streams into pollen forecasting systems using artificial intelligence and machine learning approaches. Above all, timely risk alerts personalized forecasts on allergy management are also required.

6. What are the recommendations to overcome the barriers to pollen allergy prevention and control?

Prophylaxis in pollen allergy is difficult, as humans work within the same environment and it is quite challenging to avoid airborne pollen exposure (Wang, 2005). But some basic preventive measures can be taken to reduce exposure, such as the public may be advised to stay indoors, keep windows and doors closed, avoid gardening or grass-cutting during peak pollen seasons when the quantity and propagation of airborne pollen are significant Spanish Aerobiology Network (REA, <http://www.uco.es/investiga/grupos/rea/>). Although not fully established but several ways to reduce allergic reactions have been suggested based on these three milestones as shown in Fig. 2 (Tanno et al., 2017).

The current work examined the scientific literature to understand the key measures and formulate recommendations (Fig. 3) to overcome the barriers for the prevention and control of pollen allergies as follows:

- 1) Adaptive actions required at an individual level to decrease the risk of illnesses associated with pollen allergy:
 - Keeping a regular check on pollen forecasts and minimizing exposures to the outdoor environment during high pollen loads
 - The use of HEPA (High-Efficiency Particulate Air) filters are recommended for the indoor environment to reduce exposure to pollen allergens (Sublett et al., 2010; Cipriani et al., 2017; Roubelat et al., 2020)
 - Use of already prescribed medications and seek medical help if necessary for sensitive people
 - Proper knowledge of allergen seasons will allow earlier administration of preventive medicines and improved management
- 2) Health Care Communities and Non- Governmental Organizations (NGO's):
 - Communicate and educate regarding the significance of limiting outdoor exposure on high pollutant days.
 - Regular training for patients and professionals
 - **Education and awareness:** Allergic rhinitis affects a substantial portion of the population who remain undiagnosed or

inadequately treated. Therefore, educational programs must be conducted to deliver the importance of allergen avoidance and correct ways to prevent allergies.

- **Defining pollen allergy:** Better understanding and adequately describing the **mechanism of pollen allergy** forms the fundamental basis for primary prevention. Lack of knowledge misleads to early prevention, which is primarily linked to delayed diagnosis. For this, numerous studies have been conducted in aerobiology, epidemiology, and phenology related to fundamental research. Still, the prophylaxis found has posed many doubts/queries, which remain unsolved/unanswered.
- 3) Local Governments and Agencies:
 - **Adequate knowledge of allergenic species:** Allergenic species are considered a major contributing factor to the increased incidence of allergic diseases. The intensity of allergy is directly linked to the species and taxa of airborne pollen, which depends on the threshold value of the individual species (Carriñanos and Casares-Porcel, 2011). Therefore, caution must be exercised before making green zones.
 - Keep a check and control on plant species to be planted
 1. Avoid botanical sexism (dioecious species) and plant perfect flowering plants, i.e., having male and female parts in the same flower (example: roses, tulips, lilies, orchids, apples, and cherries, etc.) so that pollination is reasonably contained.
 2. Planting monoecious plants (male and female flower grow on the same flower) offer an additional advantage over dioecious plants (distinct male and female plants), which require pollen to be spread widely (Eisenman et al., 2019).
 3. Choose plant species with low to medium pollen production. Non-allergenic or not highly allergic and entomophilous plant species over anemophilous plant species should be chosen judiciously to provide a healthy allergen-free atmosphere (Carriñanos and Casares-Porcel, 2011).
 4. Regulate and control exotic/invasive species
 - Complete knowledge of local flora distribution and guides should be available of allergenic pollen types, which are of utmost importance in managing pollen-related allergic diseases.
 - **Development of regional pollen calendar and its timely update:** Pollen calendars provide visual information about the numerous forms of airborne pollen types present throughout the year with their seasonality in a single image. They correspond as a preventive tool for sensitized individuals regarding minimizing exposure when the levels of aero-pollen are above thresholds (Mandal et al., 2008a; Elvira-Rendueles et al., 2019; Ravindra et al., 2021b). Public health officials can use calendar data to establish early warning systems, exposure guidelines and further advancements in therapy during high pollen loads. Moreover, providing access to the local pollen information will enhance the self-management of allergen avoidance and management. Therefore, pollen calendars are necessary to establish possible connections and contributions in the field of etiology to avoid allergic diseases such as pollinosis and allergic rhinitis.



Fig. 2. Graded response for pollen allergy prevention.

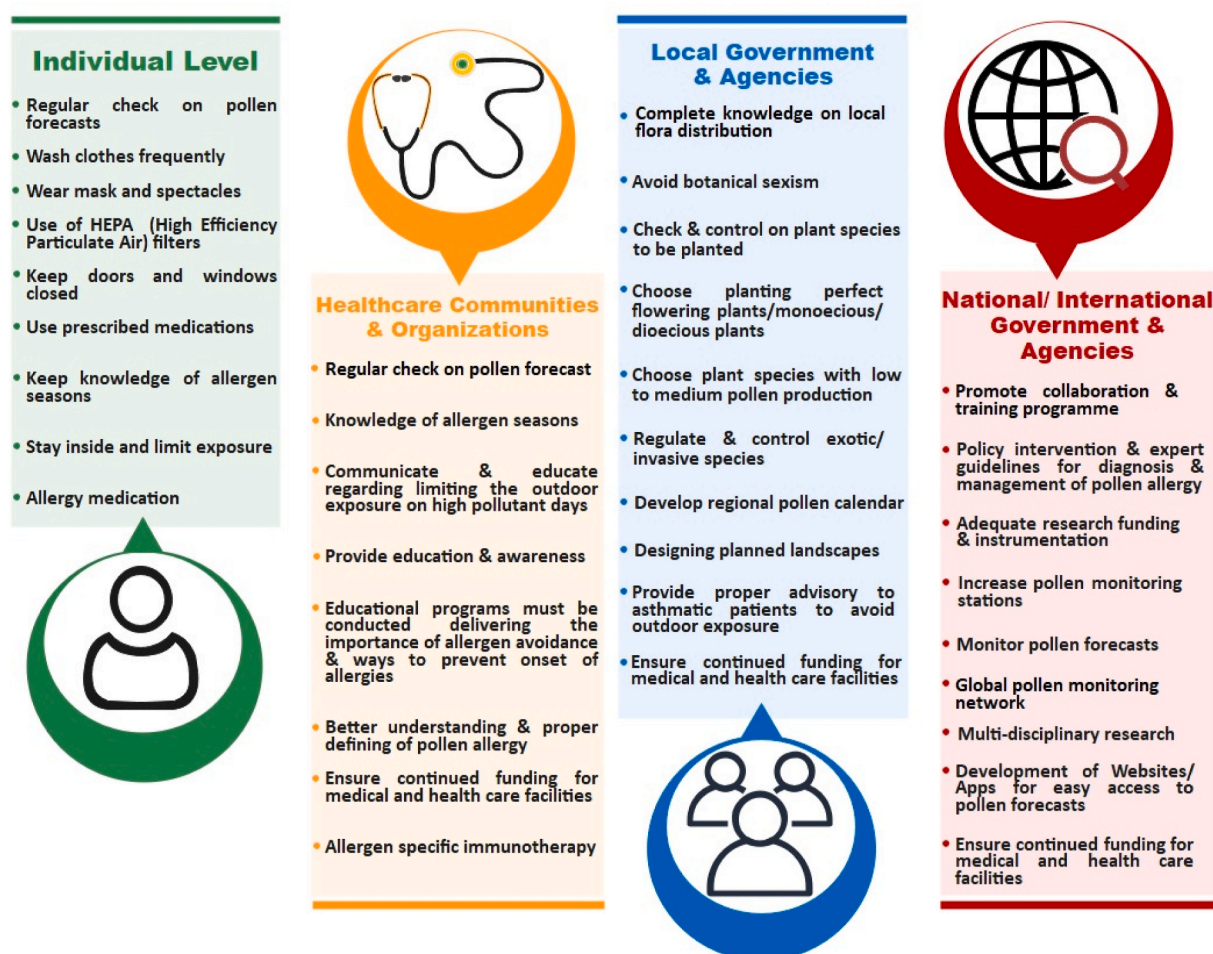


Fig. 3. Key measures and recommendations for preventing and controlling pollen allergy.

- Designing planned landscapes and management** to produce a lesser amount of pollen allergens with context to local flora. Moreover, involving experts (Botanist, aerobiologists, epidemiologists, etc.) at the planning stage to design urban green spaces. Encourage the concept of a “third landscape” site promoting the selective colonization of various and transient species in order to reduce the existence of spontaneous low-diversity populations producing allergic pollen (Clement, 2007).
 - To avoid outdoor exposure and overexertion during high pollen load days, proper advisory must be given to asthmatic patients.
 - Co-morbidities due to pollen allergies must be addressed and proper medications should be made available during the peak pollen seasons.
 - Ensure continued funding for medical and health care facilities**-to provide access to high-quality allergen extracts for immunodiagnostics and ensure the safe delivery of allergen-specific immunotherapies.
- 4) National/International Governments and Agencies:
- Collaboration and training programs:** Expand the research and collaboration to monitoring pollen trends, remote sensing, sensitization and development of asthma severity.
 - Proper Guidelines and Policy intervention:** It is crucial to set appropriate guidelines for the diagnosis and proper management of pollen allergy, mentioning the allergic species, its allergenic potential, peak pollen seasons with respect to geographic area. For example, the European Academy of Allergy and Clinical Immunology (EAACI) provided recommendations to improve the future

scenario of asthma, allergy and other immunological diseases (Agache et al., 2018).

Pollen also makes a significant fraction of the ambient air pollution. Therefore, more focus should be paid to develop climate change and air pollution mitigation strategies through policy formulation. Like in India, National Clean Air Programme (NCAP) and National Action Plan on Climate Change and Human Health (NAPCCHH), etc., could benefit from the inclusion of aerobiologists, environmental health specialists and specifically experts from plant biology and phenology to control bioaerosols. Not only this, but the improvement in air quality will help to reduce the mortality and morbidity due to air pollution. This will further result in better economic growth and human health. Fig. 4 depicts a proposed integrated framework to minimize pollen allergy as a case for India. Further, the Clean Air Initiative (CAI) by World Bank aims to advance a better understanding of pollution challenges and practical solutions on the Global Alliance on Health, Pollution and Climate Change, having focus only on the policy related to anthropogenic emissions. Thus, there is an urgent need to understand and incorporate the natural component, i.e., pollen, into the policies.

- Multi-disciplinary research:** different sciences and disciplines pertaining to epidemiology, immunology, aerobiology, etc., are required to illustrate and explain factors owing to pollen allergy properly.
- Research funding and instrumentation:** Designated laboratories to monitor and analyze daily samples. The database available will

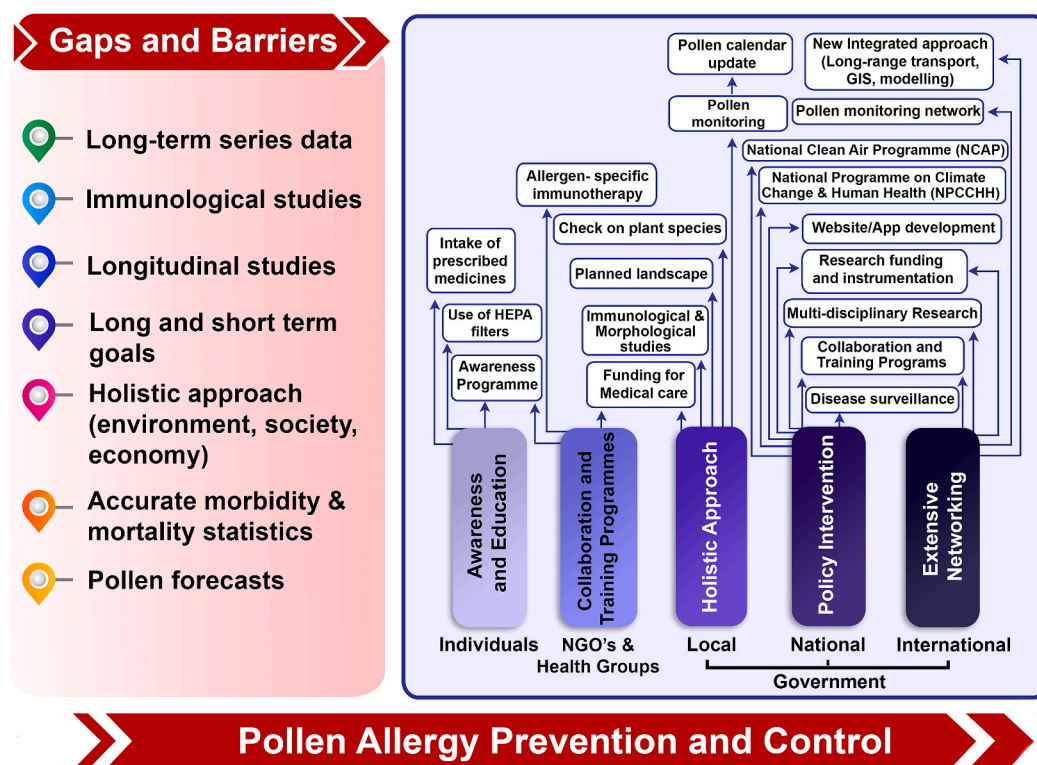


Fig. 4. Proposed integrated developmental framework for pollen allergy prevention as a case for India.

help to summarize the current and past allergen levels in the atmosphere in a very efficient manner.

- **Inadequate monitoring of pollen loads:** Sampling and aerobiological units for measurement of airborne pollen concentration are globally scarce, and most of them are established in high-income countries such as the United Kingdom, USA, Europe, etc.
- **Pollen Monitoring network:** in response to the increasing pollen allergy, a global pollen monitoring network is required to collect and disseminate the obtained pollen data. More monitoring stations could help to have larger pollen data pools. This will aid to understand the spatial and temporal trends of pollen concentration and will be fundamental for scenario analysis and policy formulation in the future.
- **Pollen Forecasting:** The aerobiology data is also valuable in creating pollen forecasts, development of medications and public awareness. Forecast for pollen levels will help to regulate and avoid allergies.
- **Development of Websites/Apps:** A well-designed website or mobile app is required featuring the pollen concentration and major allergenic species forecast for easy and prior dissemination of information for particular areas. A very few apps are available to deal with the specific arena, such as Pollen.com's Allergy Alert for the United States of America, My Pollen Forecast UK for the United Kingdom, etc.

Some measures have been recommended to prevent allergy, i.e., removing allergenic species from the environment, shown to be effective as a primary step but is ineffective when long-distance transport is considered. Another aspect of annual periodicity, when taken into account, is an essential feature in response to pollen allergy, as symptoms usually occur at the same time of the year in maximum cases (during pollination). But many have reported allergy symptoms before and after the pollen season start and ends. Thus, symptoms may occur seasonally or throughout the year. Therefore, pollen allergy may be indefinite and is masked by many other sensitization processes, which precludes or

alters its clear clinical picture in some instances.

Therefore, to address the above issues, both short-term and long-term objectives are needed to reduce allergic diseases. Under short-term objectives, the main focus remains on emergency and unscheduled visits, a relation of the epidemic to emergency hospital admissions. In contrast, longer-term objectives involve new therapies, follow-ups with patients, extensive educational programs and courses to control and prevent allergies.

7. Conclusions

Pollen allergy is considered a trivial disease and has not attained much public health attention, specially in lower and middle-income countries. Various studies have already demonstrated that climatic change and air pollution may alter pollen production, morphology, allergenicity, season and their distribution; which may increase the prevalence of allergic diseases in humans. The prevalence of pollen-associated allergies has increased in the past three decades and is likely to rise in the future. Thus, there is an urgent need to develop a strategic, multi-professional, collaborative approach to tackle the burden of allergic rhinitis and co-morbidities. With every adaptation/preventive measure, attention needs to be given to the most vulnerable sub-populations: allergic asthma, allergic rhinitis, and eczema. However, special attention needs to be given in the education sector, training for patients and professionals, developing collaborated research programs, pollen forecasts, and ensuring continued funding for medical and health care facilities. Participation and association of healthcare communities and relevant regulatory authorities at the local, national and international levels may allow acting on pollen allergy prevention and control.

CRediT authorship contribution statement

Khaiwal Ravindra: Conceptualization, Methodology, Formal analysis, Visualization, Writing – review & editing. **Akshi Goyal:**

Methodology, Formal analysis, Writing – review & editing. **Suman Mor:** Supervision, Formal analysis, Writing – review & editing.

Declaration of competing interest

Authors confirm that there's no financial/personal interest or belief that could affect the objectivity. All authors read the paper and approved it.

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