Mode of action of bio aerosols in indoor environment and their eco-friendly removal after developing Indoor Air Quality Index

A **Thesis** submitted

for the partial fulfilment of the continuous assessment of

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By

ANJALI SOREN

Examination Roll No.: M4EBT22013

Registration No. of 2016 - 2017: 136613

Class Roll No: 002030904013

Under the Guidance of

DR. SUBARNA BHATTACHARYYA

Assistant Professor

School of Environmental Studies

Jadavpur University

School of Environmental Studies

Jadavpur University

Kolkata: 700032

2021-2022

M.Tech (Environmental Biotechnology)
Course affiliated to the Faculty of Interdisciplinary Studies, Law and Management
Jadavpur University
Kolkata – 700032 (India)

CERTIFICATE OF RECOMMENDATION

This is to certify that the thesis entitled "**Mode of action of bioaerosols in indoor environment and their eco-friendly removal after developing Indoor Air Quality Index**" is a bonafide work carried out by **Anjali Soren** (University Roll Number: 002030904013) under my supervision and guidance for partial fulfilment of the requirement of Master of Technology degree in Environmental Biotechnology from School of Environmental Studies, Jadavpur University, during the academic session 2020-2022.

……………………………………

Thesis Supervisor
Dr. Subarna Bhattacharyya
Assistant Professor
School of Environmental Studies
Jadavpur University
Kolkata- 700032

……………………………………

Director
School of Environmental Studies
Jadavpur University
Kolkata - 700032

……………………………………………

Dean FISLM
Jadavpur University
Kolkata- 700032

M.Tech (Environmental Biotechnology)
Course affiliated to the Faculty of Interdisciplinary Studies, Law and Management
Jadavpur University
Kolkata – 700032 (India)

CERTIFICATE BY THE SUPERVISOR

This is to certify that the thesis entitled, "Mode of action of bio aerosols in indoor environment and their eco-friendly removal after developing Indoor Air Quality Index" being submitted by Anjali Soren to the School of Environmental Studies, Jadavpur University Kolkata for partial fulfilment of the requirement for the award of degree of Master of Technology in Environmental Biotechnology. This study was carried out by her under my guidance and supervision.

____

(Signature with seal)

Dr. Subarna Bhattacharyya
Assistant Professor
School of Environmental Studies
Jadavpur University, Kolkata

Date: _____ / _____ / __________
Place: School of Environmental studies
Jadavpur University
Kolkata – 700032 (India)

M.Tech (Environmental Biotechnology)
Course affiliated to the Faculty of Interdisciplinary Studies, Law and Management
Jadavpur University
Kolkata – 700032 (India)

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Committee of final examination for evaluation of Thesis

____

____

____

____

Signature of the Examiners

****Only in case the thesis is approved

M.Tech (Environmental Biotechnology)
Course affiliated to the Faculty of Interdisciplinary Studies, Law and Management
Jadavpur University
Kolkata – 700032 (India)

UNDERTAKING BY THE STUDENT

I, Anjali Soren hereby declare that this thesis titled "Mode of action of bio aerosols in indoor environment and their eco-friendly removal after developing Indoor Air Quality Index" submitted for the partial fulfilment of the continuous assessment of Master of Technology in Environmental Biotechnology to the School of Environmental Studies (SOES), Jadavpur University, Kolkata – 700032 is record of original work done by me under the guidance of Dr. Subarna Bhattacharyya.

This thesis is written in my own words, with reference to several published scientific papers which have been adequately cited from the original sources. It is also to be declared that this thesis does not contain any fictional or misreported data or result.

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____

Student Name: Anjali Soren

Registration number: 136613 of 2016-2017

Examination Roll No.:

Date: _____ / _____ / __________

Place: School of Environmental studies

Jadavpur University

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____

Anjali Soren
Roll No. 002030904013
Examination Roll No.: M4EBT22013
Date:
Place: School of Environmental Studies
Jadavpur University
Kolkata: 700032

EXECUTIVE SUMMARY

Chapter 1 provides a brief introduction on air pollution in general and indoor air pollution in particular. It describes the sources and classification of various air pollutants, Air Quality Index (AQI) with a special emphasis on ambient air quality and bio aerosols. The diseases caused by poor ambient air quality and the related health risks are also discussed.

Chapter 2 provides the available literature reviews on the subject. It includes studies on indoor air pollution and studies on the quality of ambient air, a few combined studies regarding health and material impacts of bio-aerosols. Studies at national and international level are included.

The thesis problem is defined and the objectives and scopes are stated in **Chapter-3**. The problem title is "**Mode of action of bio aerosols in indoor environment and their eco-friendly removal after developing Indoor Air Quality Index**" and the problem objectives are:

- To design an Air Quality Index (AQI) calculator to measure the AQI of ambient air using C++ programming and secondary data.
- To assess the degradation of concrete walls of acid producing fungi sp. (*Aspergillus tamerii*).
- To study the prevention of acid producing fungi using Mangrove plant extracts (*Excoecaria Agallocha*).

Chapter-4 elaborates the study program and methodology for assessing the quality of ambient air. The procedures for the same are also explained.

The results of the study are presented in graphical forms in **Chapter-5**. The obtained information is analysed in various ways and necessary discussions are provided. It also lists the conclusions of the studies.

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Chapter 1
Introduction

1.1 Air Pollution

Air pollution is acknowledged to be a significant public health problem, which is responsible for a growing range of health effects well documented from the results of an extensive research conducted in many parts of the world. It is defined as an atmospheric condition in which certain substances are present in concentrations such that they produce undesirable effects on man and his environment. Air pollution may also be referred to the introduction of physico-chemical or biological materials into the atmosphere that may cause harm or discomfort to humans or other living organisms, or deterioration of the natural environment. The substances include gases such as SOx, NOx, CO, particulate matter (smoke, dust, fumes, aerosols), radioactive materials and many others. Mostly, these substances are naturally present in the atmosphere in very low concentrations and are usually considered to be harmless.

Air pollutants are mainly classified as primary or secondary air pollutants. Primary air pollutants are those substances that are emitted directly from natural or anthropogenic sources, such as ash from volcanic eruptions, carbon monoxide (CO) gas from motor vehicle exhaust, or sulfur dioxide (SO2) released from factories. On the other hand, primary pollutants do not produce all of the harmful effects of air pollution by themselves. Subsequently, there are gaseous pollutants reacting with each other and with the particles in the air to produce a complex array of new chemical compounds. Secondary air pollutants are not emitted directly, but formed in the air and are responsible for several ill effects of air pollution such as haze, eye irritation, smog, and also damage to vegetation and material.

Air pollution is an obvious problem in most parts of the world that has affected humans, plants and animal health. It is also considered one of the most serious problems in today's societies at all levels of economic development. It affects the properties of materials (such as rubber), visibility, and the quality of life in general. Industrial development has been associated with emission to air of large quantities of gaseous and particulate emissions from both industrial production and burning fossil fuels for energy and transportation. The introduction of technology led to controlling air pollution by reducing emissions of particle but it was observed that the gaseous emissions continued and caused problems of their own. Current efforts to control both particulate and gaseous emissions have been partially successful in much of the developed world, but there is recent evidence that air pollution is still a major health risk even under these relatively favourable conditions.

The rapid expansion of the industry in most countries has occurred at the same time as increasing traffic from automobiles and trucks, increasing demands for power for the home, and also the rapid increase in population in large urban areas called mega cities. These results have recorded some of the worst air pollution problem in the world.

In many traditional societies, where crude household energy sources are widely available, air pollution is a very serious problem because of inefficient and smoky fuels which is used in cooking and heating houses that leads to air pollution both out door and indoors. As a result, diseases such as eye problems, and increased risk of cancer cases has been reported. [1]

1.1.1 Indoor Air Pollution

The rapid industrialization and urbanization has led to indoor air quality becoming a challenge for all the developing and developed countries. In most developing countries generally in the rural areas, due to inefficient open fires, they are highly exposed to high concentrations of solid fuel smoke that is produced by burning of biomass and coal. The main sources used for cooking purposes are preferably cow dung, wood, liquefied petroleum gas (LPG) and propane natural gas (PNG) and kerosene (Gautum et al.,2011). But in the urban areas, there is poor sanitation, generation of solid wastes, open landfilling, burning of solid wastes, inadequate housing, lack of awareness regarding toxicity of air pollutants which are emitted from various sources and water supply causing ill health effects in women and children (Bruce et. al.,2000). [2]

Most of us spend up to 90% of the lifetime indoors - at home, at gym, at work, at school or in transportation units or shops, restaurants, etc. The quality of air, one breathing indoors has a direct impact on health. In poorly ventilated houses, emissions of PM2.5, and other pollutants can be 100 times higher compared to WHO-recommended levels. Therefore, this recommendation particularly specifies that emissions of PM2.5 should not exceed 0.23 mg/min when unvented (i.e. the absence of a chimney or hood) and 0.80 mg/min when vented (i.e. with a chimney or hood). For carbon monoxide, emission rate targets (ERT)should not exceed the value of 0.16 g/min for unvented devices and 0.59 g/min for vented devices [3]. These pollutants inflame the airways and lungs, impairing the immune response and reducing the oxygen level of blood. According to statistical analysis, 4.3 million people die annually from exposure to household air pollutants, most perish from stroke (34 %), ischemic heart disease (26 %) and chronic obstructive pulmonary disease (22%). Considerably, 12% and 6% of deaths account for pneumonia and lung cancer respectively. [4]

Poor indoor air quality can be harmful, specifically to the vulnerable groups, such as children, the elderly and those suffering from cardiovascular and chronic diseases such as asthma. Household air pollution is one of the major cause of premature death in the developing world [5]. Indoor air pollutants cause health effects which may be experienced soon after exposure or, possibly, years later. The repeated or single exposures of these pollutants may show up many serious health effects such as irritations in the eyes, nose, and throat, headaches, dizziness, and fatigue. Such immediate effects produced are generally short-term and treatable. But because these effects are quite similar to those from colds or other viral diseases, it is difficult to determine if the symptoms are a result of exposure to indoor air pollution [6].

It may come as a surprise to many of us to learn that the air on an urban street, with medium traffic, actually could be cleaner than the air in our indoor spaces, where we spent our lifetime. Recent studies and research show that certain air pollutants may exist in higher concentrations indoors than outdoors. In the past, less attention has been paid to indoor air pollution significantly as compared to outdoor air pollution, especially that was caused by industrial and transport emissions. However, in the recent years the threats caused due to exposure of indoor air pollution have become more visible. [7]

1.1.1.1 Factors that affect indoor air quality

Indoor Combustion is one of the major sources of indoor air pollution. The most common contributing factor to indoor air pollution include cooking, lighting and heating. Fuel combustion in kitchen is the most dominant source of indoor air pollution and can cause severe impact on health and environment. Indoor air pollution from solid fuels is one of the top leading causes of global mortality and disease (Lopez et al.,2006). This is particularly based on the use of biomass and coal as cooking fuels in rural parts of developing countries. Incompletely vented or unvented combustion also occur to a substantial extent in economically developed countries.

1.1.1.1.1 Cooking

Mainly in the United States and many other developed countries, cooking causes air pollutant exposures that have potential public health significance. For example, the use of natural gas as a cooking fuel is associated with elevated indoor exposures to nitrogen dioxide, a by-product of the combustion process. Solid fuel smoke (biomass and coal) is exposed to one half of the world’s population in high concentrations produced by inefficient open fires, mainly in the rural areas of developing countries.

1.1.1.1.2 Smoking

Indoor smoking affects indoor air quality adversely including public health. Smoking indoors has a strong influence on indoor levels of the particulate matter (Nazaroff and Klepeis 2004, Hyland et al 2008). Environmental tobacco smoke is also an important cause of environmental exposure to certain hazardous air pollutants, including acrylonitrile, 1,3-butadiene, acetaldehyde, acrolein and formaldehyde (Nazaroff and Singh 2004).

1.1.1.1.3 Space Heating

Combustion for space heating is associated with substantial pollutant emission because of relatively large amounts of fuel used for home heating. Household use of kerosene heaters and fireplaces for heating was found to be associated with respiratory symptoms in non-smoking women. Colberk (2010) studied the particulate matter concentration increased in indoor air in winter when occupants burn wood and coal to keep them warm, concentration of particulate matter depends on the amount of biomass fuel used, duration of cooking, degree of incomplete combustion including ventilation.

1.1.1.1.4 Incense and Mosquito Coils

It has been observed that emission from cooking, smoking, burning of mosquito's coils, cigarettes, incense sticks, candles mainly lead to indoor air pollution in dwelling areas. Burning of one mosquito coil releases the same amount of PM2.5 as that of smoking of a single cigarette. Mosquito coils are widely used as repellents in various Asian countries including China, India, Malaysia, Korea, Japan and Thailand. Major active components in mosquito coil are pyrethroids such as d-allethrin, esbiothrin, transfluthrin and metofluthrin. Liu et al., 2003 studied that all particles emitted from burning mosquitoes coil was fine, <1μm in diameter most particles were in size range of 0.01-0.1μm and 0.2-0.3μm. Burning of incense sticks, candles and mosquito coils is an incomplete combustion process. It is said to produce various kinds of air pollutants including particulate matter (PM), carbon monoxide (CO), nitrogen dioxide (NOX), volatile organic compounds (VOCs) and toxic metals. Such activities release significant amount of pollutants like Particulate Matter (PM), Polycyclic aromatic hydrocarbons (PAHS), Carbon monoxide (CO) and other toxic gases which are identified as potential carcinogens (Singh et al.,2010). In India and other countries indoor pollution is also with incense, candles and mosquito coil. [8]

1.2 Air Quality Index

ASHRAE defined the air in which there are no known contaminants at harmful concentrations and where the substantial majority (80% or more) of the people exposed, do not express dissatisfaction. Indoor pollutant affects the quality of homes; there is an also indoor air quality standard that reflects quality of homes. AQI is calculated for four major air pollutants regulated by the Clean Air Act- Ground Level Ozone, Particulate Pollution, Carbon Monoxide, Sulfur dioxide.

Air Quality Index (AQI): The Air Quality Index (AQI) is a simple, unit less index used to communicate air pollution to the general public.
To calculate the AQI, the US EPA draws from various environmental monitors that each records a pollutant.
Table 1. Six pollutant types are used to calculate the AQI

$PM_{2.5}$	Fine particulate matter with 2.5 micrometer diameter or smaller; examples include ash, smoke and smog.
PM_{10}	Coarse particulate matter with 10--2.5 micrometer diameter; examples include dust, pollen and mould.
NO_2	Nitrogen dioxide
SO_2	Sulphur dioxide
CO	Carbon monoxide
O_3	Ozone

For each of these pollutants, EPA has established national air quality standards to protect public health. EPA is currently reviewing the national air quality standard for nitrogen dioxide. EPA (Environment Protection

Agency) have recommended the scale to detect Air quality index. AQI starts from 0-500. More will be the value of AQI unhealthier air and serious health effects.

Table 2. Air Quality status according to WHO standards [9]

Quality	Range	Status of Air Quality
Good	0-50	Air quality is satisfactory and poses little or no health risk.
Moderate	51-100	Range may pose a moderate health concern for a very small number of individuals
Unhealthy for sensitive gr.	101-150	Members of sensitive groups may experience health effects, but the general public is unlikely to be affected.
Unhealthy	151-200	Members of sensitive groups may experience health effects, but the general public is unlikely to be affected.
Very unhealthy	201-300	Trigger a health alert, meaning everyone may experience more serious health effects.
Hazardous	Over 300	Trigger health warnings of emergency conditions. The entire population is even more likely to be affected by serious health effect.

1.2.1 Key air pollutants

Air pollution is a worldwide problem and is reported to cause the greatest damage to the health of living things. Stationary sources generally include power plants, industrial waste incinerators, the emission of dust from urban construction works and quarries and open burning. Transboundary pollution is the transported air pollution caused by forest fires from neighbouring countries.

The six key pollutants generally present in the atmosphere include ozone, particulate matter, nitrogen dioxide, sulphur dioxide, lead and carbon monoxide. Particulate matter categorized by aerodynamic diameter such as particle less than10 lm is known as thoracic particle (PM10), all particle less than 2.5 lm is defined as fine particle, all particle less than 0.1 lm is defined as ultrafine particles (UFP) and the particle between 2.5 lm and 10 lm which is known as coarse particle (PM2.5-PM10). The micro size of particle matter can make it easily enter the respiratory tract and can cause asthma. The main source of this pollutant comes from combustion such as combustion of wood and biomass fuel.

Particulate matter is a type of air pollutants that exists everywhere around us. Particulate matter is a common airborne pollutant, which consists of a complex mixture of liquid, semi-liquid and solid particles which are suspended in the atmosphere [10,11]. It is generated through industrial activities, combustion for energy production, vehicular emissions, fossil fuel combustion and range of human activities [10,11]. The sizes of particulate matter used as indicators to describe its health effects are particles with sizes are less than 10 mm in diameter (PM10) and those less than 2.5 mm in diameter (PM2.5). Several health risks have been associated with PM10 and PM2.5 particulate matter. Inhaling particulate matter affects respiratory and cardiovascular systems in both adults and children. Fine particles (such as PM2.5 particulate) has the ability to penetrate deep into the lungs and blood streams when inhaled causing respiratory problems, lung cancer, heart attack and even death [12]. Studies have shown that short term and long-term exposure to particulate matter aggravate cases of asthma, respiratory symptoms among sensitive groups such as young children and the elderly.

Ozone is made up of three oxygen atoms. Ozone is formed in the atmosphere by photochemical reaction in the present of sunlight and pollutant such as oxides of nitrogen and volatile organic compound. It is destroyed by reactions with nitrogen dioxide and it is deposited to the ground [13]. Source of ozone pollution are coming from chemical solvent and combustion product of fuel. Exposure to ozone for a few hours will lead to chest pain, reduces lung function, coughing and asthmatics.

Nitrogen dioxide is very reactive gasses known as nitrogen oxides. It will be produced when fossil fuels such as coal, natural gas are burned. Nitrogen dioxide also emitted by motor vehicle and stationary source such as electric utilities and industrial boilers. Exposure to nitrogen dioxide for will lead to influenza and reduces lung function. Sulphur dioxide is poisonous gas. It can dissolve with water to form sulphuric acid. The sulphuric acid is the main component of acid rain. Sulphur dioxide is commonly released from the industry section such as a factory that burn high sulphur coal, petroleum refineries and solid waste that contains hazardous and medical waste. Study shows that exposure to acid rain will cause skin cancer, asthma and bronchitis. Lead is an abundant heavy metal in the earth, about 14 parts per million by weight or one part per million by moles. Lead is grey colour, soft and ductile metal. It rarely occurs in pure form in nature. Lead is usually found in ores, mostly with copper, zinc and silver. The most common lead mineral is galena, which is lead sulphide (PbS) and other minerals include lead carbonate and lead sulphate [14]. Lead has become widely distributed in the environment since it was discovered and used by humans for a long time [56]. Lead is an important metal and be used in many industrial especially in the electric battery industry. Lead emissions come from motor vehicle, fossil fuel and manufacturing and mining will cause to premature birth and neurological impairments such as seizures, mental retardation and behavioural disorders. Carbon dioxide is made up from one carbon and two oxygen atoms. Carbon dioxide is released on combustion to the atmosphere. Source of carbon dioxide pollution are mainly come from burning of fossil fuels and production of cement. Exposure to carbon dioxide will effects the range from physiologic (e.g. ventilator stimulation), to toxic (e.g. cardiac arrhythmias and seizures), anaesthetic (significantly depressed CNS activity), and lethal (severe acidosis and anoxia) [15]. However, the effect of carbon dioxide on the individuals is depending on age, health, occupation, physical activities and lifestyle.
Thus, the air quality index takes into account these six air pollutants. [16]

1.3 Bio aerosols and its adverse health impacts

Bio aerosols are very small airborne particles (ranging from 0.001 to 100 μm) that originate biologically from plants/animals and can contain living organisms (Georgakopoulos et al., 2009). Therefore, pathogenic and/or non-pathogenic dead or alive microorganisms (e.g., viruses, bacteria, and fungi) may exist in bio aerosols (Mandal and Brandl, 2011). Bio aerosols are easily shifted from one environment to another because of their small size and light weight (Van Leuken et al., 2016). In recent years, exposure to bio aerosols in both occupational and residential environments has drawn much attention in light of their probable impacts on human health.

The sources of indoor bio aerosol pollution include outdoor sources (passing through windows, doors, and ventilation); building materials; furnishings; occupants; pets; house plants; and organic wastes (Nazaroff, 2016). Regular or ordinary human activities for e.g., coughing, washing, toilet flushing, talking, walking, sneezing, and sweeping floors also generate bioaerosols (Chen and Hildemann, 2009). However, some basic environmental conditions, such as temperature and moisture content, can also influence the extent of their formation and dispersion due to their controlling effect on the formation of microorganisms (Dedesko et al., 2015). Consequently, the prevalence of bio aerosols can be associated with certain human diseases, such as pneumonia, influenza, measles, asthma, allergies, and gastrointestinal illness (Srikanth et al., 2008). Although the importance of bio aerosols and their impact on human health has been recognized, it is yet difficult to accurately describe their role in the initiation or worsening of diverse symptoms and diseases. [17]

Chapter 2
Literature Review

2.1 General studies on indoor air pollution, Air Quality Index (AQI) and related health effects (national and international)

1. A study by **Rosário Filho *et al.* (2021)** was conducted that aimed to review the background of air pollution in indoor settings and provide detailed information on the pathogenesis (mechanisms) of household pollution from a combination of effects at different levels. The health effects including pre-natal and post-natal influences on children as well as pollution effects on adults were also discussed.

2. A study by **Suman (2020)** was conducted who reviewed the different methods to interpret the air quality status. These methods consisted of various mathematical formulas. This was due to the rapid increase in urban air pollution in Indian cities. The review also provides how AQI constitutes as an effective method to estimate air pollution levels and risks. It also discusses how the development of these methods have helped the government in effective pollution control by reducing emissions from various sources.

3. **Kishore N. and Deswal S. (2017)** conducted a study that reviewed the air quality of Indian cities. The paper provided data on suspended particulate matter (SPM), total suspended particulate matter (TSPM), respirable particulate matter (RSPM), non-respirable suspended particulate matter (NRSPM) of different Indian cities and briefly concluded that the environmental issues are constantly growing in number and size, thus proper rules and regulations must be implemented and followed strictly. It also briefly emphasizes on the assessments of health impacts due to the increase in the concentration of air pollutants in Indian cities.

4. The study by **Frank J. Kelly and Julia C. Fussell (2015)** provided detailed information on the emerging risks and hazards caused by air pollution on public health. It gave a brief introduction on the historical perspective on modern air pollution and also drew attention towards the health effects, differential toxicity of particulate matter (PM) and mechanisms of PM air pollution.

5. **Soni *et al.* (2013)** studied about the indoor air quality index and the chronic health diseases caused due to poor ambient air. It discussed about the premature deaths caused by indoor air pollution which has been estimated by WHO (2006). The indoor activities such as cooking, smoking, incense, mosquitoes coil have mostly affected the ambient air and notably it was observed that young and unemployed people including women were most affected as they spent 90% of their time indoors. As the standard of living is increasing every day, indoor air quality is effected and the most vulnerable group affected by the bad quality ambient air are mostly women. The paper concluded that efforts must be made to support emerging exposure-response relationships; particularly for common and serious health problems.

6. **Sarmadi et al. (2021)** conducted a study on the air quality index variation before and after the onset of COVID-19 pandemic. It provided a comprehensive study on 87 capitals, industrial and polluted cities of the world. The purpose of this study was to investigate the changes in the air quality indices (AQI) in industrial, densely populated and capital cities in different countries of the world before and after 2020. This is an ecological study which used AQI obtained from the free available databases such as the World Air Quality Index (WAQI). The results indicated that air quality generally improved for all pollutants except carbon monoxide and ozone in 2020; however, changes in 2021 have been reversed, which may be due to the reduction of some countries' restrictions. Although this quality improvement was temporary, it is an important result for planning to control environmental pollutants.

7. **Yang *et al.* (2021)** conducted a study on the global air quality change during COVID-19. In this study, data from ground-based environmental stations, satellites, and reanalysis materials were

utilized to conduct a comprehensive analysis of the global air quality change during the COVID-19 outbreak. The results showed that the impact of COVID-19 outbreak led to a significant decrease in particulate matter (PMx) and nitrogen dioxide (NO2) occurred in more than 40% of the world's land area, with NO2 (PMx) decreasing by ~30% (~20%). It was further found that in quick-response cities, lockdowns produced a sharp decline in mobility and had a dominant impact on air quality. In contrast, in slow-response cities, mobility dropped gradually since the confirmation of the first COVID-19 case (FCC) and the impact of the FCC, lockdowns and meteorological factors were comparable.

8. **Agarwal *et al.* (2021)** reviewed the indoor air quality improvement during COVID-19 pandemic. The main objective of the paper was to review control measures and preventive sustainable solutions for the future that could deliberately help in bringing down the impact of declined air quality and prevent future biological attacks from affecting the occupant's health.

9. A study conducted by **Mirabelli *et al.* (2020)** provides details about air quality awareness among adults in the United States. The paper discusses about the association between days with air quality index ≥101 corresponding to a categorization of air quality as unhealthy for sensitive groups, unhealthy, very unhealthy, or hazardous.

10. **Mannan M. and Al-Ghamdi S. G. (2021)** did a comprehensive review on the factors influencing air pollution in residential and commercial structure. This review of scientific studies presented a broad spectrum of pollutants that was identified in both residential and commercial indoor environments, highlighting the trends and gaps in IAQ research. This review had the potential to benefit building professionals by establishing indoor air regulations that account for all indoor contaminant sources to create healthy and sustainable building environments. It also briefly discusses how direct comparison of indoor air pollutant levels is difficult and not straightforward because evaluations have been conducted over different time periods, using different instruments and sampling techniques, and in different indoor environments. Thus, it is highly recommended that more detailed scientific studies be conducted by following standardized regulations, which will allow for an inter-comparison of IAQ from studies in the future to close the existing knowledge gaps regarding IAQ.

11. **Corlan *et al.* (2020)** conducted a study on the importance of indoor air quality (IAC) monitoring, in order to reduce potential health risks in closed spaces even when artificially ventilated, such as homes, schools and offices or industrial halls. The paper presented a series of instruments which were responsible for measuring indoor air quality and focussed on IAC measurements taken in different closed spaces. Based on the concentration values detected, the conclusion of the paper indicates that, depending on the technological process or activity in enclosed spaces, it is mandatory to check the IAQ.

12. **Saini *et al.* (2020)** studied a relevant area of concern which was the direct impact of mortality and morbidity due to indoor air pollution. It mainly discussed the use of wireless technologies for the purpose of real-time monitoring of IAQ parameters that simultaneously generated alerts to the building occupants to avoid hazardous conditions. The review also provided detailed information about how various factors such as VOCs, PM_{10}, $PM_{2.5}$, CO, SO_2, NO_2, O_3, temperature, and RH have affected IAQ.

13. **Hapsari *et al.* (2018)** reviewed indoor air quality monitoring using Internet of Things (IoT). In this systematic review the author analysed and summarised articles about IAQ monitoring, obtained from particular three databases. Based on the criteria, there were 36 studies selected that discussed IAQ, 24 were for system development, six were for evaluation and comparative articles, three studies

proposed methods, and the other three were review articles. The relevant past research was also reviewed that provided discussion material on monitoring systems, sensors, devices used, and Internet of Things for Indoor Air Quality.

14. Study conducted by **Dutta *et al.* (2020)** provided a systematic review of the current state of the art on indoor air quality monitoring systems based on the Internet of Things(IoT). The paper highlights design aspects for monitoring systems, including sensor types, microcontrollers, architecture, and connectivity along with implementation issues. The main contribution of this paper was to present the synthesis of existing research, knowledge gaps, associated challenges, and future recommendations. The results showed that 70%, 65% and 27.5% of studies focused on monitoring thermal comfort parameters, CO_2 and PM levels respectively. Additionally, there were 37.5% and 35% of systems based on Arduino and Raspberry Pi controllers. Only 22.5% of studies followed the calibration approach before system implementation, and 72.5% of systems claimed energy efficiency.

15. A study by **Patil *et al*. (2020)** reviewed the prediction of air quality index and forecasting ambient air pollutants using machine learning algorithms. It focusses on the various techniques used for prediction or modelling of Air Quality Index (AQI) and forecasting of future concentration levels of pollutants that may cause the air pollution so that governing bodies can take the actions to reduce the pollution. The purpose of this literature review paper is to know in detail about the Air Quality Index (AQI) as AQI tells whether the air around us is polluted or not. As per this review most of the researchers worked on AQI and pollutants concentration level forecasting that will give the actual idea about AQI. Artificial Neural Network (ANN), Linear and Logistic Regression are the choices of many researchers for the prediction of AQI and air pollutants concentration. The future scope may include consideration of all parameters that is meteorological parameters, air pollutants while predicting AQI or forecasting the future concentration level of different pollutants.

16. **Palermi *et al.* (2022)** did a comprehensive research on the relationship between PM2.5 and PM10 in Central Italy. They did a brief study on the applications of machine learning models to segregate anthropogenic from natural sources. The paper presents the results of the analysis of continuous measurements of PM10 and PM2.5 concentrations at eight stations of the regional air quality monitoring network in Abruzzo (Central Italy), in the period 2017–2018. The application of models based on machine learning technique shows that PM2.5/PM10 ratio can be used to classify PM emissions and to know the nature of the emission source (natural and anthropogenic), under determinate conditions, and properly taking into account the meteorological parameters.

2.2 Studies on the production of organic acids from microorganisms

1. A study conducted by **Nuryana *et al.* (2019)** analysed the organic acids produced by lactic acid bacteria using High Performance Liquid Chromatography (HPLC). A total of 4 selected lactic acid bacteria (LAB) isolates were investigated for the purpose of organic acid production. The process was carried out for 5 days of incubation using a liquid fermentation process. The organic acids were analysed using High-Performance Liquid Chromatography (HPLC). The results revealed that the growth of 4 LAB isolates increased and reached about 10^7 CFU/ml during 5 days of fermentation although lactate and acetate were found to be the dominant products of organic acid production.

2. **Garcia E. F. and McGregor J. U. (2010)** studied the determination of organic acids during the fermentation and cold storage of yoghurt. The main objective of this paper was the separation and quantification of orotic, citric, pyruvic, lactic, uric, formic, acetic, propionic, butyric, and hippuric acids in a single isocratic analysis by HPLC method. The analysis resulted in all of the organic acids exhibiting varying degrees of increases and decreases during fermentation and storage. Formic and butyric acids were not detected under the conditions of this study.

3. **Ergonul P. G. and Nergiz C. (1994)** investigated the production of organic acids (oxalic, citric, malic and succinic) in olive fruit grown in Turkey using HPLC method. Organic acids were extracted from olives with water-methanol mixture solution 75:25 (v/v) and were analysed through KC-118 ion-exchange column using UV absorbance detector at 214 nm. The mobile phase was phosphoric acid (0.1% w/v). The recovery values of the organic acids added into olive fruit samples were 92.8%, 98.75%, 110% and 86% for oxalic, citric, malic, and succinic acids respectively.

2.3 Studies on bio-aerosols and prevention or elimination of fungi from indoor environments using Mangrove plant extracts

1. **Kim *et al.* (2018)** studied the airborne bioaerosols and their adverse impacts on human health. This paper discusses about the risk assessment of bioaerosols based on conventional culture methods and how these methods have been hampered by several different factors such as (a) the complexity of microorganisms or derivatives to be investigated; (b) the purpose, techniques, and locations of sampling; and (3) the lack of valid quantitative criteria. The paper also discusses about the various types of non-microbiological techniques available for sampling and analysis of bioaerosols, finally concluding that more research is required to properly establish better assessment tools for the exposure to bioaerosols and its validation.

2. A study conducted by **Kaliamurthi S. and Selvaraj G. (2016)** provided an insight on *Excoecaria Agallocha* which is supposed to possess anti-microbial, anti-cancer and anti-diabetic properties. This review articles focusses on the chemical composition, pharmaceutical and environmental applications of E. Agallocha. The plant has also been reported to possess huge amount of polyphenols and terpenoids.

Chapter 3
The Research Problem

1. **Title of the study**

   Mode of action of bio aerosols in indoor environment and their eco-friendly removal after developing indoor Air Quality Index.

2. **Objective of the study**

   The principal objective of the study is to assess the air quality of indoor environments.
   The detailed objectives are:
   - To design an Air Quality Index (AQI) calculator for the indoor environment using C++ programming and secondary data.
   - To assess the deterioration of concrete walls due to the presence of acid producing fungi (*Aspergillus tamerii*).
   - To study the prevention of acid producing fungi sp. on concrete walls using Mangrove plant extracts.

3. **Brief Methodology**

   The details of the methodology followed during the study along with the test equipment and materials are provided in the next chapter. The steps followed are listed briefly as follows:

a) AQI calculator:
   - C++ programming language (Dev C++) is used for the purpose of developing an AQI calculator.
   - Secondary data from standard papers and website is used.

b) For the study of deterioration of concrete walls by acid producing fungi the following steps are followed:
   - Three fungal and control media are prepared. These are incubated for a month such that spore formation occurs and meanwhile acids are also produced.
   - After spores are formed, the fungal media is filtrated such that the spores are separated. The fungal media (without spores) obtained is taken for observation of the acids produced by the organisms using High Performance Layer Chromatography (HPLC) technique.

c) For the study of prevention of acid producing organisms deteriorating concrete walls using Mangrove plant extracts the following steps are followed:
   - The powdered mangrove extract or the crude product is taken and acetone is extracted using the Soxhlet apparatus.
   - Nuclear Magnetic Resonance (NMR) Spectroscopy is performed on the acetone extract and the detection of groups/ compound/ molecular formula is carried out.

Chapter 4
Methodology

4.1 Methodology for developing an AQI calculator using C++ programming language:

4.1.1 The study program

In order to develop an ambient air quality index, generalized indoor locations such as drawing rooms, kitchen, bathroom, bedroom, etc. has been taken into account. The other indoor facilities such as AC, ventilators, exhaust has also been taken into consideration. The air quality index developed to calculate ambient air quality will be a general calculator and not applicable for any specific indoor location.

4.1.2 Significance of the study program

We are exposed to several unavoidable risks every day just by being alive. There are also risks present in our day-to-day lives that are avoidable, and poor indoor air quality is one of them. Air pollution is known to influence health issues but many people are unaware this includes both indoor and outdoor air. Air is one of the only things we have in common with every person in the world. If we are alive, we are breathing, so it is important we take action to consume quality air. The quality of the air outdoors is mostly out of our control but indoor air quality is not. Having the option to measure and regulate the indoor air quality of a home is critical for the health and safety of residents. Therefore, through this program the ambient air quality can be studied and measured for different concentrations, as well as AQI in indoor environments can also be calculated.

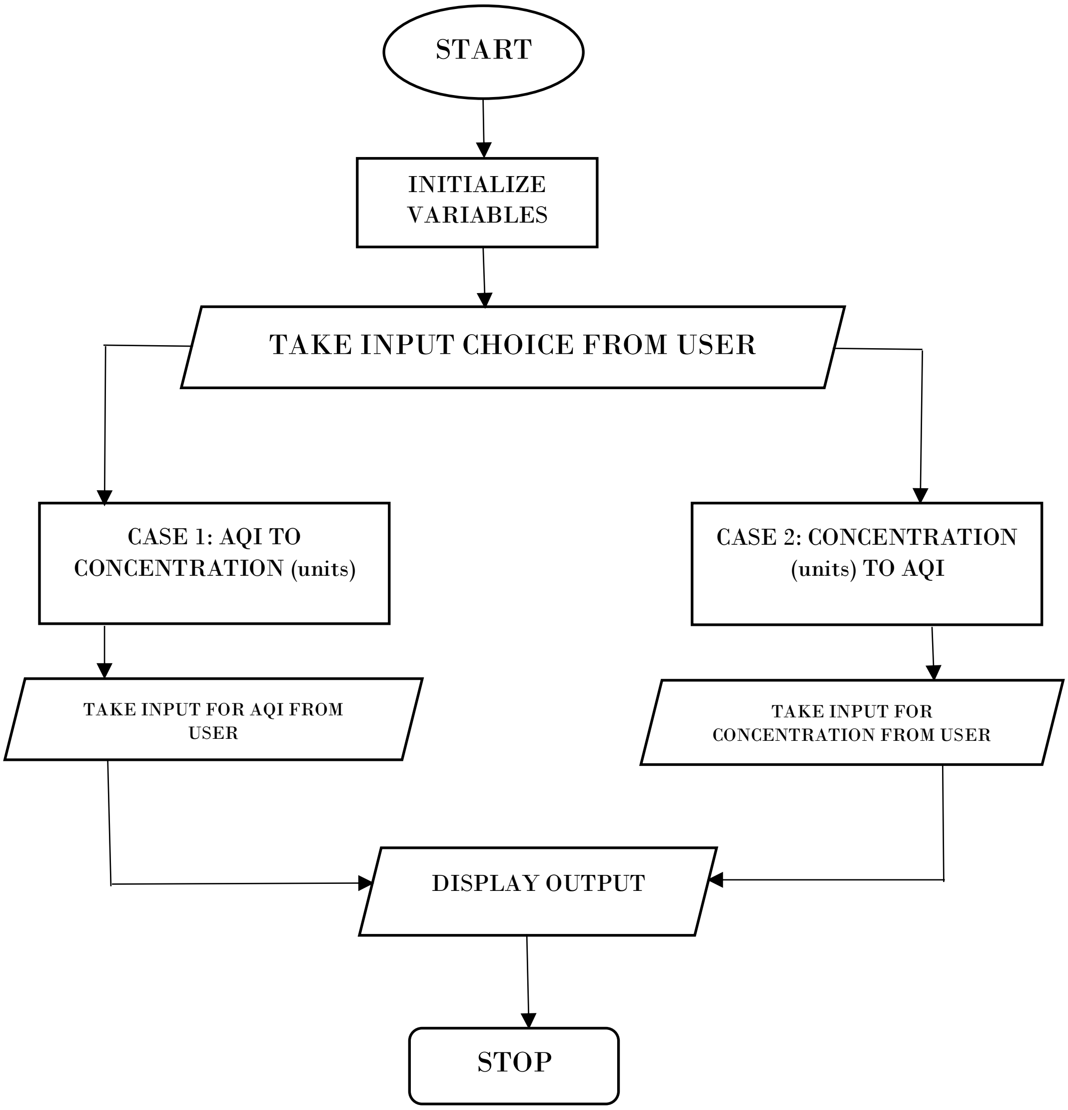
4.1.3 Logic of the program (AQI calculator)

The AQI calculator program starts with an if-else statement for the conversion of AQI to concentration and vice-versa. Then it is asked to select a pollutant which includes $PM_{2.5}$ or PM_{10} or CO or SO_2 or Ozone. If it is an AQI to concentration conversion, the AQI is asked to enter which after the required calculations displays the following results: concentration, unit, AQI category, health effect statements and cautionary statements. Similarly, if it is a concentration to AQI conversion, the concentration is asked to enter and after the desired calculations the following results are displayed eventually: AQI, AQI category, sensitive groups corresponding to the AQI value, health effects statements and cautionary statements.

4.1.4 Algorithm of the program (AQI calculator)

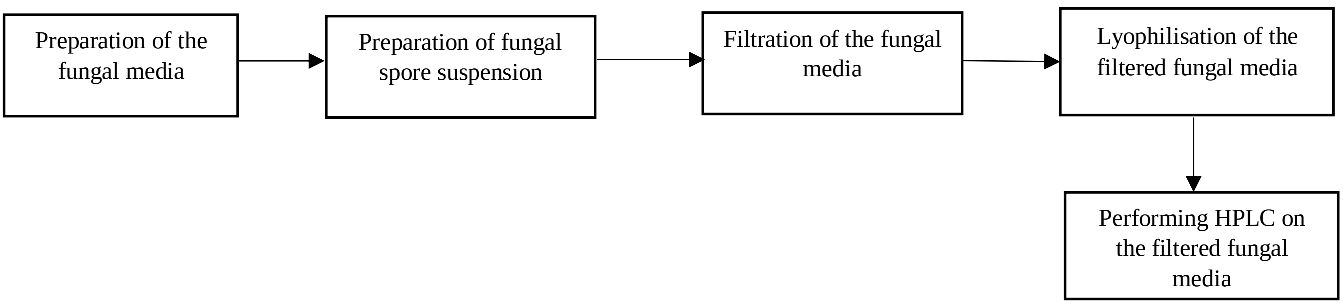
Step 1: Start
Step 2: Initialize variables
Step 3: Take input for choice
Step 4: Case 1: AQI to concentration
Step 5: Case 2: Concentration to AQI
Step 6: Display output according to case
Step 7: Stop

4.1.5 Flowchart of the program



-4.2 Methodology for assessing the deterioration of concrete walls due to the presence of fungi in ambient air:

4.2.1 Flowchart of the methodology is as follows:



4.2.2.1 Media preparation:

Apparatus required- Six 250 ml conical flasks (3 for control and 3 for infected)
Chemicals required- Czapek Dox broth, Agar, Distilled water (DW)

There are two set ups that are prepared that are as follows:

a. Control
b. Infected

a. For the preparation of the control set up, the following steps are followed:

- Three 250 ml conical flasks are taken.
- Then, 3.5 g of Czapek Dox broth and 100 ml distilled water is taken and mixed together to prepare the control media respectively.

b. For the preparation of the infected set up, the following steps are followed:

- In a 250 ml conical flask, 3.5 g of Czapek Dox broth, 100 ml distilled water and 3 concrete pieces are taken and put into the fungal media. Three similar mixtures are prepared respectively.

After that sterilization was done using autoclave. Autoclaving was done at 121 ◦C temperature at 15 pounds per square inch (1.0546 kg/ cm^2) pressure for 15 min.

4.2.2.2 Preparation of fungal spore suspension:

- Two 100 ml conical flasks are taken.
- In the first conical flask, 1.75g Czapek Dox broth, 50 ml distilled water and 1.2 g of agar is added.
- In the second conical flask, 50ml distilled water is taken.
- After that sterilization was done using autoclave. Autoclaving was done at 121 ◦C temperature at 15 pounds per square inch (1.0546 kg/ cm^2) pressure for 15 min. After sterilization, the first conical flask was tilted at 45^0 and the medium was cooled at room temperature. The medium was found to be solidified after 24h.
- The sterilized inoculating loop was dipped into the culture of *Aspergillus tamarii*. A loopful of culture was streaked on the Czapek Dox medium present in the conical flasks. The slants were incubated at growth temperature (27 ⁰C) of the microbes.
- Sterile distilled water was mixed with the agar slants after 7 days of incubation period and properly shook in laminar airflow chamber. Thus the spores of *Aspergillus tamarii* in the agar slants came into the water and the spore suspensions were put into the fresh sterilize conical flasks. The spore suspensions were ready to use.
- After that, 5 ml of spore suspension is added to six of the conical flasks containing control and infected set ups using a micropipette. The set ups are then incubated for one month to examine whether the organisms are able to produce the desired acids or not.

4.2.2.3 Filtration of the fungal media:

- After incubation for one month, the fungal media is filtered using Whatman filter paper (grade 1, diameter 110 mm) and syringe filters (0.2 micron). The filtration is done to discard the spores and obtain the clear fungal solution to examine the presence of organic acids produced by the organisms.

4.2.2.4 Lyophilisation of the fungal media:

- After filtration of the spores, the media is lyophilised.

Lyophilisation:

– There are two terms used in industry which describe the same process but in a different way: *Freeze drying* and *lyophilisation*, which means 'to make solvent-loving'.
– The term lyophilisation has become more common because it is applicable to both aqueous and non-aqueous systems. It is interesting that lyophilisation processes are often conducted in lyophilisation equipment, although the descriptive term lyophiliser is becoming more prevalent.
– In its simplest form, lyophilisation is *defined* as a stabilizing process in which the substance is first frozen and then the quantity of the solvent is reduced first by sublimation (primary drug) and then by

desorption (secondary drying) to values that will no longer support biological growth or chemical reactions.

- Apart from the reduction in thermal inactivation of the product during freezing as noted above, other advantages of the method are as follows:
    a. The avoidance of concentration effects – for example salting out proteins. The distribution of components within the drying and dried product remain unchanged throughout the process.
    b. The water content of the dried product can be reduced to very low levels. In general, the lower the water content the more stable the product, although over drying may reduce product stability.
    c. Lyophilisation operates in a more controlled environment than some other forms of drying, which potentially means less possibility for contamination.
    Because freeze material has a porous structure, the product can be instantly reconstituted by the addition of a simple diluent. [15] (Przic, N., & Petrovic, 2004)

4.2.2.5 High performance liquid chromatography (HPLC):

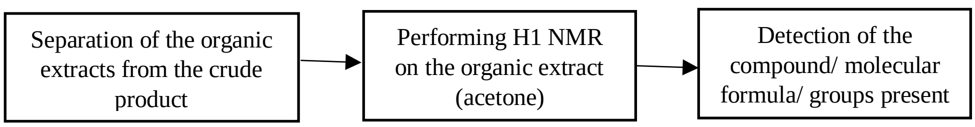
Chemicals required: HPLC grade reagents were used. Lactic, acetic, oxalic, malic, citric, kojic and fumaric acids were purchased from Sigma, phosphoric acid from Merck, phosphate dihydrogen phosphate from HIMEDIA. HPLC grade water (Merck) was used to prepare buffers, stock solutions of each standard compound and the samples.

Equipment and operating conditions: The HPLC system Shimadzu (Lc-10at Vp Shimadzu Liquid Chromatograph, Kyoto, Japan) was equipped with a manual injection system and 20 µL sample loop, a valve unit (FCV-10AL VP), a system controller (SCL-10 A VP Shimadzu System Controller), and a solvent degasser (DGU-14 A Shimadzu Degasser). The UV detector (SPD-10 A VP Shimadzu UV-Vis Detector) was set at 210 nm and operated using a Shimadzu Class-VP software. The separation was performed on a RP C18 column 150 x 4.6 mm. An isocratic flow was used at room temperature. Mobile phase was 20 mM KH_2PO_4 adjusted to pH 2.5 with H_3PO_4 and flow rate 1 ml/min. Injection volume was 20 µL for standard and sample solutions. Peak identity was confirmed when peak retention times of samples were identical to those of pure standards of each organic acid.

4.3 Methodology for the prevention/elimination of the deterioration of concrete walls due to the presence of fungi in ambient air:

The crude product used for the prevention/elimination of fungi are the dried leaves of *Excoecaria Agallocha*.

4.3.1 Flowchart of the methodology is as follows:



4.3.1.1 Separation of the organic compounds from the crude product:

- Firstly, the crude product is packed inside the glass chamber of the Soxhlet apparatus.
- Then chloroform is poured into the body of the thimble such that the crude stays immersed in the solvent.
- The heating was adjusted such that the separation starts occurring.

- This was continued for 4-5 cycles till the colour in the Soxhlet started to turn colourless from dark green.
- After that the extract was dried in the rotary evaporator for 10-15 mins till 10-15 ml extract was remaining. The entire process was repeated for acetone.
- The acetone extract was finally collected and H1-NMR spectroscopy was performed.

4.3.1.2 Performing H1 NMR on the organic extract (acetone):

Chemicals required: Acetone extract, DMSO (Dimethyl Sulfoxide)

Equipment and operating conditions:

Nuclear Magnetic Resonance (NMR) spectrometry was performed by using Bruker 300 Ultrashield Spectrometer. ^{1}H spectra were measured at 300 MHz respectively. Sample (acetone) was dissolved in 1 mL Dimethyl Sulphide (DMSO) and placed into NMR tube to make sample depth around 3.5 cm-1 to 4 cm-1 and ready to be analysed by NMR spectrometer. Chemical shifts were reported as δ units (ppm) with tetramethysilane (TMS) as internal standard and coupling constants (J) in Hz.

Integration of the 1H-NMR data was performed by using DELTA version 5.0.4 software by Bruker 300 Ultrashield. Identification of the type of each 1H-NMR was detected based on the table of characteristic NMR absorptions that published in Organic Chemistry [18] and with the guide of the possible proposed materials provided by JU library.

Chapter 5
Results and Discussions

5.1 Results and Discussion on Air Quality Index (AQI) calculator

In this program, there are two cases:

1. AQI to concentration
2. Concentration to AQI

For AQI to concentration conversion, the following inputs are required.

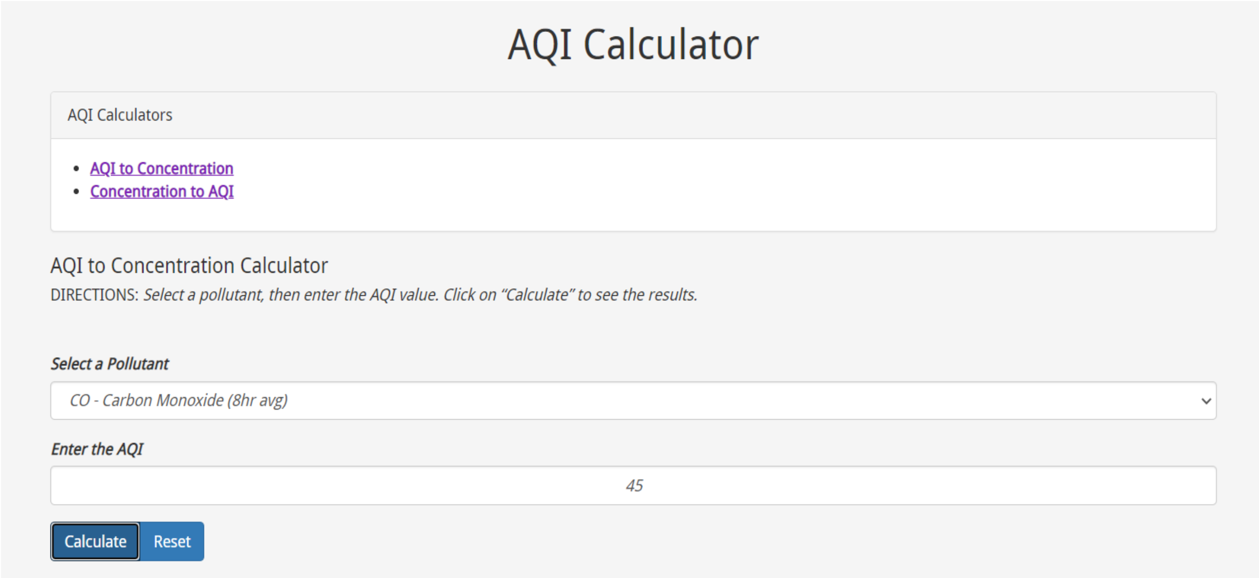


Figure 1. Inputs required for AQI to concentration conversion [19]

The output for the above will be as shown in the figure.

Figure 2. Output obtained for AQI to concentration conversion [19]

For concentration to AQI conversion, the following inputs are required.

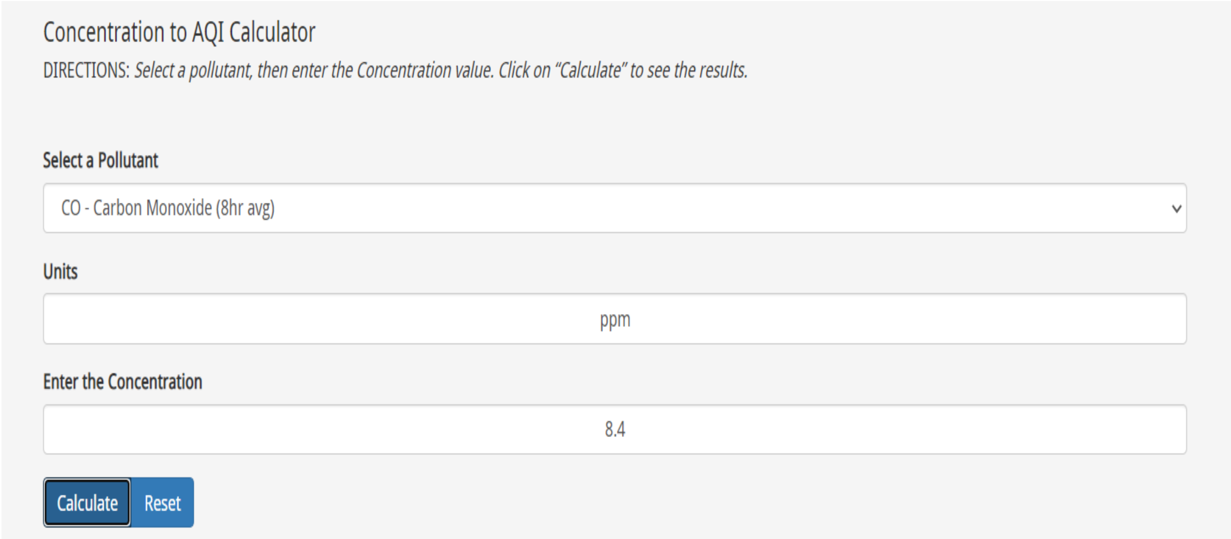


Figure 3. Inputs required for concentration to AQI conversion [19]

The output for the above will be as shown in the figure.

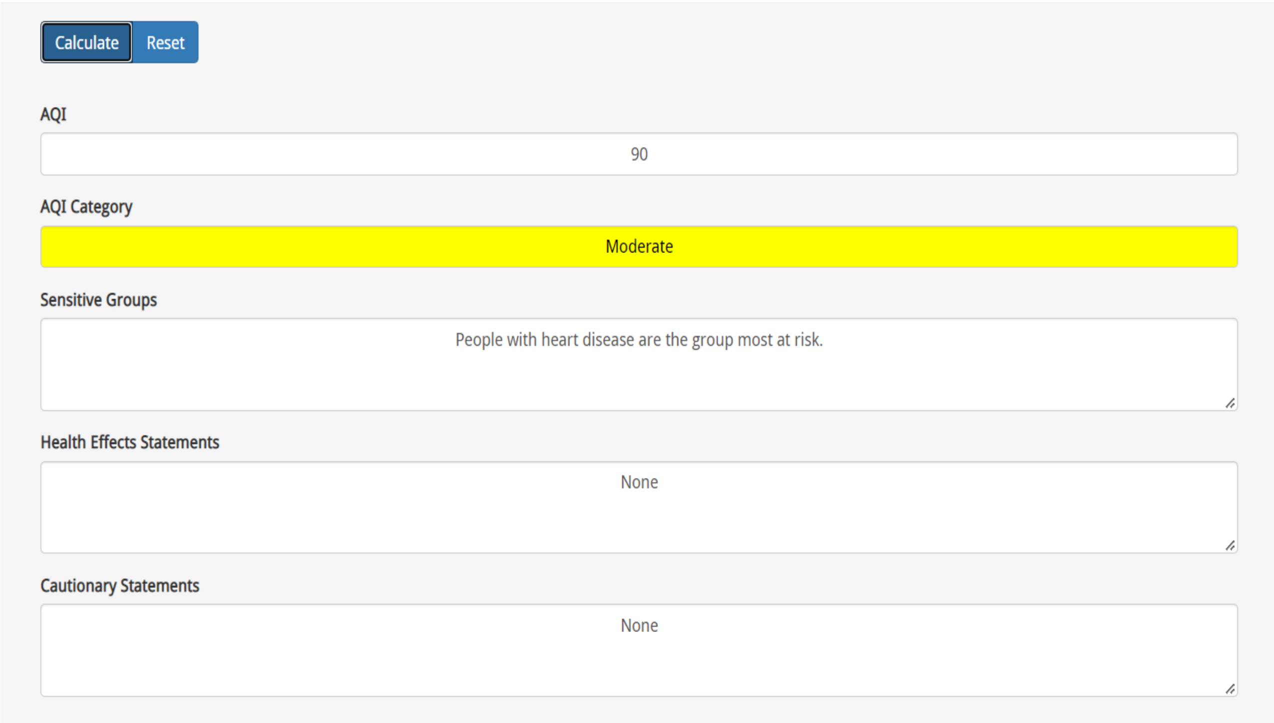


Figure 4. Output obtained for concentration to AQI conversion [19]

Conclusion:

The air quality index of an indoor locations can be easily calculated using this calculator, dominantly for a generalized indoor location and using standard secondary data.

5.2 Results and Discussion on deterioration of concrete walls due to the presence of fungi sp. (Aspergillus tamerii)

In this experiment results showed that the *Aspergillus tamerii* sp. have shown the ability to produce a total of 3 compounds of organic acids: Oxalic, Kojic and Malic. The HPLC method was able to quantify different types of organic acids i.e., oxalic, malic and kojic that exist in the liquid medium of fermentation. The retention time of Kojic acid (standard), oxalic acid (standard) and malic acid (standard) were much similar to that of the sample (fungal media) compared to the other organic acids. The retention time for each compound of the organic acids peaks was clear. In general, the use of HPLC is an accurate and convenient analytical technique for quantification and identification of organic compounds including organic acids.

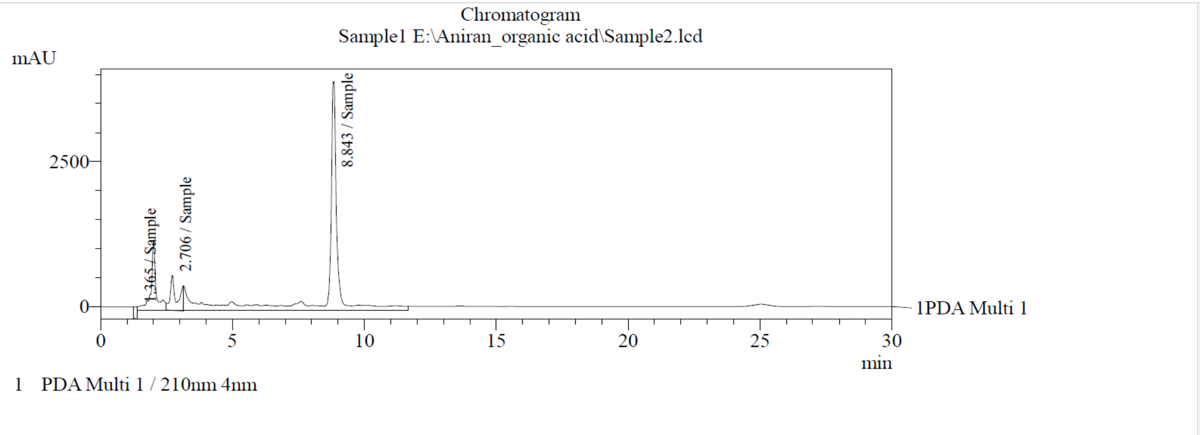


Figure 5. The retention peaks of sample 1 for the organic acid products

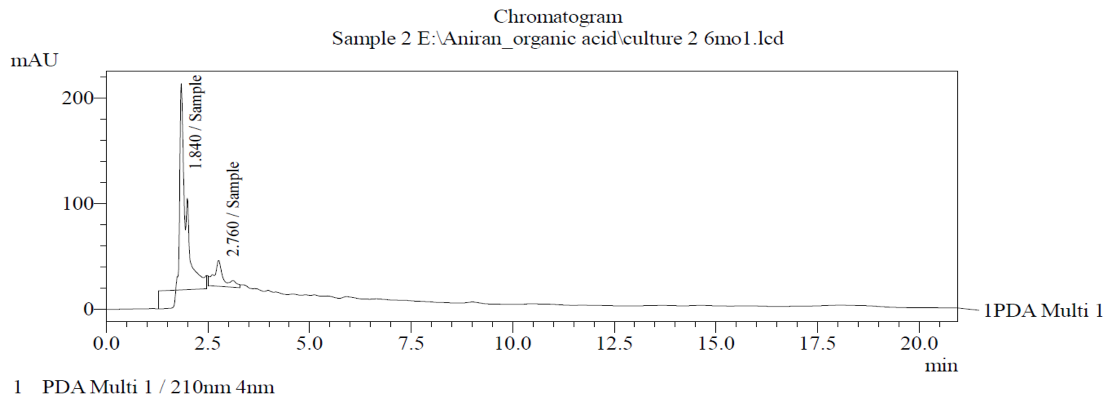


Figure 6. The retention peaks of sample 2 for the organic acid products

Table 3. The retention time of organic acid products (sample)

		Retention time of organic acid products (mins)		
S. No.	Samples	Oxalic acid	Malic acid	Kojic acid
1.	Sample 1 (fungi + concrete)	1.365	2.706	8.843
2.	Sample 2 (fungi)	1.840	2.760	

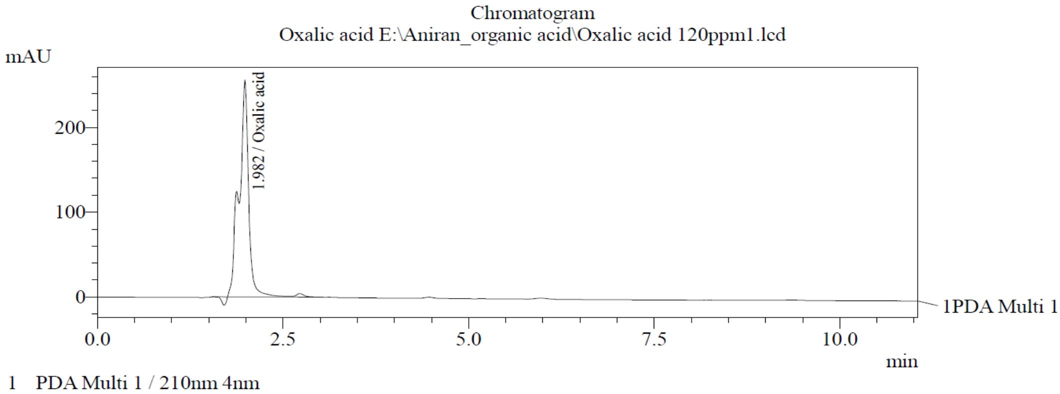


Figure 7. The retention peak of standard oxalic acid

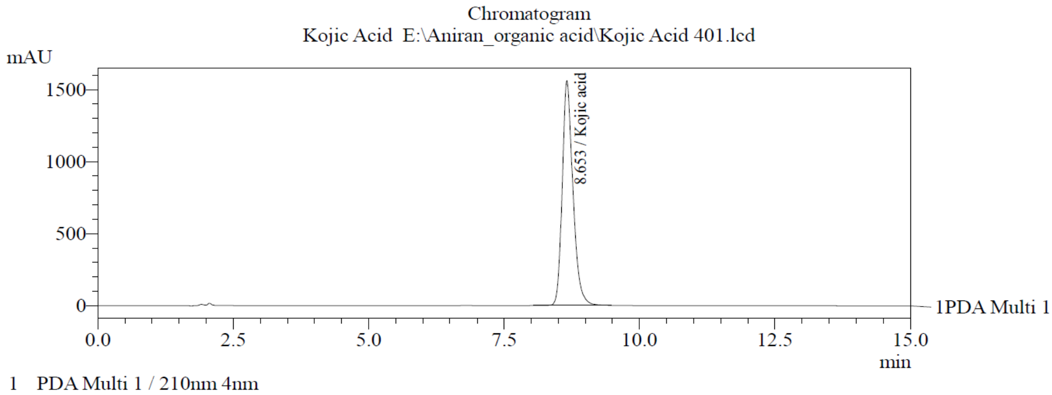


Figure 8. The retention peak of standard kojic acid

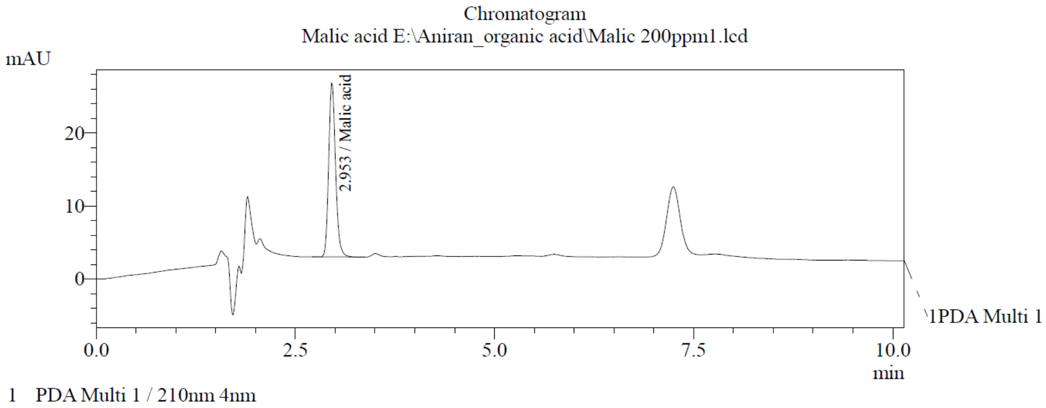


Figure 9. The retention peak of standard malic acid

Table 4. The retention time of organic acid products (standard)

S.No.	Organic acids (ppm)	Retention time (mins)
1.	Oxalic	1.982
2.	Kojic	8.652
3.	Malic	2.953

Conclusions:

This research concluded that the *Aspergillus tamerii* sp. were able to produce various compounds of organic acids, in particular kojic acid, oxalic acid and malic acid were produced during the fermentation.

5.3 Results and Discussion on prevention or elimination of fungi sp. from ambient air using Mangrove plant extracts

In this experiment, there are a total of 8 peaks obtained. Out of those 8 peaks, a clear peak is obtained at 3.938ppm for H1 chemical shift.

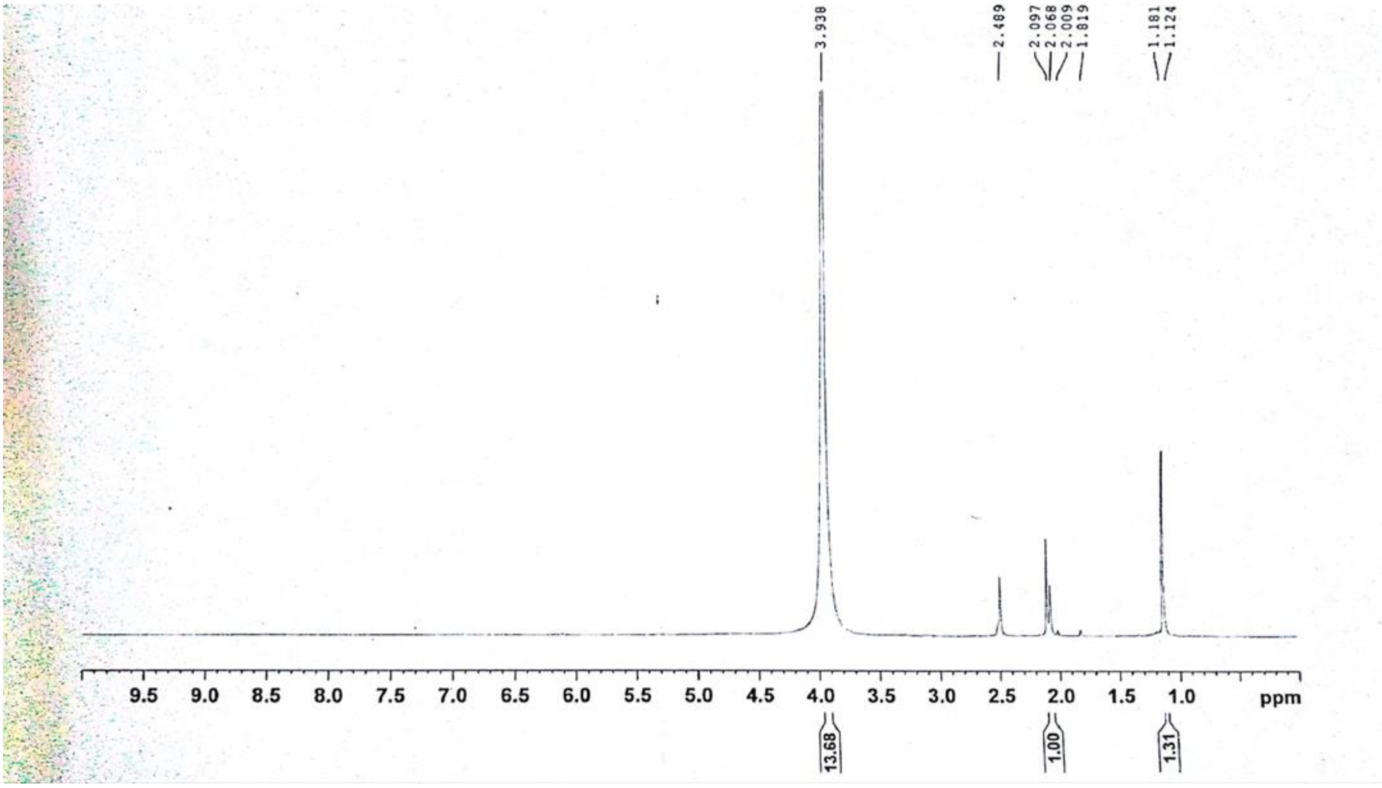


Figure 10. Peaks obtained during H1 NMR spectroscopy

Table 5. Chemical shifts (δ) ppm of the 8 different peaks obtained.

S.No	**Chemical shift (δ) (ppm)**
Peak no 1	1.124
Peak no 2	1.181
Peak no 3	1.819
Peak no 4	2.009
Peak no 5	2.068
Peak no 6	2.097
Peak no 7	2.489
Peak no 8	3.938

2.3 ^{1}H NMR Spectroscopy

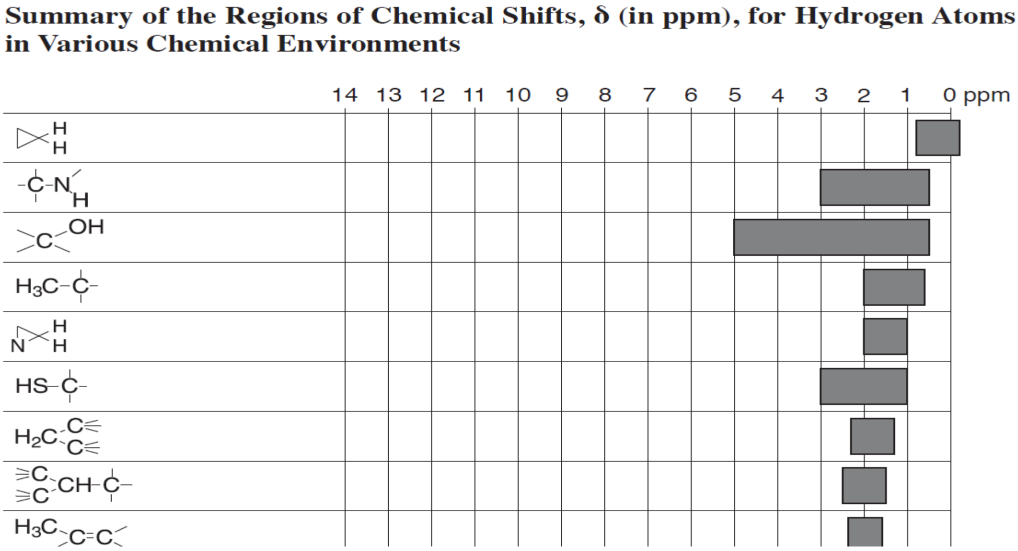


Figure 11. H1 NMR spectroscopy for hydrogen atoms [20]

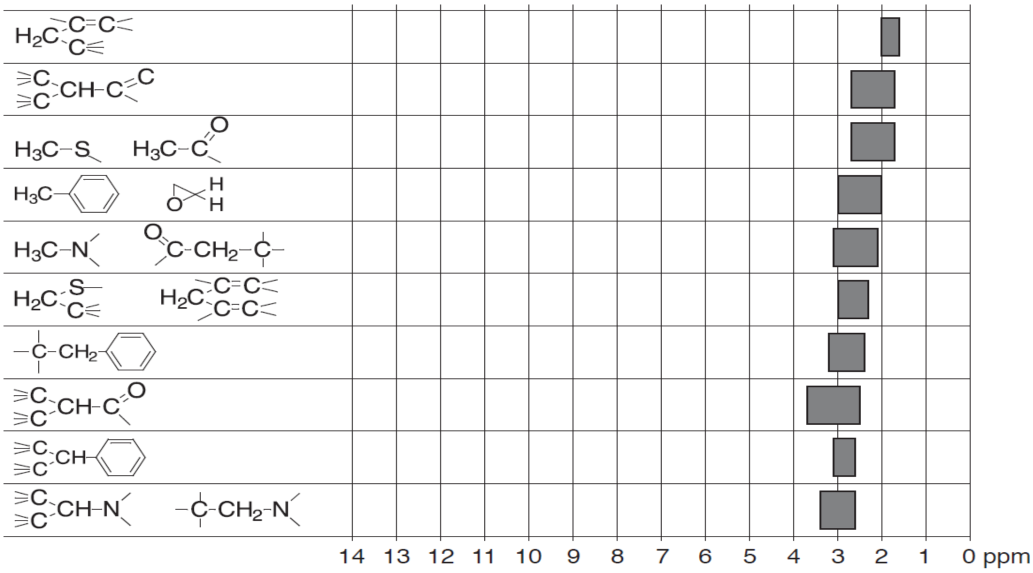


Figure 12. H1 NMR spectroscopy for hydrogen atoms [20]

Conclusion:

Based on this experiment, we can conclude the peak with 3.938 ppm chemical shift for H1 hydrogen atoms contains either ketone, ether or sulphide groups as similar peaks have been observed when compared to the table given above.

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