

Prevalence of Microorganisms in Indoor Household Environments and their Pathogenesis

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Abstract

Microorganisms have a ubiquitous distribution and are found in several environments including indoor settings, particularly in household compartments. In different household areas, their prevalence varies depending on different factors. These microorganisms comprise bacteria, fungi, viruses, mites, etc. and are exclusively found in the kitchen, bedroom, washrooms, fans, indoor dust and walls of the house. The current literature indicates the high prevalence of microorganisms in the different parts of indoor environments. The entry of these microbes in the indoor environment follows different channels like air, people, pets, water and growing plants. These microorganisms are also found greatly on cell phones and thus make them a causative tool of various diseases. The value of studying of these microorganisms is more promising if it is known to be a pathogenic species. The informative data were collected from PubMed, ScienceDirect and Google Scholar by searching key terms related to the scope of the review and analyzed carefully. This review aims to summarize the cumulative knowledge about indoor microorganisms and their role in pathogenesis with the hope that everyone should take care of themselves and their environments. The high prevalence of microorganisms in such niches is due to the presence of their ideal growth conditions and mostly transfers to each other by human contact. It is also evident that all types of these indoor microbes have the potential to cause infections and diseases including, asthma, pneumonia and allergy.

Keywords: Microorganism • Indoor environment • Bacteria • Fungi • Pathogenesis

Introduction

Microorganisms have ubiquitous distribution in the environments and are found in air, soil, water and animals with varying species prevalence with the approximate number of 159,000 species [1]. These microorganisms include bacteria, fungi, protozoists, algae, mites and viruses [1-3]. The distribution of microorganisms in environments depends on several factors, making them high in one environment and very less in other niches [4]. For instance, in drinking water Proteobacteria and Bacteroidetes are the dominant [5]. Particularly in household environments, these microbes are found in the kitchen, bed, windows, dust, air conditions, coolers, fans, plumbing systems, etc. [2,3,6]. It is evident that microbial growth is more in damaged and moist homes and varies both qualitatively and quantitatively [7,8]. The presence of a greater number of indoor microorganisms are also supported by the controlled indoor conditions that nourish these microbes, like, humidity, warmth and moisture [2,8,9].

Microbes enter into indoor buildings through various channels like outdoor air, soil, water, living plants, various food products, other people, pets, insects and animals [4,10-12]. The potential point of entry of these microbes into the household environments is shown (Figure 1). Indoor air pollution is

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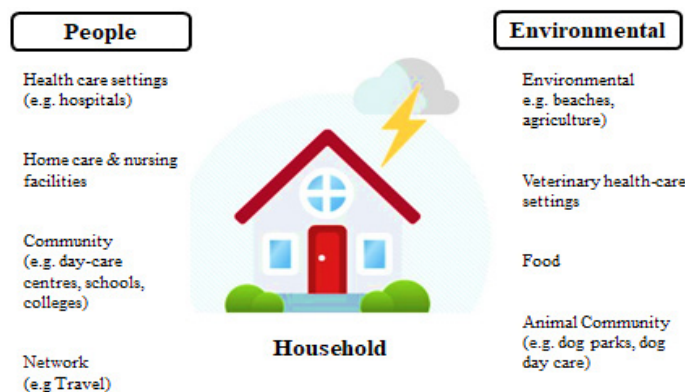


Figure 1. Main points for entry of microorganisms into the household's environments.

also considered a threat to the transmission of various diseases and people who spend more time indoors are suffering more [12-14]. It is estimated that approximately 3.8 million deaths occurred in 2016 due to indoor air pollution [13]. The quality of indoor air contributes a lot to the health of the residents [15]. The objective of the review is to summarize the recent knowledge about indoor microorganisms and their role in pathogenesis so that everyone should take care of themselves and remain safe from their causative disease potential. This review also gives an in-depth analysis, insight knowledge, recent survey about indoor microorganisms particularly in the house compartments and also focuses on common microbial diseases that are thought to be caused by indoor microorganisms.

Literature Review

The literature survey was performed by searching different key terms like, household microbes, microorganism, microbial pathogenesis, indoor microbes, microorganism's prevalence, kitchen microbes, microbes and house

prevalence, dust microorganism, etc. in PubMed, ScienceDirect and Google Scholar to collect related literature for this review. All the relevant materials were screened for the relevance of the article scope, to remove the grey literature and to reduce the literature data. This review article gives more and precise information about microorganisms that are involved in the emergence of infections and diseases particularly in the indoor environments. The selected data were analyzed critically and only relevant, recent and useful materials were chosen to provide concise, informative and meaningful literature on the aforementioned topic. The selection method followed is summarized in (Figure 2).

Indoor household places having the highest microbial prevalence and their effects

The kitchen is the area of a house that is most intensively colonized by microorganisms and it is also the indoor environment where most people are exposed to the widest variety of bacteria. Kitchen sponges are also considered as the reservoir of microbes that catch microorganisms during the cleaning process and hence can prevail during handling [16]. In indoor water, the microorganism also prevails extensively and extends to washrooms, kitchen water, tap water and other household water bodies. An extensive review of the indoor water micro-biome was published recently by Babic, et al. Microorganisms from ready-to-eat foods and other eating foods were also identified in the study of [17,18], hence showing that these microbes are not always pathogenic and can help in various food processing [19]. One of the most crucial devices of modern life, the cellular phone, also has thousands of microorganisms that are reproduced due to the warmth of the phone's extensive use [20-22].

In the bathrooms, the microorganisms enter *via* exhaust and remain with the walls and floor, thus making the bathroom contaminated [4,23]. There are multiple methods that are helping to isolate, identify and culture the isolated microbial colonies from indoor environments, some commonly used techniques are summarized previously [10]. A comprehensive review on indoor household microbiome and airborne microorganisms has been published recently [4,24], which focus on the microorganisms present in different parts of the household. The simple bio aerosol source in indoor environments is illustrated (Figure 3).

The presence of these microorganisms in the stated environments indicates that bio-contaminants are present everywhere and cannot be finished. Almost all these microorganisms in the aforementioned environments have the potential to cause various diseases and increase the mortality rate of humans and other animals in indoor environments. The presence of these microorganisms is affecting almost all aspects of our lives including the lifestyle of the residents. People both indoors and outdoors are suffering equally from these microorganisms and acquire many diseases. It is documented that more people (90%) currently live indoors [8,10,15,25] where they are exposed to different kinds of microorganisms and allergens [26,27]. Spending more time at home can also contribute to allergic diseases in humans, especially in children [28].

Factors affecting the distribution of microorganisms in indoor environments

The high prevalence of microorganisms in the indoor environment is mostly because of human activities and the design of buildings [3,9,26,27]. The indoor microorganisms are considered the permanent residents of the buildings and enriched with fungi and bacteria [29], in which the earlier is detected by their peculiar characteristics like mycelial growth, visible mold and odor [3], whereas the indoor bacterial community is heavily influenced and homogenized by household inhabitants. People are frequently exposed to many indoor germs, including bacteria, fungi and dust mites. Several of these microbes have the potential to cause allergies and infectious diseases, especially in young children, elderly people and persons with compromised immune systems [14]. Recently it has been reported that indoor microorganisms are affected by some parameters including geographical region distribution [25,29]. The comprehensive factors which affect indoor microorganisms are recently reported in the review of Rai S, et al. [8].

Bio-contaminants in the indoor household environment

As already mentioned household environments are a rich source of

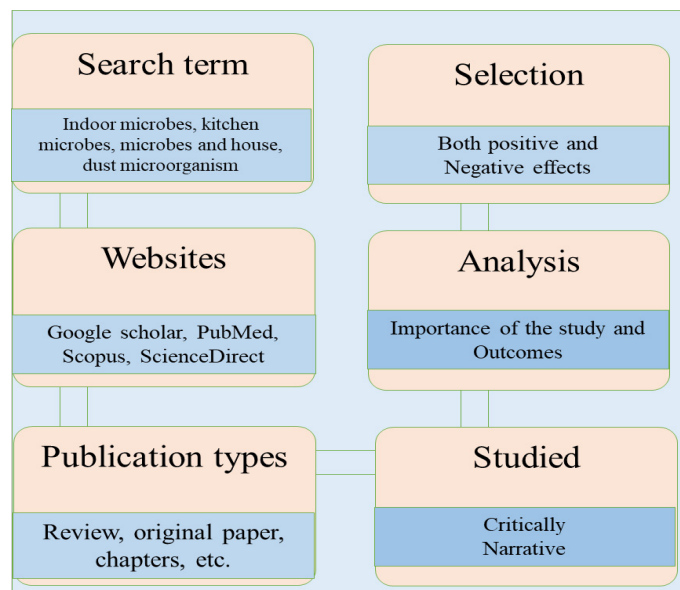


Figure 2. Schematic representation of methodology used in this article.

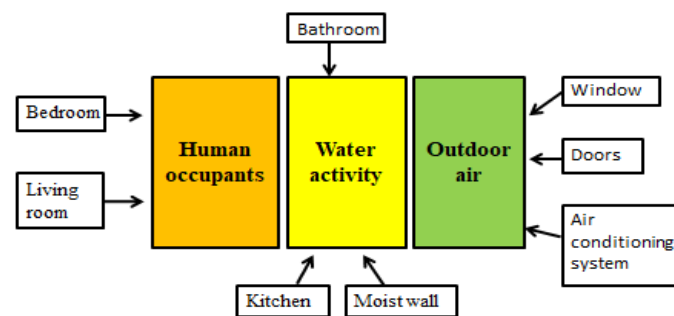


Figure 3. Simple illustration of bio aerosol sources in the indoor household environment.

all kinds of microorganisms that have the potential to cause illness. These microorganisms in indoor environments are changing both qualitatively and quantitatively with conditions as described by Jayaprakash B, et al. [7]. House dust is also considered a rich source of various microorganisms that are comprised of almost 1000 different microbial species [4,11,25]. The house dust and its potential human risks are recently reviewed [25]. Indoor pathogenic transmission is controlled by different mechanisms including improvement in the quality of latrine and kitchen environments [6]. One of the interesting reports show that in empty indoor environments, the size of aerosol and other microbial particles are less than the occupied indoor environments [12]. The common indoor microorganisms are described below.

Bacteria: Bacteria are the most common type of microbial species identified in household environments that are associated with different stuff like buildings, bedrooms, water, baths, phones, kitchens and food sources [2]. It has been published that 32 different phyla of bacteria both Gram-positive and Gram-negative species are identified in indoor environments. Mostly bacteria have ubiquitous distribution in indoor environments but their prevalence in particular environments is also well-defined depending on their morphological, behavioral and pathogenic characteristics. In indoor environments, the dominant bacterial species from gram-positive include *Enterococcus*, *Deinococcus*, *Lactococcus*, *Firmicutes* *Bacillus*, *Staphylococcus*, *Carnobacterium*, *Rhodococcus*, *Streptomyces* and *Micrococcus* [25], while from Gram-negative Proteobacteria, *Bacteroidetes*, *Staphylococcus aureus*, *Stenotrophomonas maltophilia*, *Escherichia coli*, *Clostridium perfringens* and *Pseudomonas putidawere* [2,4,8,16,25]. It is also reported that the prevalence of Gram-negative bacteria is almost one-third of Gram-positive bacteria in the household settings *Staphylococcus* can spread on common surfaces as cabinet tops, shelves, clothes and bed line [21,30,31]. The hostile nature of genus *Enterococcus* makes them fit to use as faecal indicator bacteria.

Due to the rare handling of some household locations (e.g. shelves, cabinet, etc.), any identified bacteria may have survived for an extended period or may have settled as a result of bacteria adhering to airborne dust. Airborne bacterial infections in indoor environments are more common because of activities like coughing, sneezing and handshaking. Indoor floor dusts were also found an enriched source of bacteria [32,33]. Another potential source of indoor bacteria are the shedding of human skin cells, hairs and nostrils, human can shed approximately 102-107 bacteria from their skin every day [10]. The complete profile of the skin microbiome and its interplay in the environments are published somewhere else. Shan Y, et al. reported bacteria from children's beds the dominant bacteria is *Listeria monocytogenes* [25], indicating their close association. The pathogenic bacteria and their diseases are listed in Table 1.

Fungi: Fungi due to their long hyphae can attach to various surfaces and their prevalence depends on the local environment; for instance, there are more fungal spores in moist homes as they have more water concentration [2,22]. In indoor environments, the fungal species prevalence is affected mostly by outdoor factors [25,29,32]. The fungal community commonly associated with indoor environment comprise (*Aureobasidium pullulans*, *Alternaria alternata*, *A. penicilloides* and *A. restrictus*, *Eurotium repens*, *Candida*, *Cryptococcus*, *Rhodotorula*, ascomycetous and basidiomycetous colonies) [2,15,22,25,34]. *A. fumigates*, *Fusarium*, *Trichoderma*, *Yeast*, *Phialophora* and *Stachybotrys* are common in areas with high water activity, whereas *A. versicolor* and *Penicillium* thrive in areas with relatively low to moderate water activity [35].

Fungi also produce secondary metabolites called Mycotoxins which are the causative agents of different diseases i.e. cancer and pulmonary haemorrhage in animals and humans [2,22,35]. Abbot 10,000 of such metabolites is identified in fungi [35]. It is also reported that allergens from indoor fungal sources are the causative agent of asthma [36]. Similarly, fungi also produce volatile organic compounds called volatile fungal metabolites [22] (e.g. 2octen-1-ol) that act

as indicators of biological contaminants and hence aid in its positive face. The fungal secondary metabolites are recently explained in detail [36].

Viruses: Viruses are acellular organisms that can develop on both natural and synthetic things, but they need a host to replicate and multiply. It is commonly noticed that viruses are not described very well as bacteria and fungi and hence they are known as the forgotten sibling of the microbiome family [37].

Indoor air often extends the lifespan of respiratory viruses and increases the risk of infection and sickness [2]. Due to the presence of rodents, Hantavirus infection in humans is highly common in indoor situations. Viruses are considered the key causative agents of nosocomial infections and are responsible for almost 5% of infections [38]. Not all viruses are pathogenic there are some healthy viromes also present [37]. It is also evident that viral transmission mostly depends on humidity and temperature [39].

Allergens: The substances that cause allergies are known as allergens. They have a pretentious nature with varying molecular weight and are produced by many types of microorganisms [2]. The allergy they cause depends on the type of microorganism from which they originate. For instance, fungal allergens cause type-1 hypersensitivity [2,36]. Species from mites like *Dermatophagoides pteronyssius*, *D. farinae* are also producing allergens [2,40]. In indoor environments substances like poultry and bakery are the potential source of allergens, which are considered the potential risk of asthma in children [40].

Discussion

Pathogenicity of household microorganisms

The pathogenic nature of household microorganisms is vast as these are

Table 1. Different types of indoor microorganisms and their role in various diseases.

Microorganisms	Role in disease	References
Bacteria		
<i>Mycobacterium Tuberculosis</i>	It causes Tuberculosis (TB) which has worldwide mortalities. The annual increment in new TB cases is ranging from 7.5 to 10 million. It is transmitted via sneezing, coughing and talking.	Kumar P, et al. [2]
<i>Staphylococcus aureus</i>	They cause toxic shock syndrome, food poisoning and infections of the skin and soft tissues. Nosocomial infections are a significant cause of about two million patient illnesses each year as well as almost 90,000 fatalities.	Kumar P, et al. [2]
<i>Pseudomonas aeruginosa</i>	It is the chief cause of nosocomial infections which are assisted by biofilm formation. They cause severe disease which accounts for approximately 0.1 million deaths annually.	Mulcahy LR, et al. [44]
<i>Clostridium tetani</i>	It results in tetanus in all ages, with an approximate number of 34,000 neonatal tetanus was observed in newborns in 2015.	Carrer P, et al. [40]
<i>Bacillus cereus</i>	This bacterium is the causative agent of both gastrointestinal and non-gastrointestinal illnesses, frequently found in soil.	Carrer P, et al. [40]
<i>Listeria monocytogenes</i>	They are the primary cause of listeriosis, which largely affects pregnant women and babies. In 25–30% of cases, listeriosis causes septicemia, meningitis and encephalitis.	Carrer P, et al. [40]
<i>Legionella pneumophila</i>	Legionellosis is the disease of <i>L. pneumophila</i> , which inhibits the water system and makes a biofilm.	Kumar P, et al. [2]
<i>Mycobacterium laprae</i>	This bacterium causes an airborne disease called Leprosy which affects skin, nails and respiratory tracts.	Kumar P, et al [2]
<i>Enterobacteriaceae</i>	Causes several diseases, like meningitis and shows multi-drug resistance.	Osaili TM, et al. [16]
<i>Bacillus anthracis</i>	Inhalation of this bacteria cause highly infectious diseases called Anthrax, which is mostly spread by lung, skin and intestinal route.	Kumar P, et al. [2]
Fungi		
Fungi	The fungal infection is called mycosis which varies with its location in the body. It is more prone to immunocompromised people.	Kumar P, et al. [2]
<i>Aspergillus</i>	Mycotoxicosis is caused by the secondary metabolite of fungi and is associated with cytotoxicity. They are also the causative agent of cancer, asthma and other respiratory diseases.	Kumar P, et al. [2], Khan AAH and Karuppaiyl SM [22] and Ceylan E, et al. [36]
<i>S. chartarum</i>	They can produce three different kinds of toxins and are involved in different diseases.	Miller JD and McMullin DR [35]
<i>Candida albicans</i>	It is involved in the disease of nasal polyps and skin.	Khan AAH and Karuppaiyl SM [22]
Viruses		
Influenza virus	This virus causes influenza	Clements N, et al. [39]
(SARS) virus	Severe Acute Respiratory Syndrome (SARS) virus is spread via bio-aerosol process and causes respiratory illness.	Kumar P, et al. [2], Prussin AJ, et al. [37]

responsible for a large number of diseases. The rate of infectious disease is increasing rapidly and the situation is going more worst in poor countries where more than 25% of residents are suffering from nosocomial infections [20]. The house dust microbiome has a large number of disease-causing species that are causing allergies, asthma, etc. [25]. Mostly, widely spread microbes of indoor environment are pathogenic, while some are good called friendly bacteria. The common diseases and their causative agents are summarized in Table 1.

It is generally stated that bacteria from non-hospital sources are less or non-pathogenic as compared to clinical sources. In these environments, bacteria form biofilm and increase their pathogenicity [41]. Hospodsky D, et al. reported that indoor bacteria are the causative agents of several diseases like asthma and other respiratory diseases [33]. The structural part of bacteria and fungi (1, 3)- β -D glucans are also detected in indoor dust which are involved in respiratory infections [2,22,35], while the indoor endotoxins are involved in causing asthma. In developed countries, the exposure of fungi to various indoor environments was consistently observed and it was found that fungi are involved in the spreading of asthma, pneumonitis, allergy, rhinosinusitis and respiratory diseases [35].

It is common practice to inspect and investigate settled dust in indoor environments to determine the types and quantities of particles to which building occupants are exposed. Bacteria and fungi are the most prevalent of the many investigated components [11]. Typically, soil, plant and animal particles contain microorganisms. On moist indoor surfaces, bacteria and fungi flourish very well. These are also present on carpets and other floors covering that have been carried into buildings, if the right conditions, like enough moisture, are present and cause diseases like mycosis and mycotoxications. Microorganisms and other particles of biological origin when come into contact with mucosal membranes result in hypersensitive reactions, irritation, or other reactions [11].

Due to elements including land usage, seasonal change and topography, the outside environment has a bigger diversity and complex composition of microorganisms than the inside environments [42]. However, their presence in indoor environments may be enhanced by human actions, household features and building design [42]. Indoor allergens and microbes play a significant role in the development of several health disorders. In a global perspective change in the environment are also related to the prevalence of such disorders in which greater increments were observed in the last decade. Climate and environmental conditions may affect the permanence and intensity of allergen exposure and allergy disorders because allergen exposure accounts for the bulk of allergic diseases [14]. According to one American study, the presence of pests pets or, mildew, a musty outdoors is linked to greater indoor allergens levels, which have an interaction with the high prevalence of asthma and wheezing in adults and children. According to certain studies, indoor allergen levels are also significantly influenced by household and outdoor environmental conditions. These studies have found a direct correlation between indoor allergens intensities and allergic illnesses such as rhinitis, dermatitis and conjunctivitis [43].

Mushrooms that survive in moist habitats are also found in indoor environments [44,45]. Moisture fills the pores in the materials according to their relative humidity of the space [46]. Wallboard gets wetter as a result of condensation, leaks, or floods, which makes more water available for microbial development. This idea applies to any substances that can foster the formation of mold. Materials may have completely different water contents even when they have the same amount of accessible water. Mycotoxins which are low-molecular-weight secondary metabolites of fungi have been shown a detrimental effect on human and other animal's health. For example, the aflatoxin precursor sterigmatocystin and 5-methoxy-sterigmatocystin are produced by *Aspergillus*, which is most frequently seen growing on water-damaged construction materials. These two substances are directly linked to water-damaged building materials, which are spread to people and result in aspergillosis [35].

Conclusion

In conclusion, microorganisms are found everywhere in our environments

with varying frequencies and are responsible for causing various diseases. Indoor environments are the enclosed areas where most time is spent by their residents. In these indoor settings i.e. households the prevalence of microorganisms is more due to human activities and the availability of suitable growth conditions. In the kitchen, in the bedroom and in the bathrooms these microbes are attached to different things and cause diseases. The most common microbes in such environments are bacteria, fungi and viruses, which are responsible for respiratory diseases and other illnesses. It is of great importance that special attention should be given to properly identifying, characterizing and well documenting the nature i.e. pathogenic or non-pathogenic of these microorganisms and hence their disease is controlled after proper treatment.

Author Contributions

The concepts, ideas and end formatting were performed by Abrar Hussain and Syed Abid Ali. Tayyaba Bibi, Rida Fatima, Isha Arif and Mukul Machhindra Barwant write the initial manuscript, Mariam Rahman critically analyze the review and help in proper formatting.

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Conflict of Interest

The authors have no conflict of interest.

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