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Original Article

APPLICATION OF AIR POLLUTION TOLERANCE INDEX IN ASSESSING THE AIR QUALITY

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ABSTRACT

Objective: The rapid growth of urban population both natural and through migration, has put heavy pressure on air quality of an urban area through increase in industrial sectors. The increase in vehicular movement and industrial activities results in significant increase in air pollution. Air quality has been worsened in the major metropolitan cities of India and there are various studies evolving to control and mitigate this problem. One of the studies among several, is on the use of plant as both monitoring and assessment tool. Evaluating the application of Air pollution tolerance index is to assess the ambient air quality and for development of green belt.

Methods: A literature search has been done on Scopus scientific database to review the existing knowledge. A variety of search keywords are used related to air pollution tolerance index study. There are total of 63 studies has been published related to Air pollution tolerance index and they were classified based on study area and other parameter.

Results: The review has found several pathways to link the air pollution and plant. There are scientific evidence that plants can bio accumulate the air pollutant. The recommendation and suggestions have been provided to carry out further research works based on the limitation found in existing knowledge.

Conclusion: These research findings provide an understanding or view about identification of tolerant species and sensitive species in any study area so that these species can be used for a green belt development to prevent the air pollution problems.

Keywords: Air pollution tolerance index, Industrial sector, Traffic roads, Air pollution.

INTRODUCTION

There is a rapid development in industrial and automobile sector in all cities and town. The industrial growth coupled with sharp increase in vehicular population, has caused a serious change in the atmospheric system. Some of the contributions are also from domestic, agriculture and farming. The impact of such man made emissions into the atmosphere and their transformation, reaction and modification is responsible for chronic and acute disease. They also have impact on the plant community and it is reported that plants are more sensitive to air pollutants in comparison to other organisms [1].

Deposition of pollutants occur only either through wet or dry deposition. Wet deposition is less important since the pollutants present in the atmosphere is washed away and even from the leaf surface so much less duration of exposure. But the dry deposition process makes the leaf to expose to the ambient condition for the longer time [2].

The symptoms of plant or any biochemical changes in the plants acts as an indicator of the polluted environment. Since, the plant system is completely exposed to atmosphere and always the leaves exchange the gaseous molecules in and out of the system, any change in the atmosphere are reflected on the plant health. Thus regular monitoring of certain parameters of the plant physiology and biochemical parameters in plant indicates air pollution in terms of the severity and degree. Most obvious symptoms are chlorosis, necrosis and epinasty [1]. Plants experience a wide array of symptoms when exposed to pollutants during photosynthesis, respiration, enzymatic reactions, stomatal behavior, membrane disruption, senescence and ultimately death. In India, the economic loss of plants as a result of air pollution is not documented yet, but there are reports that it does damages to the crops [3]. Since plants are immobile and they are exposed to the surrounding atmosphere of an industry or commercial sector at the same rate it is exposed to the air pollutant generated from the sites. The intensity of the pollutant in the atmosphere is directly proportional to the change in the biochemical parameter such as pH, relative water content, ascorbic acid and total chlorophyll [4-7]. It is possible to evaluate the overall effect of pollutants as total pollution by measuring changes in the plants [8]. Studies have shown the impacts of air pollution on ascorbic acid content [9], Chlorophyll content [10], leaf extract pH [11] and relative water content [6, 12-16].

A literature search on electronic databases of scientific publication in Scopus, up to date has been documented. Using a different search algorithms and combination of key words related to air pollution tolerance index, studies have been selected related to plant tolerance towards a polluted environment. The studies have been reviewed to provide background information on air pollution tolerance index and its application. To avoid duplication and redundancy, the articles which contained same title and same content from same author are excluded.

Studies included

This review includes a total of 63 studies, from the abstract and they were classified based on study area, categorization, analysis, number of plant species studied etc.

In this review, few articles are included based on the context of heat island effect, CO_2 sequestration and Green belt development along with the APTI search since these are additional benefits from the plants where they can enhance a better environment by mitigating the global and regional level problems. The statistical analysis using the ANOVA tool provides the significance interlinking between the air pollutants and the plants.

Air pollution tolerance index

The Air pollution tolerance index is an empirical relation which evaluates the tolerance level of plant species towards air pollution from leaf biochemical parameters such as Leaf extract pH, relative water content of the leaf, ascorbic acid and total chlorophyll. The sensitivity of plants and tolerance parameters varies with air pollutant level at the study area. The APTI is formulated by Singh and Rao [17, 18]. Air pollution tolerance Index is been used in studies like Green belt development [19], traffic noise reduction [20]

and Pollution mitigation at roadside sites and around industries [13, 21, 22]. The categorization of the plant species is based on method of Singh and Rao (1983). The formula of APTI is given as

APTI = A (T+P)+R/10

Where A = ascorbic acid content (mg/g)

T = total Chlorophyll (mg/g)

P = pH of leaf extract

R =relative water content of leaf (%)

The plants are categorized into intermediate, sensitive and tolerant species when the APTI values lies between 1-16, 17-29 and 30-100 respectively

Plants and pollutant interactions

From the scientific studies, information are obtained about the plant pollutant interaction and role of absorption of pollutants. Plants are usually aimed to screen the pollutant from society. Industrial areas, residential areas and roadsides are the targeted places for green belts. Primary pollutants are SO_x, NO_x, CO and SPM. These pollutants are taken up based on the fate of transport of the pollutant within the plant body and form in which it ends, determines the scavenging process. When the pollutants are taken up at higher rate, it results in injury of the plants.

Pollutants enter plants through the stomata apertures. Most of the pollutant enters through these gaseous exchanges. The gaseous pollutant passes through the mesophyll intercellular spaces and gets absorbed on the wet cell-walls diffuse into the cell sap. Presence of SO_2 degrades the chlorophyll molecule through oxidation [23-26]. NO_x absorption reacts on cell walls to form HNO_2 and HNO_3.

The pH drops and leads to toxicity, cellular pH is lowered; metabolism is inhibited leading to growth suppression. Fluoride enters leaf through stomata and moves along transpiration stream towards leaf tips and margin, where it gets accumulated. Chlorosis of the leaf tip is the first visible injury, with increase in accumulation. It will get extend inwards from veins and along margins. CO plants act as natural sinks and convert it into CO_2.

They are not phytotoxic gas. Suspended particulate matter usually clogs stomata apertures and prevents the exchange of gases by leaves. The film of dust causes hazardous situation for plants results in reduction of effective pollination [27].

Table 1: Impact of selected air pollutants on Plant [1]

S. No.	Pollutant	Threshold dose	Plant injury/symptoms
1	Sulphur dioxide	0.70 ppm (1820 µg/m^3) for 1hr; 0.18 ppm (468 µg/m^3) for 8hr; 0.008-0.017 ppm (21-44 µg/m^3) for growing season	Interveinal necrotic blotches. Red brown dieback or banding in pines
2	Nitrogen dioxide	20 ppm (38X10^{3}µg/m^3) for 1hr; 1.6-2.6 ppm (3000-5000 µg/m^3) for 48hr; 1 ppm (1900 µg/m^3) for 100hr	Interveinal necrotic blotches similar to those by SO_2
3.	Fluoride	<100µg/m^3 fluoride	Red brown distal necrosis in pines
4	Ammonia	55 ppm (38 X 10^{3}µg/m^3) for 1hr	Tip and margin necrosis
5	Chlorine	0.5-1.5 ppm (1400-4530 µg/m^3) for 0.5–3hr	Interveinal necrotic blotch similar to those by SO_2 and distal necrosis in pines.
6	Ethylene	Variable, undetermined	Chlorosis, Necrosis, abscission, Dwarfing, premature defoliation
7	Hydrogen Sulphide	100 ppm (14 X 10^{4}µg/m^3) for 5hr	Interveinal necrosis blotches. Detials necrosis in pines
8	Trace Metals	Variable. Undetermined	Interveinal chlorosis tip and margin necrosis, Distal necrosis
9	Ozone	0.2-0.30 ppm (392-588µg/m^3)for 2-4hr some confers 0.08 ppm (157 µg/m^3) for 12-13 hr	Upper surface flecks distal necrosis and stunted needles in pines
10	Peroxy acetyl nitrate	0.02-08 ppm (989-3958 µg/m^3) for 8hr.	Lower surface bronzing, chlorosis, early senescence
11	Acid rain	pH<3.0	Necrotic spots, Distal necrosis pines

Effect of Seasonal variation on air pollution tolerance index

Environmental factors such as water, soil and air cause variation in leaf pigments content due to the accumulation of dust on leaf surface of the plant. The studies had shown that variation of chlorophyll content during different seasons. Plant exhibited higher concentration of chlorophyll content during rainy seasons followed by summer and winter season. During rainy season the total water content in the leaf is high and the gases and dust particles are completely washed away so there is no much effect of the air pollutant. During winter, the dust particles on the leaf surface will get accumulated, which inhibits the chlorophyll production due to the accumulation of various metal and aromatic compounds in turn, these substance induce toxicity and inhibits the enzymatic reactions which are necessary for chlorophyll synthesis. The gases which are present in the atmosphere, it will be absorbed by the cell sap of the leaves which will be lost due to the transpiration of the leaves. Sometimes, SO_2 gases dissolve and break to form bisulphite compound and releases two oxygen free radicles which in turn oxidizes the organic content present in the leaf. The air pollutants enters the tissues through the stomata causes degradation of chlorophyll content and it is found due to the replace of Magnesium ions by two hydrogen atoms. So the reduction in chlorophyll content in the leaves during summer and winter seasons may be due to the alkaline condition because of dissolution of chemicals present in the dust particles in the cell sap which is responsible for chlorophyll reduction. Ascorbic acid content was higher in winter followed by rainy and summer season. Ascorbic acid plays a role in the cell wall synthesis, defense and cell division which is a strong reducer and plays an important role in photosynthetic carbon fixation. Ascorbic acid influences the resistance of plants to adverse environmental conditions and its reducing power is directly proportional to its concentration. Leaf relative water content was high during rainy, low in winter and least in summer. High relative water content of the leaf can be explained by the high water content in the soil and low rate of transpiration loss from leaves. Leaf extract pH was found high during winter season followed by summer and rainy season. High accumulation of dust during winter season is due to foggy condition of the climate and wet surface provided by the plant which helps in capturing the dust. This is due to dust particles makes the plant pH alkaline condition by the release of H^+ions caused by the dissolution of dust particles in the cell sap. High concentration of dust during summer, high wind speed is the reason behind relative lower dust accumulation in summer than winter. Dust accumulation is least due to washing of leaves during rainy season and this causes the low leaf pH extract [28].

Estimation of Bio-chemical parameters

Bio-chemical parameters which act as key indicator in the plants are used to assess the changes in the tolerance level of plants with respect to air pollution. The biochemical parameters which are used

to assess the tolerance capacity of the plants are relative water content, total chlorophyll, pH and ascorbic acid [3, 12, 28-32].

Relative water content

Relative turgidity is a direct measure of deficit in leaves. Relative water content indicates the capacity of the cell membrane to maintain its permeability under polluted conditions. Relative water content was estimated by Bars and Weatherley's [33, 34].

Relative turgidity =Fresh weight–dry weight X 100

Fully turgid weight-dry weight

Ascorbic acid

Ascorbic acid content in plant leaves which acts as a strong reducing agent, the presence of higher amount ascorbic acid in the leaves shows the tolerant capacity of the plants towards air pollution. The studies have shown that decline of ascorbic acid level due to continuous exposure of air pollution[23]. The plants can detoxify the SO_2absorbed under normal day conditions. So, it has been an important biochemical parameter to study the susceptibility and tolerance of the plants. Ascorbic acid is estimated through spectrophotometric method [35-39].

Leaf extract pH

pH of the leaf extract signifies the tolerant capacity of the leaf species. Studies have shown that decline of pH during the presence of acidic pollutant, pH of leaf is found lowered in sensitive species than tolerant plants [40-42]. Higher level of pH in leaf extract indicates that the plants are tolerant under polluted conditions. pH plays an important role in signifying the condition of plants with respect to the study area. pH is estimated followed by Singh and Rao's procedure[18].

Total Chlorophyll content

Chlorophyll level varies with the pollution stress at the study locale. Studies have shown that amount of chlorophyll usually decreases with the pollution stress. Few studies have also linked the synthesis or degradation of chlorophyll with the tolerance capacity of plants to SO_2 [24, 43]. Total chlorophyll is estimated by Arnon and Maclachan's procedure [44-46].

Classification based on study area-Industries and Traffic roads

Case studies related to Industrial areas

From the studies, evidences have been shown that industrial activities have impact on plant species surrounding the industry. The physiological or biochemical change occurs in plant are also due to the air pollutants in the local atmosphere. Air pollution tolerance index measurement is conducted at regular time intervals to keep an eye on pollution [47]. Researchers have recommended the plants which are tolerant and sensitive species to the study area based on the analysis of the APTI [30, 48]. Plant acts as bio-indicator of the study area [49]. Few studies have shown that acidic leaf content in sampled site are due to diffusion of SO_2, NO_x from the surrounding air and form acid radicals by which reacting with the leaf water content. This in turn affects the chlorophyll content of the leaf. Along with APTI, few studies including Expected Performance Index are performed. Researchers have also recommended plants for green belt development around industries through Anticipated Performance Index [50]. Evaluation of anticipated plant performance might be very useful in selecting the species which should be robust in nature and able to tolerate the extreme climate at the locality. In addition to API, the selection of tree species for green belt development will be based on the regional extent of the pollution load together with soil quality, rainfall, temperature and human interactions. In any green belt development, monoculture is not advisable due to its climatic factor and other environmental constraints. A plant for use in a green belt should have the following natural characteristics such as fast growth rate for the development of canopy, strong branches to withstand storms, large leaf size for retention of pollutants, dense foliage for better trapping of pollutants, tolerance to soil compaction and nutrient stress and long span for, an longevity of green belt itself [19].

A study on oil exploration station where the plants are randomly selected in the vicinity of the station is reported [8]. The plant leaf samples were collected near the oil explorated site and a control site chosen to study for the biochemical parameters such as leaf extract pH, leaf water Index. Totally 10 species was chosen both at the experimental and control site. And found tolerant species near the experimental site. The determinations of APTI are of greater importance with increase in industrialization, there is increase in danger of deforestation due to air pollution.

Studies had conducted in three industrial areas [51]. And traffic density of the location is high during morning and evening and moderate in the afternoon. For the purpose of the study 17 species were chosen and three replicates of matured leaf samples were taken from vicinity of the industrial areas and the plants samples were studied for the bio-chemical parameter. The biochemical parameter varied based on the pollutant stress on the locality. Plants showed higher index value which are tolerant to air pollution and these plant can be used as sink to mitigate pollution. Plants with low index value which has less tolerance and used as indicators of air pollution.

A biological survey at three sites was carried out and they also conducted monitoring of ambient CO_2 at three sampling locations[52]. Using remote sensing, the land use pattern was collected to strengthen the baseline information from IRS P6 (Resources AT-1) LISS III. Meteorological data such temperature, humidity and rainy day during the study period were collected. Vegetation at three study areas covered a different percentage range in which tree plantation, shrub plantation, herb plantations small plantations and grasses. Studies concluded that CO_2 the vegetation cover in the sampling sites have restricted the increase of CO_2 concentration at the residential and industrials areas where as less vegetation in commercial areas leads to the raise in CO_2 concentration. Plants act as the best sinks for CO_2 sequestration and it is completely dependent on the nutrients availability and relatively proportion of C_3 and C_4 plants.

The sensitivity and resistance of plants around a brick kilns towards the pollution stress was studied[53]**.** Study area was chosen around brick kilns where the vegetation area is subjected to pollutant stress. Four brick kilns where chosen for study and details about the kiln like kiln capacity, coal consumption, pollution control devices, total emission, stack height, stack diameter, cross sectional area of the stack, specific fuel consumption and stack emission were collected. Compared the kilns based on the kiln characteristics and the emission rate categorized into least, moderate and most polluting kilns. The leaf samples were collected around kilns and APTI value was determined found that at less polluted sites the APTI value were less and the plants with higher APTI value which are considered to be resistant species are present at most of the sites. They act as bio-accumulators in the reported sites. Study concluded that resistant plants collected for further investigation which can be employed for mitigation and control of air pollution.

A study is conducted on industrial area and a village site [54]**.** Pigeon Pea a pulse yielding crop and similar crop were collected for APTI determination with five replicates on the selected sites and immediate lab analysis were conducted. The outcome is Urbanization and industrialization caused immense loss to the yield and based on the results obtained from APTI determination, recommended few crops to the farmers in industrialized urban and peri-urban areas.

A Study area consists 27 species were selected around the cement factory within radius of 6km. The plants were chosen from five different areas around the factory such as in and around the factory, within a 2 km of the factory, 2-4 km away from the factory and 4-6km away and a control zone 10-12 km away from the factory. Plants were collected from each zone thrice in a week. The outcome of the study is reported [55]. Based on the analysis, significant variations in individual parameter were found and also in the APTI values were seen for the same species. All the species surrounding the cement industry showed high pollution concentration when compared to the control. Generations of new trees are reduced in the polluted area when compared to non-polluted zone and also

various factors can lead to this condition. The trees which are located around the factory showed more tolerance. Study suggested that highly tolerant, moderately tolerant and intermediately tolerant species will be suitable for an effective green belt around the cement industry.

A study on air pollution tolerance Index was carried out Anand city [56]. The sampling site is classified as disturbed and undisturbed community based on level of pollution stress at the sites. Sampling was carried out using belt transect and quadrate was used. Data obtained from the field were subjected to ecological methods for the assessment of species diversity and dominance pattern of the selected trees. Along with which APTI was also estimated and the main aim of the study is to find the keystone species. Diversity was found higher for undisturbed site when compared with disturbed site. *Azadirachta Indica* was found to be tolerant and observation from the studies suggests that plant acts as excellent qualitative and quantitative indices of pollution. APTI acts as handy tool in assessing the increase in industrial and vehicular pollution. This study is also useful in selecting tolerant species fit for the landscape.

Case studies related to traffic roads

Roadside environment is usually considered to be subject to a continuous source of pollution, vehicular exhaust mainly. Visible effect on plant species due to auto exhaust pollution showed necrosis and chlorosis are the most frequent effects. The plants are immobile making them even more susceptible to the increased pollutant loads when the vehicular volume increases. Plants accumulate the pollutant at slower rate. Few researchers analyzed the plants near the traffic roads and suggested few tolerant plant species for green belt development [39] and they also act as bio-accumulators [50]. The observed significant reduction in total chlorophyll, ascorbic acid and relative water content showed inverse relationship with traffic density. Similarly, the pH followed an exponential decrease with increase in traffic pollution and drifted towards the acidic range [57]. The chlorosis effect in plants was due to the effect of sulphur dioxide, which enters the leaves through stomata damaging the parenchymatus tissues.

A study is conducted near a state highway and around the area which included 15 plant species carried out [12]. The plants were subject to analysis of biochemical parameters such as leaf pH, Total water content, total chlorophyll and ascorbic acid. The APTI value show out of 15 plants species 8 plants were found to be sensitive and 8 were intermediate tolerant and 9 were found to be tolerant in that area.

A survey on analysing traffic volume and ambient air monitoring. Plants were chosen along the roadside to study pollutant stress due to automobile pollution. Traffic volume where analysed at the study area and found vehicular density per minute. Plants where chosen at two study area out of which four plants were kept at both the study area for analysing the comparision between two sites and control. The parameter analysed were APTI, total nitrogen, sulphate, total solids were analysed and comparison was done. Ambient air monitoring was also done at both the sites to know about the vehicular emission in terms of particulate matter, SO_x and NO_x. The outcomes of the study were reported [58]. One of the study plant has shifted the tolerance level from tolerant to intermediate at both the selected site. Tulsi is most sensitive to pollution and a minor change in pollution level also been detected by this plants. Visual observation on the plant Tulsi can be used for bio-indicator of automobile exhaust pollution.

The studies on roadside plants has nine sampling station were chose of interval of 8km along the roadside of NH-47 and stations are mainly busy traffic junctions of the highway [59]. Study was conducted during summer and monsoon season. The traffic density was predicted by counting the number of vehicles through the National Highway-47. Leaves were collected from trees at morning time of almost having same diameter at breast height and also from the shrubs of the same height. The fresh leaves were analyzed for Leaf pH, Total chlorophyll, ascorbic acid and relative water content. Based on the results obtained, the tolerant and sensitive species were suggested for the study area.

A study on National Highway was carried out [21]. They have also obtained metrological data and recorded the annual rainfall at the study area. And a control site was chosen 100 m away from the edge of the road. Leaf sample were collected from the control and study area. They were weighed in a single electric balance to for measuring dust content actually present. Air samples were collected to measured dust, So_x and NO_x. Six replicates from each tree species were analyzed on each sampling date. The selected plant species in the study area showed visible effects like necrosis and chlorosis. The studies concluded that road side are economically important since they act as an absorbent of the various pollutants and this gives the pollutant stress on the particular area.

A study on road side plants in hilly areas is reported [6]. The study area comprises of 20 bends and they were divided into 3 points. From those 3 points within two kilometers from the bends different plant species were selected. And these leaf samples were used for the analysis of bio-chemical parameters such pH, relative water content, Ascorbic acid content and Total chlorophyll content. APTI is been found for all the selected species in the above mentioned points. They have categorized based on the APTI value to be sensitive, intermediate and tolerant. It is suggested that all the plants which ever categorized under sensitive species might be due to climatic condition prevailed in that place.

A study have been conducted to mitigate traffic generate noise and air pollution through Green belt development [20]. Under the study tolerant species were selected effectively in the study area, since tolerant species can be used for green belt development. The study was carried out in Varanasi city. The traffic generated noise was accounted. The traffic is the source, the abatement of air and noise pollution is still complex. The vegetation belts in the roadside can play a major role in mitigating the air and noise pollution problems to nearby exposed residents. The effectiveness of green belt is given by the attenuation factor, is the ratio of mass flux reaching the same distance in the presence of the green belt. The study consists of 35 plants to develop a green belt which were selected for the determination of APTI and API. The plants can acts as absorber of noise and also deflect the noise upward. Studies have suggested that *Azadirachta indica* and *Putranjvaroxburghi Wall* to be the best sound absorbers and can be planted near residential, industries and along roadsides. The trees have the capacity to reduce noise up to 5-10dB. The phenomenon is that acoustic energy which is absorbed by the plant leaves is converted into kinetic energy vibrating the air molecule which tends to vibrate the pattern of the leaves. Therefore vibration energy is lost since it is transferred to heat, the leaf vibration occurs in a plants. *Ficusinfectoria* found to be a keystone species which plays a major role in ecosystems. When a key stone species is absent, there will be a loss in the measure of has productivity by the ecosystem. *M. indica* and *F. religiosa* were tolerant plant and which has dense canopy. Out of 35 species, 15 species were moderately tolerant are recommended due to their aesthetic value and sensitive species were not recommended.

Key data gaps and suggested research strategies

This review has found pathways to interlink the air pollution with plants. Available research findings support links along several of these pathways. Critical limitations in the available techniques for measuring the heavy metal concentration in plant leaf from air are the research gaps which has to be identified as there are only very few studies reported on this aspect. A technique or tool has to be developed to quantify different air pollutants in the ambient air through the physiochemical or biochemical changes of the plants. More studies have to be evolved regarding sampling procedure and sampling season. In few of the case studies belt transects are followed for sampling and in other studies the plants are randomly chosen in sample site and control site. Only few researchers have provided complete statistical association between air pollution tolerance index and air pollutants using ANOVA [21]. Thus, more justification exists now for using air pollution tolerance index to assess the air quality and suggesting the tolerant species to be grown in the study area. In addition to APTI, anticipated performance index used along with the APTI for the green belt development studies. Anticipated performance index is used to

know about the abundance, spread and economic value of the species in a study area, hence it can be used in green belt development studies [39, 60-62]. This study can be developed furthermore, in such way that an effective modeling approach can be devised in order to establish a cleansing mechanism in the environment to provide better air quality.

CONCLUSION

The primary goal of this review is to summarize available knowledge relevant to the application of air pollution tolerance index from the studies reported. There are direct scientific evidence of plants to bio-accumulate pollutants and to act as sensitive species. Summary of findings from other studies provide suggestive evidence that the plants can be used as a monitoring tool and also as an assessment tool for air quality. Development of green belt around an industry or nearby roadside should consist of both tolerant and sensitive species. So that an effective self-cleansing environment can be developed and in turn other benefits like carbon sequestration and substantially the temperature in the urban area can be reduced since more amount of tree plantation will reflect back the radiation into the atmosphere. Thus, these research findings provide an understanding or view about identification of tolerant species and sensitive species in any study area so that these species can be used for a green belt development to prevent the air pollution problems.

CONFLICT OF INTERESTS

Declared None

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