



Share Your Innovations through JACS Directory

# Journal of Environmental Science and Pollution Research

Visit Journal at <http://www.jacsdirectory.com/jespr>



## The Impact of Criteria Air Pollutants on Soil and Water: A Review

Shifa Zuhara<sup>1</sup>, Rima Isaifan<sup>1,2,\*</sup>

<sup>1</sup>Sustainable Development Division, College of Science and Engineering, Hamad Bin Khalifa University, Qatar Foundation, Education City, Doha, Qatar

<sup>2</sup>Qatar Environment and Energy Research Institute, Hamad Bin Khalifa University, Qatar Foundation, P.O. Box 5825, Doha, Qatar.

### ARTICLE DETAILS

**Article history:**

Received 12 May 2018

Accepted 30 May 2018

Available online 10 June 2018

**Keywords:**

Air Quality  
Criteria Pollutants  
Heavy Metals  
Environment

### ABSTRACT

In the past few years, air pollution has become of growing concern around the world. The effect of criteria pollutants which include carbon monoxide, nitrogen oxide, ozone, particulate matter, sulphur oxide and lead are being studied to understand the effects of air pollution. Usually, the effects on human health are addressed and studied in great details. Nevertheless, the effect of air pollution on the environment is of paramount importance and is not adequately discussed. Therefore, this paper conducts literature review on the effect of criteria pollutants on soil and water. It sheds light on how particulate matter affects the quality of crops and marine productivity. The various impacts of tropospheric ozone on plants such as decreased photosynthesis and decreased metabolism are also discussed. The effect of sulphur oxide and nitrogen oxide is presented mostly in terms of the issues being caused due to acid rain. Acid rain is known to hamper productivity in marine organisms in addition to reducing soil fertility which further reduces plant productivity. The effect of carbon monoxide on soil and water is less explored; however, soil is known to be a significant sink for the gas. To this end, the impact of Lead and other heavy metals on plants and marine life is as well presented.

### 1. Introduction

Air pollution is a problem that has risen in the recent past. More specifically, the last 50 years have led to the greatest contribution to air pollution due to rapid industrialization [1]. The trend in air pollution has been changing. Post-world war II, the most significant compound attributing to air pollution was sulphur dioxide combined with soot which was mainly from the burning of fossil fuels for heat and power production [1]. When that issue was solved by carrying out several corrective actions such as switching to cleaner fuels and converting to higher stacks, new concerns have arisen due to nitrogen oxides and volatile organic compounds (VOCs) from increased traffic in addition to photochemical smog in other parts of the world [1]. Recently, the focus has been shifted to understand the prevalence of small particles and more exotic organic compounds that can be analyzed using sophisticated new analytical tools and techniques [2]. The common air pollutants got grouped and started getting addressed as the criteria pollutants. Generally, in literature, the health effects of the air pollutants are studied to a great extent. Some epidemiological studies were conducted to connect premature mortality and air pollution [3]. When the global burden of diseases for 2010 was considered, outdoor pollution caused by PM<sub>2.5</sub> leads to about 3.3 million premature deaths per year worldwide [3]. Majority of the deaths were caused in Asia [3]. Fig. 1 shows how the premature deaths caused by air pollution is greatest in developing countries like India. Some model projections show that the premature deaths caused by outdoor pollution could be doubled by the year 2050. Moreover, premature deaths and illnesses caused just due to ozone is estimated to be in the order of hundreds of millions to tens of billions of U.S dollars in the 2010 market rate in the year 2030 [4].

According to a study conducted by Kim et al., the health effects caused due to PM<sub>10</sub> and PM<sub>2.5</sub> mainly impact the respiratory and cardiovascular systems (Fig. 2) [5]. The effects are mainly dependant on the size of the particle. As the size reduces, the chances for it to enter lower airways rises, causing more harm to the human body [5]. After several studies, it is confirmed that even at low concentrations of air pollutants, the burden that comes along is significant [5].

Regional and traffic-related pollutants are known to increase asthma incidences, it is also noted that the risk of other respiratory diseases such as wheezing, bronchitis and airway inflammation becomes more prevalent with increase in air pollutant concentrations [6].

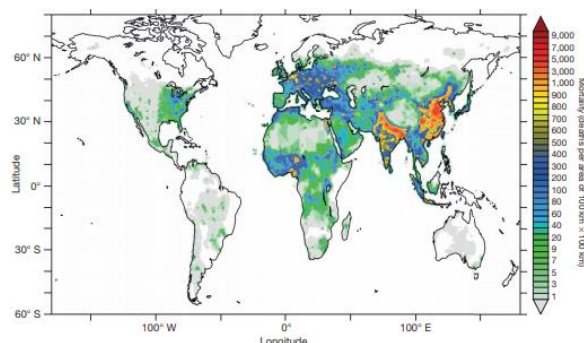


Fig. 1 Premature deaths caused by air pollution around the world [3]

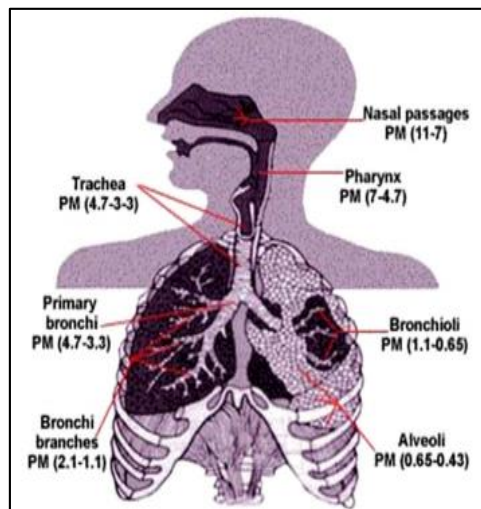


Fig. 2 Potential of various particles to deposit in the respiratory pathway [5]

\*Corresponding Author:risaifan@hbku.edu.qa(Rima Isaifan)

An air pollutant that is known to trigger asthma attacks is ozone. A correlation study conducted in 2011 showed that the relation between ozone concentration and immunoglobulin E (IgE) levels was found to be significant and it showed that children who were exposed to higher concentrations of ozone were observed to have higher total IgE concentrations [6].

In addition, heavy metals in air are also known to cause issues to human health. They may sometimes interfere with the metabolic processes taking place in the body. Some metals are known to be accumulated in the body being chronic in nature. Some other metals such as aluminium can be eliminated by some activities [7]. High levels of lead ( $>60 \mu\text{g}/\text{dL}$ ) may cause problems to the excretory system by causing renal dysfunction [8]. In some cases, even low concentrations approximately  $10 \mu\text{g}/\text{dL}$  may also cause the same issue [8]. Degeneration of some parts of the brain is caused when it comes in contact with lead. At very high concentrations, it may lead to serious issues such as ataxia, paralysis and coma [8]. Another important study suggested that a child's IQ is reduced when exposed to lead. There are other metals such as arsenic that are known to cause many effects on humans (Fig. 3) [9].

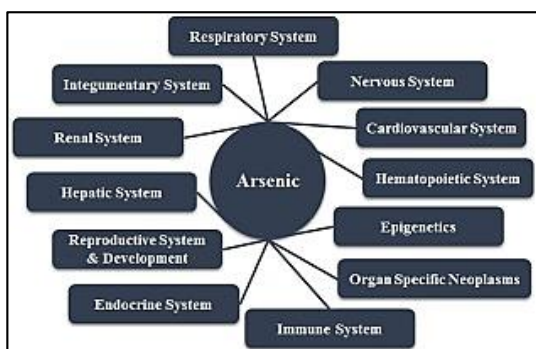


Fig. 3 Effects of arsenic on human health [9]

Effects of air pollutants on monuments and heritage is also discussed in the literature. The average pollutant concentration has fluctuated in the period from 1987 to 2009 [10]. After careful analysis, the corrosion of materials was found to be higher when the concentration of pollutants such as nitrogen dioxide, sulphur dioxide and ozone were at increased levels [10]. Monuments are usually made of limestone or marble to make it durable, but the downside of this, is that it becomes more susceptible to damage from acid rain [11]. Some of the world's most famous monuments such as Taj Mahal were affected by air pollution caused due to nitrogen and sulphur dioxide [10]. However, this paper will deal with the effects of air pollutants especially criteria pollutants on soil and water.

## 2. Criteria Pollutants

Criteria pollutants include carbon monoxide, nitrogen oxide, ozone, particulate matter, sulphur oxide and lead [12]. Carbon monoxide is an important atmospheric gas that performs significant roles in the troposphere [13]. There are various sources for carbon monoxide production which involves both natural and anthropogenic. In rural areas, the natural sources of carbon monoxide is the oxidation of methane, natural hydrocarbons, ocean and vegetational emissions [13]. On the other hand, the emissions of carbon monoxide in urban atmosphere are mostly attributed to anthropogenic sources such as fossil fuel burning, industrial activities and biomass burning [13].

The second criteria pollutant is sulphur dioxide. Sulphur dioxide is primarily emitted from coal and oil-fired plants and fossil fuel combustion in industrial processes. Usually, the combustion products such as sulphur oxides, acid aerosols, and particulate matter are present together as an intricate mixture [12]. Coal and crude oil are known to contain approximately 1-2% sulphur by weight [14]. Nowadays, the anthropogenic sources of sulphur oxide are significantly larger than natural emissions [15].

The third pollutant of interest is nitrogen dioxide. Nitrogen dioxide is formed in fewer amounts when oxygen reacts with nitrogen during high-temperature combustion [12]. Nitrogen dioxide reacts with hydrocarbons in the presence of sunlight and forms ozone and another photochemical oxidant after some complex reactions [16]. The main source of NO and NO<sub>2</sub> is from motor vehicle emissions, however, there is a major contribution from power plants and fossil fuels as well [17].

Particulate matter is the next group of pollutant. Airborne particulate matter varies over a wide range, usually from diameters of a few nanometers to around 100 micrometers. There are two commonly used

<https://doi.org/10.30799/jespr.133.18040205>

particle metrics; PM<sub>10</sub> (particulate matter with diameter equal or less than 10  $\mu\text{m}$  and PM<sub>2.5</sub> which have diameter equal or less than 2.5  $\mu\text{m}$  [18]. Emissions from the roadside are considered the main source of PM emissions within urban areas [19]. Several reduction measures have been achieved in the exhaust emissions in the past, yet the non-exhaust emissions contribute to a significant amount [18].

The next group of pollutants that fall under this category is called ground-level ozone. Ozone is a gas that is formed in the stratosphere in the presence of sunlight involving nitrogen oxides and volatile organic compounds [20]. Furthermore, it occurs with other photochemical oxidants to cause smog. Also, ozone reacts with some extracellular and intracellular molecules containing C=C bonds, amine groups or thiols [20]. In addition, ozone plays a critical role in the formation of the greenhouse effect [21]. Tropospheric ozone is an important greenhouse gas, which is known to cause a radiative forcing of about 0.35 to 0.37 W/m<sup>2</sup>. It is considered the second most significant air pollutant after particulate matter known to cause about 5 to 16% of the global temperature rise from the pre-industrial times [22].

The next pollutants are sulphur and nitrogen oxides. The most significant effect of these gases is their role in acid rain formation. Acid rain is an ongoing issue which involves a great number of effects on the environment. Reactions between nitrogen oxide, sulphur oxide and some amount of ozone are the reason for causing acid rain [23]. Fig. 4 shows the steps to the pathway of acid rain. First, the nitrogen and sulphur dioxides are released into the air (path 1). Further on, the pollutants that are converted to the acid particles are transported over long distances (path 2). These particles further fall down through dust, rain and snow (path 3). Finally, this acid rain may cause effects on soil, forest, streams or lakes (path 4).

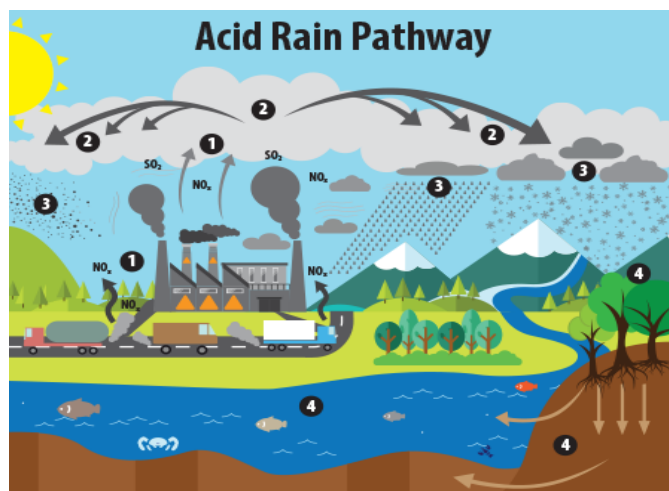


Fig. 4 Acid rain pathway (Source: USEPA - United States Environmental Protection Agency)

The last pollutant in the criteria group that shall be discussed is lead. All types of organic life require metal ions for survival. In general, the elemental constituents of organic life namely, plants, animals and human life, can be classified as major and trace elements. The trace elements group is known to contain both essential and non-essential elements (which includes toxic elements). In addition to lead, most of the other heavy metals are known to cause a serious threat to the environment [24]. Some examples of such heavy metals are cadmium, copper, lead, chromium and mercury. However, only lead is considered to be part of the criteria pollutants. There are various sources of heavy metals in the environment; ranging from natural, agricultural, industrial, domestic and atmospheric sources. Anthropogenic sources such as mining, smelting are known to have contaminated different areas of the world such as Japan, Indonesia and China [25].

## 3. Effect of Air Pollution on Soil

### 3.1 Particle Pollution (Particulate Matter)

In literature, the effect of particulate matter is known to be prominent in the field of health [26]. According to Grant et al. [26], there are known effects on both natural and managed ecosystems. Furthermore, it was mentioned that the longest impact was observed when particulate matter interfered with the biodiversity which eventually led to the loss of ecosystem goods and services [26]. Particulate matter is known to deposit externally such as on the vegetative surfaces or penetrate deeper into the

soil. As the particulate matter is of very small size, it is difficult to know the routes with certainty [26]. However, there are known effects on both watershed and regional levels; which confirms its significant contribution.

Atmospheric deposition can mainly occur through two means; firstly, the wet deposition which is when particles are deposited in rain and snow. The second process is slower and it is by dry deposition. In addition to both these methods, there is also another route called the occult deposition, which is caused by fog, mist or cloud-water; all of which does not fall under the previous two categories. There can be many problems due to particulate matter deposition; such as changes in species diversity because of changes in competition, disturbing the biogeochemical cycles, a decline in the ability of self-regulation etc. [26].

The atmospheric particulate matter is known to affect vegetation and ecosystems by an excessive range due to mass loading of the chemical components present in it [26]. Additionally, photosynthetically active photon flux that helps reach the photosynthetic tissues is considerably reduced due to the presence of dust. If the source is acidic or basic, it may cause injury on the leaf surface, while some other materials may be taken into the cuticle [26], affecting the inner plant body. Fig. 5 shows a scanning electron micrograph of some dust particles on the different surfaces of two different plants [22].

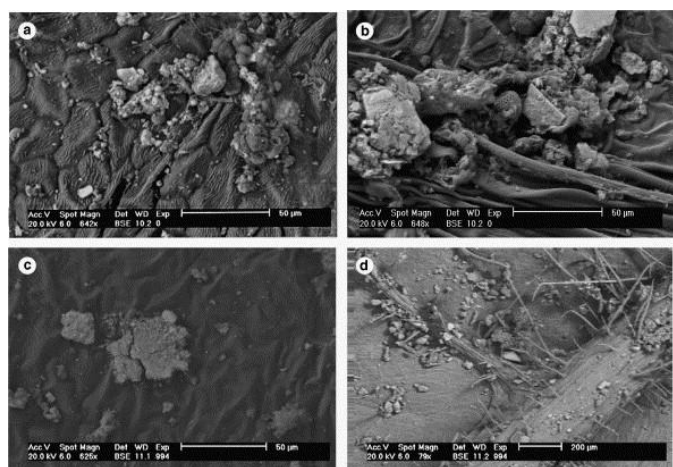


Fig. 5 Scanning electron micrographs of particles deposited on (a) upper surface (b) lower surface of the leaf of *A. hippocastanum*; and the upper (c) and lower (d) surfaces of *C. colurna* [22]

According to Prajapati et al. [27], the interception of dust on the plant depends on leaf properties like hairs cuticles, height and canopy of trees. Pollutants from the air is removed by three means: either by absorption by the leaves of plants, deposition on the leaf surfaces or by being deposited on the sheltered side due to slow air movement [27]. Usually the leaf petioles are better than stems or leaf lamina in terms of particulate matter collection [27]. However, rain can reduce the amount of particulate matter accumulation on the leaves [28]. Therefore, other climatic conditions need to be considered while understanding the particulate matter deposition on plants and other living organisms.

3.2 Ground-Level Ozone

The mean surface ozone concentration is expected to rise by about 23% by the year 2050 [29]. Many previous studies report economic losses due to increased ozone levels mainly routed from the loss of crop yields [29].

Ground-level ozone is becoming more of a prevalent problem around the world. China is considered one of the most air-polluted countries in the world. The maximum hourly concentrations calculated in China was higher than 56 ppb [30]. Surprisingly, the maximum values were not always recorded in the urban areas. In Guangzhou, a city in China, the maximum concentration was found to be higher in the rural areas than the urban areas. It was also observed that there were mass crop losses in the area due to the high ozone levels [30].

Another study conducted by McCrady et al. [31], showed that ozone negatively affected the below-ground carbon allocation in wheat after conducting a series of experiments. According to Ainsworth et al. [32], ozone enters the leaves of the plants through the stomata and generate oxygen species causing oxidative stress. This is known to reduce photosynthesis, which eventually leads to reduced plant growth [32].

According to Emberson et al. [33], the ozone indices vary with a difference in the plant species in addition to the location of the species (Fig. 6). Furthermore, this study also confirms the importance of phenology and soil moisture deficit (SMD) on stomatal ozone flux. Therefore, it can be confirmed that various factors are playing a role in this process.

<https://doi.org/10.30799/jespr.133.18040205>

Cite this Article as: Shifa Zuhara, Rima Isaifan, The Impact of criteria air pollutants on soil and water: A review, J. Env. Sci. Pollut. Res. 4(2) (2018) 278–284.

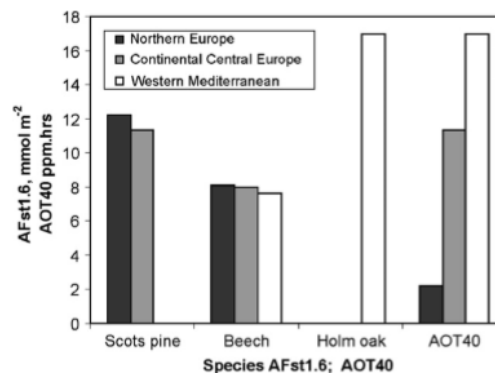


Fig. 6 Comparison of ozone indices by location and species [33]

The effect of ground-level ozone was studied on soybean to understand the yield under open-air field conditions by Morgan et al. [29]. The study confirmed the losses that were predicted for the future in addition to confirming that the effect of ozone is going to be greater in open-air fields (Fig. 7).

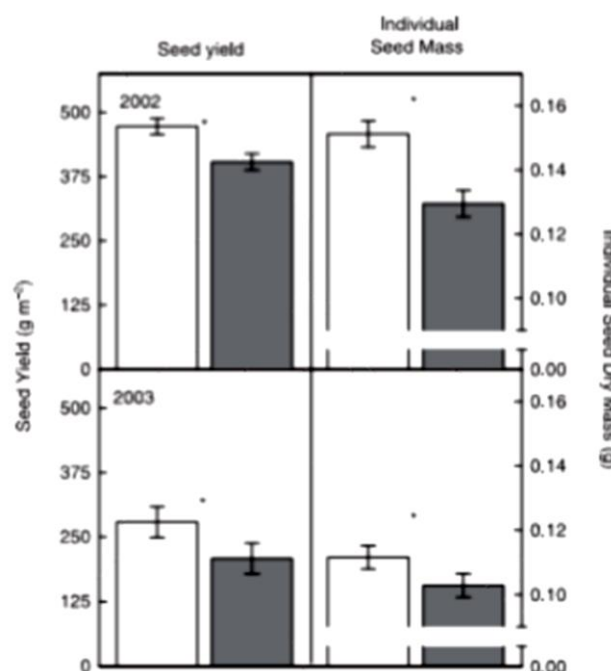


Fig. 7 Soybean seed yield has grown under normal (open bars) and levels of ozone (closed bars) in the field [29]

Table 1 Effects of ozone on plant processes at different scales [32]

Level	Effect
Community	Decreased net primary productivity. Increased shifts in composition of species and genotypes.
Whole plant	Decreased biomass. Decreased leaf area. Decreased reproductive output. Increased defense. Increased senescence.
Leaf	Decreased photosynthesis. Decreased starch metabolism. Decreased sucrose metabolism. Increased respiration. Increased foliar damage. Increased wax accumulation.
Cellular	Decreased RuBisCO content and its activity. Increased reactive oxygen species scavenging capacity. Increase protein repair and turnover. Increased flavonoid biosynthesis.

Another vital conclusion from the study is that the yield losses might be aggravated by extreme climatic conditions. For instance, in the year 2003, there was a hailstorm, where the yield worsened to a great extent post the event. This result proves that as the world moves towards climate change with rapidly rising disaster occurrence, increased ozone levels and their implications might be another effect we humans may not be able to avoid.

Similar trends of reduction in crop varieties were also observed in Asian countries after a study conducted by Emberson et al. [33].

Furthermore, the effects of ozone on plant processes at different scales are shown in Table 1. This gives an overall idea of the effect ozone has on the plants.

Additionally, according to Mcgrath et al. [34], Fig. 8 and Table 2 give an idea as to how ozone affects the leaf of a cotton plant. In Fig. 8(a), the leaf is exposed to chronic levels of ozone. Hence, premature senescence and some purple pigmentation were observed in the interveinal areas. Fig. 8(b) shows the upper surface of the black cherry plant purple. Fig. 8(c) is a yellow poplar plant that is shown to have purple spots on its upper surface.



Fig. 8 Effect of ozone on leaves of different plants [34]

Additionally, there are some effects on the plant's diseases in the presence of ozone.

Table 2 Effect of ozone on plant diseases [34]

Pathogen	Host plant	Effect on disease
Fungi		
<i>Puccinia coronata</i>	Oats	Reduced growth of uredia
<i>Puccinia graminis</i>	Wheat	Decreased hyphal growth and uredio-spore production on O <sub>3</sub> injured leaves.
Bacteria		
<i>Pseudomonas glycinea</i>	Soybean	Reduced number of lesions
<i>Xanthomonas alfalfae</i>	Alfalfa	Reduced severity of bacterial infections

Especially in developing countries, ambient ozone concentrations are even known to cause reduction in the productivity of crops [35]. Attached below are some of the ozone levels seen in different regions of a place. From Table 3, it can be observed that the ozone concentrations are higher in the urban and sub-urban areas as compared to the remote areas.

Table 3 Typical summertime daily maximum surface level O<sub>3</sub> concentrations [34]

Region	O <sub>3</sub> nL/liter <sup>a</sup>
Urban-Suburban	100-400
Rural	50-120
Remote tropical forest	20-40
Remote marine	20-40

<sup>a</sup>a: nL/liter = 1 ppb

It is also important to understand the effect ozone has from an economic perspective. A study that was conducted by Van Dingenen et al. [36], used four crops as a case study to analyze the global impact of ozone on agricultural crop yields. After modeling using the market prices in 2000, about 14 to 26 billion dollars were estimated as a loss caused due to the reduction in crops. About 40% of these losses were estimated to have been caused in China and India [36]. This shows how evident the issue is around the world.

### 3.3 Carbon Monoxide (CO)

As per Sanhueza et al. [37], CO is known to have an influence on the ozone and OH radicals which are both oxidizing species in the troposphere. The soil is known to consume CO from the atmosphere at rates between 190 and 580 Tgyr<sup>-1</sup> [37]. Additionally, it is also known to be a major sink into the temperate forest soils [36]. The topmost layer which contains the humus layer is known to be the most active layer for the uptake. Humus and leaf layers are essential factors in regulating the CO uptake in deciduous forest soils [36]. Particularly the depth of these two layers are the main reason that effects the rates of uptake by temperate soils [37]. This is also supported by a study conducted by Sun et al. [38], according to which soil is considered as an important natural sink for CO and is hence known to be causing an influence on the tropospheric CO

budget. However, the variabilities and magnitudes remain uncertain as of now. The deposition velocity of CO determines the concentration of CO in the soil and in turn the effects on the plants depend on that. In general, the literature that covers the effects of carbon monoxide on soil is minimal.

### 3.4 Sulphur Dioxides and Nitrogen Oxides

The following are some of the effects of nitrogen dioxide and sulphur dioxide. Even though the levels of NO<sub>x</sub> are small in comparison to SO<sub>2</sub>, its contribution to the production of acid rain is increasing [39]. There are many recorded effects of acid rain as it is the most discussed effect of these oxides. According to Lu et al. [40], acid rain is known to result in the acidification of soil. This increases the exchange between hydrogen ion and various nutrient ions such as potassium, magnesium, calcium in the soil [40]. These cations are known to be rapidly leached out into the soil along with sulfate from the acid input. This eventually leads to the loss of soil fertility which eventually leads to the decrease in the growth of plants and trees. Therefore, there is a visible loss of nutrient cycling as well [39]. In addition to this, there have been various effects on the physiological parameters of the plants such as the photosynthetic rate [41] and morphology [42] etc. Additionally, according to Wang et al. [43] the reduction in photosynthetic response has led to the decline of rice production. It is also known to cause disturbance to microorganisms and their microbial processes [39]. This may be due to the effect acid rain has on the soil. It is known to have an effect on the soil chemistry and soil leachate chemistry [44]. According to Lv et al. [45], there was a recorded effect of acid rain on the litter decomposition processes. Additionally, there was also observed effects on the microbial biomass and their enzymatic processes in one of the subtropical forests in China [45].

### 3.5 Lead and Other Heavy Metals

Metal-based contamination is becoming growing concern in countries like India. It is observed that the contaminant levels of cadmium, copper, lead etc., are higher in areas with more influence from anthropogenic sources. There is an overgrowing concern for the effects these metals on have food safety, crop growth and health of the organisms present in the soil [24]. Furthermore, the uptake of metals from the various sources such as air, water, and soil are influenced by the plants and their metabolic activities [24].

It is observed that the plants that are growing in a polluted environment are known to show negative effects such as altered metabolism, reduction in growth, lesser biomass production. Some metals are known to be needed for the plant. However, the number of metals and toxicity tolerance are of importance when considering metal poisoning. In almost all metals, it is observed that the annual emission is known to be majorly contributed by the windblown dust (Table 4). When considering lead, it is observed that the windblown dust accounts for more than half of the total annual emissions [24].

Table 4 Sources of metals from natural sources [24]

Sources	Global production	Annual lead emission (kg x 10 <sup>6</sup> )
Windblown dust	6-1,100	10
Volcanogenic particles	6.5-150	6.4
Forest wild fires	2-200	0.5
Vegetation	75-1,000	1.6
Sea salt	300-2,000	0.1
Total		18.6

According to Harrison et al. [46], lead is known to have both soil and air as contributors. This might not be true for some other metals such as cadmium, chromium etc., which has more input from the soil [46]. Additionally, the importance of meteorological factors was also asserted. The contribution of metal aerosols through direct atmospheric input is more dependent on the plant part than the specific metal. These metal concentrations can translocate to areas that are not exposed [46].

The phytotoxic effects of lead are well recorded in literature. According to Ahmed [47], lead reduced the seed germination in maize plants. It was also found that both the fresh and dry weights in both genotypes were known to reduce in the presence of lead. This negative influence is also supported by a study conducted by Malar et al. [48], in which the growth of water hyacinths plants has significantly tampered at 1000 mg/L lead concentrations. Even though the growth of these plants was hampered in the presence of lead in the soil; it gives an insight as to how lead can affect the plants in general, irrespective of the source. According to a study conducted by Singh et al. [49], it was shown that lead concentrations were declining when going further away from the road which indicates the role of traffic for the presence of lead. The lead concentrations were observed to be high even at the depths of 15 cm in the soil. Four plants namely, *Oryza*

*sativa*, *Colocasia esculentum*, *Luffa cylindrica* and *Cynodon dactylon* were known to have considerably high concentration of lead accumulated in them [49]. The severity of the problem was further understood when the milk samples from cows that used to randomly graze by the roadside contained the increased amount of lead [49]. As per another study conducted by Laidlaw et al. [50], both atmospheric and soil concentration of lead aerosols were observed to have seasonal patterns with higher concentrations during the summer and autumn months due to variation in evapotranspiration potential and soil moisture. It was even observed to be higher on the weekdays than weekends showing the significant contribution from locomotives.

#### 4. Effect of Air Pollution on Water

##### 4.1 Particle Pollution (Particulate Matter)

The literature that discusses the effects of particulate matter on the marine system is minimal. In general, atmospheric aerosol plays an essential role in the global biogeochemical cycles in addition to the climate system of the earth. Aerosol transport helps to move nutrients in and out the oceans, which is a seemingly important process for maintaining the productivity in some of the remote regions [51]. A review of the pollutants present in the sea-surface microlayer (SML) suggested that the pollutants, which could be part of particulate matter from the atmosphere, could be affecting marine organisms to a great extent. For example, it could hamper the productivity of fish due to its effects on eggs and larvae which will in turn affect the ecosystem web [52]. Furthermore, the relationship between particulate matter and the sea can be established when aerosol particles which are achieved in the polar cores can be used as tracers to rebuild the climatic conditions in their original regions [53].

##### 4.2 Ground-Level Ozone (O<sub>3</sub>)

There is no information regarding the effects of ground-level ozone on marine organisms or marine water quality.

##### 4.3 Carbon Monoxide (CO)

As for the ground-level ozone, the effect of carbon monoxide on the water system is also less known in the literature.

##### 4.4 Sulphur Dioxides and Nitrogen Oxides

As per a study conducted by Doney et al. [54], an estimated 0.8 Tmol/yr and 2.7 mol/yr of reactive sulphur and nitrogen respectively are deposited in the atmosphere in the coastal and open ocean regions. The sources are mainly attributed to fossil fuels and agriculture. These deposits are known to tamper with the sea surface alkalinity, pH and inorganic carbon in the water system [54]. Only a few studies show the impact of acid rain on marine organisms. According to Gao et al. [55], there was a decline in biodiversity in terms of species richness in the intertidal zones of a city in China induced due to acid rain. As per a study conducted by Li et al. [56], there was an observed physiological effect to *Ulva prolifera* (a seaweed), when treated with simulated acid rain. The effects were mainly attributed to enzymatic, respiration and photosynthetic activities. However according to Parker et al. [57], when some adult marine organisms got exposed to acid rain, their offspring and larvae are known to inherit some positive carryover effects making them more adaptive to the conditions.

According to Schindler et al. [58], juvenile fishes and many small organisms are known to be negatively affected by low pH levels in the water they live in. The increasing disappearance of organisms may lead to an imbalance in the food chain as the amount of food the larger organisms need to consume declines. Another study conducted by Riddell et al. [59], showed that the lichen species in the Los Angeles basin might be declining due to the nitric acid concentrations. Additionally, According to Kroglund et al. [60], rivers that are moderately or episodically acidified might cause a significant reduction in the return of the Atlantic Salmon species.

**Table 5** The link between sulphur oxide and nitrogen oxide to various environmental issues [61]

Issue	Connection to acid deposition
Coastal Eutrophication	Nitrogen added to the coastal water due to the atmospheric deposition
Mercury	Mercury accumulation in fishes are increased due to acid deposition
Visibility	Aerosols present in the atmosphere reduces the visibility and view.
Climate Change	Nitrous oxide is a greenhouse gas
Tropospheric Ozone	Emissions of nitrogen oxides help in the formation of ozone.

<https://doi.org/10.30799/jespr.133.18040205>

Cite this Article as: Shifa Zuhara, Rima Isaifan, The Impact of criteria air pollutants on soil and water: A review, J. Env. Sci. Pollut. Res. 4(2) (2018) 278–284.

To conclude, Table 5 shows the various links between sulphur oxide and nitrogen oxide have to various environmental issues in the water system. In general, acid rain is the most discussed issue with regards to nitrogen and sulphur oxides.

##### 4.5 Lead and Other Heavy Metals

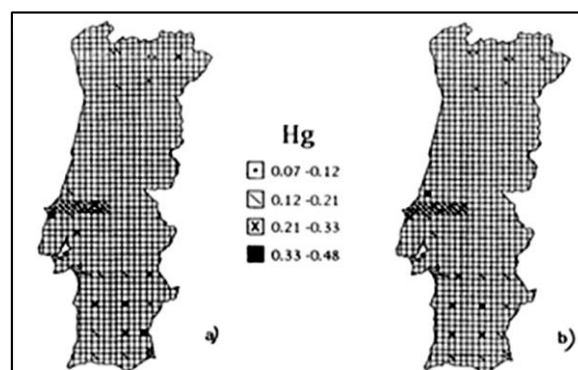
As mentioned before, lead is another example of metal pollution from anthropogenic sources. The increase in the lead was mainly caused when lead was being used in gasoline fuel in vehicles [62]. Heavy metal pollution is of significance as it was known to show extensive effects on the freshwater ecosystems [62]. As mentioned before, the increase in acid rain increases the bioavailability of heavy metals to the organisms in the freshwater. The effects of heavy metal on marine organisms are more related to its sources from sewage and industrial effluents and not the atmosphere. As per Downs et al. [63], the increased mercury concentration from the industry has been believed to be the main source of mercury to the aquatic biota. This is because even in the absence of a point source of industrial effluent, the levels were observed to be high [63].

There are studies discussing the accumulation of lead and other heavy metals in the marine organisms. A study conducted by Somero et al. [64], showed how the lead concentrations varied in the tissue of Estuarine Teleost Fish, *Gillichthys mirabilis* (Table 6). In the spleen and the vertebrae samples, even after shifting the tissues from the lead-treated water to the normal seawater, the lead levels continued to rise successively. Hence, showing that the effects can be quite serious and prolonged.

**Table 6** Tissue lead content in the Estuarine Teleost Fish, *Gillichthys mirabilis* [64]

Tissue lead content (µg/g dry weight)									
Group	Spleen	Gills	Fins	Intestine	Skin	Vertebrae	Liver	Muscle	Brain
A	31.24	21.78	24.55	13.77	7.14	13.73	1.41	0.65	6.21
B	20.30	19.32	18.27	13.24	7.53	11.69	1.72	0.55	-
C	18.78	28.81	24.39	13.16	8.37	17.98	3.42	0.71	-
D	14.08	17.60	18.48	13.91	7.95	12.72	1.19	0.75	5.38
E	20.85	16.85	18.53	10.46	6.98	13.66	1.05	0.73	-

The determination of heavy elements in two lichen varieties of the species *Parmelia caperata* and *sulcata* was studied with the intention of using them for bioaccumulation studies. From Fig. 9, it is obvious that both species accumulated a huge amount of mercury. Therefore, heavy metals are known to be a major issue in terms of effects on water and the organisms living in it.



**Fig. 9** The concentrations of Ca and Hg for *P. caperata* (a) and *P. sulcata* (b) [65]

#### 5. Conclusion

Air pollution causes serious effects on both land and water. Particulate-matter and its effects are studied at many levels; however, its effect is mostly focused on crop losses and food productivity. The effect on water is mainly associated with productivity of fishes and other marine organisms. Effects of ozone are observed on plants as decreased photosynthesis, decreased metabolism and increased respiration. Carbon monoxide is a relatively less explored area of air pollution with regards to effect on soil and water. Sulphur and nitrogen oxides majorly cause effects as part of the formation of acid rain. Acid rain is known to cause some serious negative effects on plants. Even marine organisms are known to have effects due to acid rain such as on their larvae and hence leading to lack of productivity. Lead and other heavy metals are also studied in detail. Here, bioaccumulation of these toxic elements is to be considered as the most imperative threat to the environment.

The number of published work in this field suggests that the research carried out on some of the pollutants are not sufficient. In general, the lack of known effects was more dominant in the water section of the paper.

This can be maybe due to the fact that it is very hard to study and understand the effects of air pollutants in the marine ecosystem. Therefore, more research needs to be focused on that area to understand the effects in depth.

### Author Contributions

Author S. Zuhara contributed to writing this article and R. Isaifan helped with technical input, reviewed and edited the content for final submission.

### Additional Information

Competing financial interests: The authors declare no competing financial interests.

### References

- J. Fenger, Air pollution in the last 50 years - From local to global, *Atmos. Environ.* 43 (2009) 13–22.
- S. Fuzzi, U. Baltensperger, K. Carslaw, S. Decesari, H. Denier Van Der Gon, et al., Particulate matter, air quality and climate: Lessons learned and future needs, *Atmos. Chem. Phys.* 15 (2015) 8217–8299.
- J. Lelieveld, J.S. Evans, M. Fnais, D. Giannadaki, A. Pozzer, The contribution of outdoor air pollution sources to premature mortality on a global scale, *Nature* 525 (2015) 367–371.
- N. Fann, C.G. Nolte, P. Dolwick, T.L. Spero, A.C. Brown, S. Phillips, S. Anenberg, The geographic distribution and economic value of climate change-related ozone health impacts in the United States in 2030, *J. Air Waste Manag. Assoc.* 65 (2015) 570–580.
- K.H. Kim, E. Kabir, S. Kabir, A review on the human health impact of airborne particulate matter, *Environ. Int.* 74 (2015) 136–143.
- M.D. Peitzmeier, Z.D. Koontz, T.M. Lynch, F.E. Hughes, D.E. Slone, Outcome of medial patellar ligament desmoplasty for treatment of intermittent upward fixation of the patella in 24 horses (2005–2012), *Can. Vet. J.* 56 (2015) 193–195.
- M. Jaishankar, T. Tseten, N. Anbalagan, B.B. Mathew, K.N. Beeregowda, Toxicity, mechanism and health effects of some heavy metals, *Interdiscip. Toxicol.* 7 (2014) 60–72.
- M.A. Assi, M.N.M. Hezmee, A.W. Haron, M.Y. Sabri, M.A. Rajion, The detrimental effects of lead on human and animal health, *Vet. World.* 9 (2016) 660–671.
- K.S. Mohammed Abdul, S.S. Jayasinghe, E.P.S. Chandana, C. Jayasumana, P.M.C.S. De Silva, Arsenic and human health effects: A review, *Environ. Toxicol. Pharmacol.* 40 (2015) 828–846.
- J. Tidblad, V. Kucera, M. Ferm, K. Kreislova, S. Brüggerhoff, S. Doytchinov, et al., Effects of air pollution on materials and cultural heritage: ICP materials celebrates 25 years of research, *Int. J. Corros.* 2012 (2012) 2005–2006.
- S. Dubey, Acid rain-the major cause of pollution: Its causes, effects and solution, *Int. J. Sci. Eng. Technol.* 13 (2013) 2277–1581.
- H.S. Koren, Associations between criteria air pollutants and asthma, *Environ. Health Perspect.* 103 (1995) 235–242.
- V.P. Aneja, A. Agarwal, P.A. Roelle, S.B. Phillips, Q. Tong, N. Watkins, R. Yablonsky, Measurements and analysis of criteria pollutants in New Delhi, India, *Environ. Int.* 27 (2001) 35–42.
- S.J. Smith, J. Van Aardenne, Z. Klimont, R.J. Andres, A. Volke, S. Delgado Arias, Anthropogenic sulphur dioxide emissions: 1850–2005, *Atmos. Chem. Phys.* 11 (2011) 1101–1116.
- V. Vestreng, G. Myhre, H. Fagerli, S. Reis, L. Tarrason, Twenty-five years of continuous sulphur dioxide emission reduction in Europe, *Atmos. Chem. Phys.* 7 (2007) 3663–3681.
- A.J. Haagen-Smit, M.M. Fox, Photochemical ozone formation with hydrocarbons and automobile exhaust, *Air Repair.* 4 (1954) 105–136.
- K. Skalska, J.S. Miller, S. Ledakowicz, Trends in NOx abatement: A review, *Sci. Total Environ.* 408 (2010) 3976–3989.
- A. Thorpe, R.M. Harrison, Sources and properties of non-exhaust particulate matter from road traffic: A review, *Sci. Total Environ.* 400 (2008) 270–282.
- R.M. Charron, A. Harrison, P. Quincey, What are the sources and conditions responsible for exceedences of the 24 h PM<sub>10</sub> limit value ( 50 µg·m<sup>-3</sup> ) at a heavily trafficked London site ?, *Atmos. Environ.* 41 (2007) 1960–1975.
- H. Pleijel, Critical Levels for Ozone - Level II, SAEFL Environ. Document. 115 (1999) 20–22.
- S. Meul, M. Dameris, U. Langematz, J. Abalichin, A. Kerschbaumer, A. Kubin, S. Oberlander-Hayn, Impact of rising greenhouse gas concentrations on future tropical ozone and UV exposure, *Geophys. Res. Lett.* 43 (2016) 2919–2927.
- M. Tomašević, Z. Vukmirović, S. Rajšić, M. Tasić, B. Stevanović, Characterization of trace metal particles deposited on some deciduous tree leaves in an urban area, *Chemosphere.* 61 (2005) 753–760.
- C. Ramlall, B. Varghese, S. Ramdhani, N.W. Pammenter, A. Bhatt, P. Berjak, Sershen, Effects of simulated acid rain on germination, seedling growth and oxidative metabolism of recalcitrant-seeded *Trichillia dregeana* grown in its natural seed bank, *Physiol. Plant.* 153 (2015) 149–160.
- P.C. Nagajyoti, K.D. Lee, T.V.M. Sreekanth, Heavy metals, occurrence and toxicity for plants: A review, *Environ. Chem. Lett.* 8 (2010) 199–216.
- N. Herawati, S. Suzuki, K. Hayashi, I.F. Rivai, H. Koyama, Cadmium, copper, and zinc levels in rice and soil of Japan, Indonesia, and China by soil type, *Bull. Environ. Contam. Toxicol.* 64 (2000) 33–39.
- D.A. Grantz, J.H.B. Garner, D.W. Johnson, Ecological effects of particulate matter, *Environ. Int.* 29 (2003) 213–239.
- S.K. Prajapati, B.D. Tripathi, Seasonal variation of leaf dust accumulation and pigment content in plant species exposed to urban particulates pollution, *J. Environ. Qual.* 37 (2008) 865.
- A. Przybysz, A. Sæbø, H.M. Hanslin, S.W. Gawro, Accumulation of particulate matter and trace elements on vegetation as affected by pollution level, rainfall and the passage of time, *Sci. Total Environ.* 481 (2014) 360–369.
- P.B. Morgan, T.A. Mies, G.A. Bollero, R.L. Nelson, S.P. Long, Season-long elevation of ozone concentration to projected 2050 levels under fully open-air conditions substantially decreases the growth and production of soybean, *New Phytol.* 170 (2006) 333–343.
- X. Wang, W. Manning, Z. Feng, Y. Zhu, Ground-level ozone in China: Distribution and effects on crop yields, *Environ. Pollut.* 147 (2007) 394–400.
- J.K. McCrady, C.P. Andersen, The effect of ozone on below-ground carbon allocation in wheat, *Environ. Pollut.* 107 (2000) 465–472.
- E.A. Ainsworth, C.R. Yendrek, S. Sitch, W.J. Collins, L.D. Emberson, The effects of tropospheric ozone on net primary productivity and implications for climate change, *Annu. Rev. Plant Biol.* 63 (2012) 637–661.
- L.D. Emberson, P. Büker, M.R. Ashmore, G. Mills, L.S. Jackson, M. Agrawal, et al., A comparison of North American and Asian exposure-response data for ozone effects on crop yields, *Atmos. Environ.* 43 (2009) 1945–1953.
- M.T. Mcgrath, C.P. Andersen, F.L. Booker, K.O. Burkey, A.H. Chappelka, B.I. Chevone, et al., Ambient ozone and plant health, *Plant Dis.* 85 (2001) 4–12.
- R. Rai, M. Agrawal, S.B. Agrawal, Threat to food security under current levels of ground level ozone: A case study for Indian cultivars of rice, *Atmos. Environ.* 44 (2010) 4272–4282.
- R. Van Dingenen, F.J. Dentener, F. Raes, M.C. Krol, L. Emberson, J. Cofala, The global impact of ozone on agricultural crop yields under current and future air quality legislation, *Atmos. Environ.* 43 (2009) 604–618.
- E. Sanhueza, Y. Dong, D. Scharffe, J.M. Lobert, P.J. Crutzen, Carbon monoxide uptake by temperate forest soils: The effects of leaves and humus layers, *Tellus, Ser. B Chem. Phys. Meteorol.* 50 (1998) 51–58.
- W. Sun, L.M.J. Kooijmans, K. Maseyk, H. Chen, I. Mammarella, T. Vesala, et al., Soil fluxes of carbonyl sulfide (COS), carbon monoxide, and carbon dioxide in a boreal forest in southern Finland, *Atmos. Chem. Phys.* 18 (2018) 1363–1378.
- A. Singh, M. Agrawal, Acid rain and its ecological consequences, *J. Environ. Biol.* 29 (2008) 15–24.
- X. Lu, Q. Mao, F.S. Gilliam, Y. Luo, J. Mo, Nitrogen deposition contributes to soil acidification in tropical ecosystems, *Glob. Chang. Biol.* 20 (2014) 3790–3801.
- B. Odiyi, A. Eniola, The effect of simulated acid rain on corticolous myxomycetes, *Jordan J. Biol. Sci.* 8 (2015) 54–54.
- B. Francisco Sant'Anna-Santos, L. Campos da Silva, A. Alves Azevedo, J. Marcos de Araújo, E. Figueiredo Alves, E. Antônio Monteiro da Silva, R. Aguiar, Effects of simulated acid rain on the foliar micromorphology and anatomy of tree tropical species, *Environ. Exp. Bot.* 58 (2006) 158–168.
- L. Wang, W. Wang, Q. Zhou, X. Huang, Combined effects of lanthanum (III) chloride and acid rain on photosynthetic parameters in rice, *Chemosphere.* 112 (2014) 355–361.
- Q. Qiu, J. Wu, G. Liang, J. Liu, G. Chu, G. Zhou, D. Zhang, Effects of simulated acid rain on soil and soil solution chemistry in a monsoon evergreen broad-leaved forest in southern China, *Environ. Monit. Assess.* 187 (2015) 1–13.
- Y. Lv, C. Wang, Y. Jia, W. Wang, X. Ma, J. Du, G. Pu, X. Tian, Effects of sulphuric, nitric, and mixed acid rain on litter decomposition, soil microbial biomass, and enzyme activities in subtropical forests of China, *Appl. Soil Ecol.* 79 (2014) 1–9.
- R.M. Harrison, M.B. Chirgawi, The assessment of air and soil as contributors of some trace metals to vegetable plants I. Use of a filtered air growth cabinet, *Sci. Total Environ.* 83 (1989) 13–34.
- M.S.A. Ahmad, M. Ashraf, Q. Tabassam, M. Hussain, H. Firdous, Lead (Pb)-induced regulation of growth, photosynthesis, and mineral nutrition in maize (*Zea mays* L.) plants at early growth stages, *Biol. Trace Elem. Res.* 144 (2011) 1229–1239.
- S. Malar, S. Shivendra Vikram, P.J.C. Favas, V. Perumal, Lead heavy metal toxicity induced changes on growth and antioxidative enzymes level in water hyacinths [*Eichhornia crassipes* (Mart.)], *Bot. Stud.* 55 (2016) 54–64.
- N. Singh, V. Pandey, J. Misra, M. Yunus, K.J. Ahmad, Atmospheric lead pollution from vehicular emissions - Measurements in plants, soil and milk samples, *Environ. Monit. Assess.* 45 (1997) 9–19.
- M.A.S. Laidlaw, S. Zahran, H.W. Mielke, M.P. Taylor, G.M. Filippelli, Resuspension of lead contaminated urban soil as a dominant source of atmospheric lead in Birmingham, Chicago, Detroit and Pittsburgh, USA, *Atmos. Environ.* 49 (2012) 302–310.
- A.J. Watson, D.C. Bakker, A.J. Ridgwell, P.W. Boyd, C.S. Law, Effect of iron supply on Southern Ocean CO<sub>2</sub> uptake and implications for glacial atmospheric CO<sub>2</sub>, *Nature* 407 (2000) 730–733.
- O. Wurl, J.P. Obbard, A review of pollutants in the sea-surface microlayer (SML): A unique habitat for marine organisms, *Mar. Pollut. Bull.* 48 (2004) 1016–1030.
- H. Fischer, U. Ruth, R. Ro, Glacial / interglacial changes in mineral dust and sea-salt records in polar ice cores: sources, transport, and deposition, *Rev. Geophys.* 45(1) (2007) 1–26.
- S.C. Doney, N. Mahowald, I. Lima, R.A. Feely, F.T. Mackenzie, J.F. Lamarque, P.J. Rasch, Impact of anthropogenic atmospheric nitrogen and sulphur deposition on ocean acidification and the inorganic carbon system, *Proc. Natl. Acad. Sci.* 104 (2007) 14580–14585.
- S. Gao, Q. Sun, Y. Tao, X. Wang, W. Li, L. Huan, M. Wu, G. Wang, A decline in macro-algae species resulting in the overwhelming prevalence of *Corallina* species is caused by low-pH seawater induced by short-term acid rain, *J. Exp. Mar. Biol. Ecol.* 475 (2016) 144–153.
- Y.H. Li, D. Wang, X.T. Xu, X.X. Gao, X. Sun, N.J. Xu, Physiological responses of a green algae (*Ulva prolifera*) exposed to simulated acid rain and decreased salinity, *Photosynthetica.* 55 (2017) 623–629.

<https://doi.org/10.30799/jespr.133.18040205>

- [57] L.M. Parker, W.A. O'Connor, D.A. Raftos, H.O. Pörtner, P.M. Ross, Persistence of positive carryover effects in the oyster, *Saccostrea glomerata*, following transgenerational exposure to ocean acidification, *PLoS One* 10 (2015) 1–19.
- [58] A.D.W. Schindler, *S. Science, N. Series, N. Jan*, Effects of acid rain on freshwater ecosystems, *Science* 239 (1998) 149–157.
- [59] J. Riddell, T.H. Nash, P. Padgett, The effect of HNO<sub>3</sub> gas on the lichen *Ramalina menziesii*, *Flora* 203 (2008) 47–54.
- [60] F. Kroglund, B. Finstad, S.O. Stefansson, T.O. Nilsen, T. Kristensen, B.O. Rosseland, et al., Exposure to moderate acid water and aluminum reduces Atlantic salmon post-smolt survival, *273* (2007) 360–373.
- [61] C.T. Driscoll, K.M. Driscoll, M.J. Mitchell, D.J. Raynal, Effects of acidic deposition on forest and aquatic ecosystems in New York State, *Environ. Pollut.* 123 (2003) 327–336.
- [62] A. Valavanidis, T. Vlachogianni, Metal pollution in ecosystems, *Ecotoxicology studies and risk assessment in the marine environment*, *Sci. Adv. Environ. Toxicol. Ecotoxicol. Issues Feb.* (2010) 1–9.
- [63] S.G. Downs, C.L. Macleod, J.N. Lester, Mercury in precipitation and its relation to bioaccumulation in fish: A literature review, *Water. Air. Soil Pollut.* 108 (1998) 149–187.
- [64] G.N. Somero, T.J. Chow, P.H. Yancey, C.B. Snyder, Lead accumulation rates in tissues of the estuarine teleost fish, *Gillichthys mirabilis*: Salinity and temperature effects, *Arch. Environ. Contam. Toxicol.* 6 (1977) 337–348.
- [65] M.C. Freitas, A.S. Nobre, Bioaccumulation of heavy metals using *Parmelia sulcata* and *Parmelia caperata* for air pollution studies, *Jour. Radioanal. Nuclear Chem.* 217 (1997) 17–20.