Air Contamination and Its Impact on Plants, Humans and Water of Pakistan-A Review

Nukshab Zeeshan[2], Muhammad Salman Nasir[1*], Abdul Nasir[1], Saifullah[2], Zia Ur Rahman Farooqi[2], Khurram Naveed[2]

[1]Department of Structures and Environmental Engineering, University of Agriculture Faisalabad, Pakistan;
[2]Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad

ABSTRACT

Air is a need of humans for breathing and sustaining their lives. The particulate matter, organic and inorganic pollutants found unhealthy and hazardous according to EPA Pakistan standards, in the different cities of Pakistan like Lahore, Quetta, Gujranwala, Peshawar, Islamabad, Karachi, Rawalpindi, and Faisalabad. These have great impacts on the plants as well as human life and ultimately deteriorating food chain. To use the air for respiration needs, there are some standards beyond them; the air quality is not recommended for use because the many types of chemicals (heavy metals, organic compounds, Aerosols, Greenhouse gasses), microbes (pathogens) and all harmful agents can cause serious problems in human body which are discussed here in this review. To maintain these air quality standards, there are many regulatory bodies like EPA's in almost all countries, WHO standards etc. Human activities of development like industrialization, agriculture, motorvehicles etc. has alleviated the standards from their permissible limits owing to excessive use of fossil fuels, roadside traffic load, fertilizers, pesticides, and harmful industrial pollutants which join ambient air by exhaust from burning or exploiting, when this contaminated air is used for breathing purposes, it causes severe problems. This problem is faced by many industrial countries. Pakistan is one of them whose citizens are severely affected by different harmful airborne diseases like asthma, lung cancer etc.

KEYWORDS: air, contamination, particulate, microbes, airborne

INTRODUCTION

Aerosols in Pakistan contaminating air quality day by day. Anthropogenic activities enhanced the level of aerosols in the atmosphere from preindustrial age [1]. The aerosols play a key role in the chemistry of the atmosphere. The activities such as cleaning of roads, painting, repairing are the sources of particulate matter[2]. Due to their detrimental effects, the aerosols were the major concern of the new studies because the particulate matter was very dangerous for human as well as plant life. Researchers pointed out that the developing countries have high dust intensity due to traffic load and less developed infrastructure. Particulate matter (PM_{10}) can enter from nose to alveoli of lungs and cause direct breathing effects on humans. Aerosols were divided into two types i.e. aerosols emitting from the source is called primary aerosols and the secondary aerosols are those which were produced as a result of oxidation of primary aerosols. Secondary aerosols usually comprise of 50% of the total carbon mass basis [3]. International organization for standardization concluded that PM_{10} in human is damaging in the thoracic region and $PM_{2.5}$ the alveolar fraction [4].

The population explosion in African and Asians countries are the major cause of the destruction of air quality[5]. Increasing gas demand in Pakistan, Turkey, Thailand, Morocco, Tunisia, and Malaysia, is also a great indicator for policy makers to reduce emissions [6][7][8].

Contaminated air consists of solid particles and gases which are coming from cars emissions, chemicals from factories, dust, pollens and mold spores might be suspended in air as particles[9]. Ozoneplays a major part in air pollution of cities. Ozone is also the reason of smog formation. Megacities facing many health issues regarding air pollution. It has great and adverse impacts on children brains. Mexico City Metropolitan Area showed the high level of oxidative stress, small blood vessels pathology and also the early symptoms of Alzheimer's and Parkinson disease in children[10].

High-level exposure of pregnant women to the air pollution increase the risk of Hypertensive disorders of pregnancy (HDP, including hypertension of gestation, preeclampsia, and eclampsia) in women [11].

---

*Corresponding author: Muhammad Salman Nasir, Department of Structures and Environmental Engineering, University of Agriculture Faisalabad, Pakistan; e-mail: salmannasir@uaf.edu.pk

AIR QUALITY IN PAKISTAN

Air pollution is a permanent threat to the world. In Pakistan poor air quality creates problems like aerosols production, lead toxicity, asthma, and greenhouse gas accumulation. Immediate action is required to save 140 million people[12].Punjab is more developed and more industrialized than the other provinces of Pakistan. The research was conducted by Mohmand in the urban and rural area of Punjab, Pakistan about the concentration of different heavy metal in dust, hair, nail and serum samples. Zinc, lead, Copper, Nickel, chromium, cobalt and cadmium were found in the samples. Trace metals also found in the descending order Zinc, Lead, Mn, Cu, Cr, Ni, Co, and Cd. The sample taken from urban areas showed a high concentration of trace metal than industrial samples (Pb, Cu) than those taken from the rural area. Bioaccumulation of Cd, Pb, Co and Ni is through dietary sources. The samples compared with worldwide and found to be much concentration. Hazard index calculated that Cd and Pb have more hazardous than all sub-groups[13].

A studyconducted by Kamal et al., (2015) reported that air pollution from road traffic is not only a major source of exposure to polycyclic aromatic hydrocarbons (PAHs) but also a growing problem in the city of Lahore (Pakistan) They pointed out that on the basis of daily time spent in the middle of heavy traffic, traffic police officers and rickshaw drivers are often experienced from the adverse head and respiratory symptoms. The study also concluded that increasing traffic pollution can be associated with important health risk factor not only for the workers in transport industry but also for the public [14].Air quality of Lahore badly affected due to high traffic load on the roads resulting more aerosols production as documented in a study conducted by von Schneidemesser et al., (2010) reported that aerosols contain ahigh concentration of Lead, Zinc, and Cadmiumi.e., 4.4, 12 and 0.077 $\mu g\ m^{-3}$. The Pb (84%), Zn (98%), and Cd (90%) were dominant in the fine particulate fraction (PM$_{2.5}$). During 2007 annual average PM$_{10}$ mass concentration was 340 $\mu g\ m^{-3}$, which was found well above the WHO guideline of 20 $\mu g\ m^{-3}$. They finally concluded that high concentration of Pb, As, Cr and Cd were found to be associated with the industrial source [15].

Plant growth also affected when exposed to poor quality of air according to Wahid et al., (1995) Wheat plants, when grown under unfiltered air and infield, showed stunted growth and accelerated rate of leaf senescence with pronounced reductions in stomatal conductance (7–24%), net photosynthetic rate (20–22%) and photosynthetic efficiency (9–17%) compared with charcoal filtered air [16]. Similarly, health of inhabitants and workers of brick kiln also affected due to their continuous exposure to suspended toxic air pollutants as reported by Kamal et al., (2014b) in Lahore and Gujranwala cities brick kiln workers both adults and children were exposed to high-potential carcinogenic polycyclic aromatic hydrocarbons (PAH) during the brick making process. The highest levels of ΣPAH were measured in the dust samples collected in Sohdra village of Gujranwala city (mean 2578 ng g^{-1}d.w., range 302–6757 ng g^{-1} d.w.) followed by Chung Khurd (mean 882, range 692–1007 ng g^{-1} d.w.) a village of Lahore city [17].

Karachi city is the city of lights. Heavy traffic and the high noise level were reported in the city as well as air pollution particularly dust. The heavy metals were reported during the study in Punjab, Pakistan where toxic level of heavy metals is as follow, Zinc (Zn), Lead (Pb), Manganese (Mn), Copper (Cu), Nickel (Ni), Chromium (Cr), Cobalt (Co), and Cadmium (Cd) in dust, hair, nail and serum, sampled in rural, urban and industrial areas [18] and Shah studied in Hyderabad that Pb accumulation in the people of Hyderabad, Pakistan which is living in the areas near the industries. A total of 339 school going children of age 5-10-year sample and compared to the industrial area school children. They found that the concentration of the Pb in industrial area school children is 44-64% higher than others area. This is due to the presence of heavy metals in the air samples. It is also found that boys are more exposed than the same age girls. The Pb levels are rising in both age groups[19].Among different OCPs investigated, ΣDDTs and ΣHCHs were more prevalent compounds in ambient air samples of the study area(Sultana et al., 2014).Polychlorinated naphthalene was reported in India and Pakistan. The concentration found in India is 29 pg/m^3 and In Pakistan 7.7pg/m^3. These concentrations were low than the previous in the Asian countries but still higher than standards, major sources of these PCNs were the re-emission of halowax and industrial thermal processes [20].The particulate matter reported in different cities of Pakistan are shown in Table 1.

Table.1. Particulate Matter concentration (ug m^{-3}) in different cities of Pakistan

CITY	SOURCE	PM$_{10}$	PM$_{2.5}$	REFERENCE
Lahore	Biomass burning, Diesel engines, Residual fuel oil, Combustion	336	194	[21]
Quetta	Industrial and residential Sources of Quetta	126–709	104–222	[22]
Gujranwala	Brick kiln, Road traffic	5190		[23]
Peshawar	Road traffic	720	110	[24]
Rawalpindi	Road Traffic	709		[23]
Faisalabad	Road Traffic	3477		[23]

The study also concluded different organic and inorganic pollutants found in different cities of Pakistan are shown in Table 2.

Table.2. Organic and inorganic pollutants in different cities of Pakistan:

Sr. No	CITY	ORGANIC POLLUTANTS	INORGANIC POLLUTANTS	REFERENCES
1.	Karachi	Not reported	Pb,SO4,NO2, (NH4)2SO4, NH4NO3	[25]
2.	Lahore	Polly Chlorinated Hydrocarbons	Cadmium	[26] [27]
3.	Rawalpindi	PVC (polyvinyl chloride)	Cd, Cr, Cu, Pb, Zn	[28]
4.	Islamabad	DDTs (Dichlorodiphenyltrichloroethane), HCHs (Hexachlorocyclohexane) and chlordane	Na, Fe, Zn , K, Mg, Cu, Sb, Pb and Sr	[29] [30]
5.	Peshawar	Naphthalene, phenanthrene, fluoranthene, and pyrene	Pb and Cd	[31] [32]
6.	Gujranwala	Polyaromatic Hydrocarbons Organochlorines	Not reported	[33]
7.	Hyderabad	Black Carbon, chlordane, heptachlor, and Hexa-Chloro-benzene	Not Reported	[34] [35]
8.	Sialkot and Lahore	Not Reported	Pb, Cd and Cr	[36]

Jaffery et al., (2014) reported that in the southern Pakistan where wood is used as a fuel and their impacts on the worker and habitats.A study conducted among the women who using natural gas as fuel and a villager or southern Punjab where natural gas(Methane) is not available. The study revealed that the eye congestion, nasal congestion, throat congestion, throat related symptoms is higher in the people using wood as fuel and has a greater rate of asthma compared to the natural gas user. Twenty-eight-year women were showed acute eye symptoms with 95% confidence interval. A great number of women had reported as chronic respiratory symptoms, mainly cough as compared to CNG user [37].

IMPACTS OF AIR POLLUTANTS ON VEGETATION
Air pollutants have significant impact on the health of natural vegetation as described by Chen in 1990.

Table.3. Impact of air pollution on vegetation

Pollutant name	Emission sources	Impact	Mode of pollutant's entry
Sulfur Dioxide (SO_2)	Industrial, Commercial, Domestic and Power generation Plants.	Chlorosis, Foliar injury, retarded plant growth.	Stomata.
Nitrogen Oxides (NO_x)	Power generation and transportation.	Necrosis, low photosynthesis, Altered plant growth, increased sensitivity.	Stomata.
Ozone (O_3)	Secondary pollutant.	Foliar injury, reduced plant growth, loss of membrane integrity and function, oxidation of plasma lemma and cytosol, bleaching, bronzing, flecking, stipplinganduniandbifacialnecrosis.	Leaf cuticle, stomata.
Suspended Particulate Matter (SPM)	Industry, domestic, power generation, transportation.	Reduced plant growth, increased sensitivity, low gaseous exchange and light transmission.	Deposited on leaf surfaces.
Fluorides	Smelting and manufacturing processes.	Fluorosis, Chlorosis, necrosis, reduced plant growth(Chen et al., 1992).	Deposited on the leaf as well as penetrated through leaves and diffusion through the cuticle.

[38]
Similarly, foliar injuries were found in leaves of potatoes, onion and cotton of North West Pakistan when the mean concentration of ozone exceeded the limit of 45 ppb. Aphid attack on cotton crop also increases when the ozone concentration increases from the limits[39].Reduction in grain yield of rice and wheat crops found by wahid in 1995a and 1995b, he revealed 37% to 42% yield decrease in rice and 34.8 to46.7% in wheat due to air pollution [40][41]. Choice of vegetation in urban areas is a crucial element for air pollution concentration. Vegetation having large surface areapoints for deposition and porous surface allows a lot of pollutants to be deposited on them while air pollution is decreased in that area [42]. Pollutants like NO_X, O_3 and PM_{10} are detrimental to crops and urban plants in terms of yield, quality, their Pests and fungal pathogens especially lichens [43]. Air pollutants such as

ozone, sulfur dioxide, NOx, Peroxyacetyl Nitrate(PAN) were damaging the leaf of grapes, Navel orange, and Alfalfa.

The oxidants were observed from the automobileexhaustsPeri-urban agriculture study showed that the crops grown in the urban areas like mong-bean (*Vigna radiate*), cabbage (*Beta vulgaris*), wheat (*Triticumaestivum*) and mustard (*Brassica competes*) were greatly affected by the air pollutants and crop yield reduction occur due to pollution [44].The study was conducted in Lahore in 2004-2005 to check the air pollution effects on four cultivars of barley (*Hordeumvulgare* L.) cultivars (Haider-93, Haider-91, Jou-87, Jou-85). The comparison was conducted between unfiltered air grown crop of barley and charcoal filter air grown crop. The comparison showed that the unfiltered air crop of barley showed less transpiration rate 20-27%, photosynthetic rate 13-21% and stomatal transpiration 6-12% were observed. Due to these the yield loss of the barley crop is significant [45], The same study conducted for three wheat cultivars (Inqilab-91, Punjab-96, Pasban-90) and noted that ten weeks old plant of wheat showed reduce dry weight of 15-13 in unfiltered air experiment than filter air experiment [31].

As heavy metals are also contributors of air pollution so, to check the effects of heavy metals,a study conducted on roadside in Peshawar and found that the Cadmium and Plumbum concentrations in plants samples was 49.1 and 10.9 mg/ kg respectively which has great impacts on plants metabolism and other enzymatic processes in plants [31][47].

Polychlorinated biphenyl's concentration in plants samples of wheat and Rice from the two tributaries of Chenab River which were ranged from 0.15ng/g dW and 0.05-2.22ng/g dW respectively. A study conducted in the UK and increased defoliation along the motorway side Oak trees were found more as compared with another site. Motor emissions are the main cause of urban pollution. Motor emissions have damaging impacts on plants. Effects of air pollution on 12 herbaceous species characteristics were studied which were growth, flower development, leaf senescence and leaf surface wax characteristics. The drought and phenology found affected in these species. The study clears the picture of air pollution in Pakistan and their impacts on plants growth

Soya bean was grown in the vicinity of Lahore without ozone protectants and noted that EDU (N-[2-{2-oxo-1-imidazolidinyl} ethyl]-n2 phenylurea) were found high and had harmful impacts observed on growth and yield. The ozone has damaging impacts on the crops yield[48] as well as tobacco plants said that PCNs are entering the food chain via cereals crops in Pakistan.

IMPACTS ON HUMAN HEALTH

According to the US- EPA (2015) [47] report air pollutants have known or suspected harmful effects on human health and the environment. These pollutants may not only prove a problem in the immediate vicinity of these sources but can travel long distances. Major pollutants are Ozone (O_3) Nitrogen Dioxide (NO_2), Particulate Matter (PM_{10}, $PM_{2.5}$), Sulfur Dioxide (SO_2), Lead (Pb), Carbon Monoxide (CO) etc. These are involved in Asthma, bronchitis, emphysema and other respiratory problems. Table 4 shows the effect of air pollutants on human health.

Table 4. Effect of air pollutants on human health

Pollutant	Sources	Health effects	Permissible limit [47]
Ozone (O_3)	Gasoline vapors, chemical solvents, combustion products, industry, gas stations, bakeries, dry cleaners.	Respiratory inflammation, chest pain, coughing, nausea, pulmonary congestion, structural damage to lungs.	9 ppm.
Nitrogen Dioxide (NO_2)	Fuel burning, vehicle exhaust, industrial boilers, power generation.	Lung irritation, acute respiratory illness.	0.1 ppm.
Particulate Matter (PM_{10}, $PM_{2.5}$)	Diesel vehicles, wood stoves, power plants.	Respiratory illness, cancer, premature death (Brauer et al., 2012).	PM_{10}= 150 µg/m^3 $PM_{2.5}$= 15 µg/m^3
Sulfur Dioxide (SO_2)	Smelting, industry, fuel combustion.	Cardiovascular diseases, respiratory illness, bronchitis, emphysema (Cakmak et al., 2014).	0.50 ppm
Lead (Pb)	Smelters, batteries.	Anemia, kidney diseases, mental retardation, reproductive disorders, slowed growth, central nervous system damage.	1.5 µg/m^3
Carbon Monoxide (CO)	Motor vehicle exhaust, boilers, incinerators.	It reduces oxygen delivery to the body's organs and tissues.	9 ppm

According to WHO, total 81% of total population is exposed to contaminated indoor air and 56100 deaths occur per year due to this reason and 30,000 deaths occur due to outdoor contaminated air exposure. A study on $PM_{2.5}$ showed the direct chance of cardiovascular diseases and respiratory illness in humans and the polychlorinated aromatic compounds were found a major cause of severe head and respiratory symptoms in the people who passed

their time on roads like traffic police officers and wardens. The study concluded that the increasing population increasing the transport as well as the regarding atmospheric [48].

The small particles inhalation is the major cause of deterioration of health of the public. The particles which have a particle size less than 2.5 are fine particles and it badly affects the lungs. The depth study suggests that air pollution control strategies should be implemented in the best of their health [49].The arsenic is monitored in the dust outside of different urban areas of Punjab, Pakistan. The arsenic has carcinogenic effects on humans. The study showed that the samples have a high level of arsenic contamination than the WHO threshold limit of one milligram/kilogram. The study is helpful to access the arsenic contamination level in different part of the country[50].

The study of incinerator flue gases in Rawalpindi which analysis indicated the high level of particulate matter from these flue gases. The exhaust gases from the incinerator clearly have bad impacts on human health. The exhaust gases include particulate matter, nitrogen, sulfur and carbon oxides which have worst impacts on public [51].Polychlorinated naphthalene has toxic effects on humans due to the persistence in the environment and bioaccumulation and ultimately the part of human food chain. They have carcinogenic effects of humans [52].

In this study, it was concluded that the major health impacts were associated with the urban people than rural people. Benzo(a) pyrene which is classified as carcinogenic and it initiates mutations in people having long exposures to it. It was observed that about 70 genes have the potential of mutation when exposed to said element and causes lung cancer and mutation in genes and genetic material detrimental to human and animal's health.

Organic phosphorous compounds are used in flame retardants, plasticizers and ubiquitous in many environment compartments. The exposure to humans is studied via skin, dermal, dust ingestion, inhalation and ingestion routes[53].Particulate matter exposure in humans results in the respiratory symptoms, increased hospital admissions and early age lung infection and premature deaths. The further studies showed that the dust exposure causes the loss of birth weight in infants breathing problems, wheezing, coughing and pain in the chest [54].

IMPACTS ON WATER

The Fallah Shoshana in 2015suggested that it is very difficult to generate a model which can clearly identify the air pollution effects on water. But he generated the model between the fair concentrations of road traffic pollution effects on water. Modeling approaches for simulating air and storm water pollution due to on-road vehicles are reviewed and discusses [55]. The further studied on the samples from rainwater were collected and found that there is a high concentration of water contaminants like heavy metals and aerosols. Sulfur is the main contaminant reported in the study and contaminating water bodies. The mean concentration of $PM_{2.5}$ analysis has following result ammonia $11.57 mgL^{-1}$ nitrate $1.72 mgL^{-1}$ and phosphorus $0.019 mgL^{-1}$ [56].

Cahoon in 2015 described the use of coal is major fuel in many industries and the emissions have great impacts on the water. The greenhouse gases are emitting from the coal burning and the remaining ash leachate down toward ground water has become the major reason for ground water pollution. The leachate usually contains toxic metals such as Cadmium, Chromiumetc which when toreach down contaminate the groundwater and cause health effects also in human beings which are the consumer. The mitigation strategies should adopt to enhance the use of alternative fuels than coal [57].

The fish population is strongly disturbed if the water is contaminated. The study revealed that the sodium and potassium ion balance in the gills is reversed if the fish allowed to live in clean water which has no pollutant [58].

The air pollution has great effects on coral reefs and rain forests. The acid rain due to air pollution is more damaging and can cause biomes shift that could enhance the greenhouse gases in the atmosphere and directly effects on expansion of water [59].

CONCLUSIONS

The air quality of Pakistan is not deeply studied yet. Some major cities are the focus of the researchers. But the severity of the pollution in major cities summarizes the whole condition of ambient air. It is very dangerous not only for plants but also for humans and water bodies and their impacts discussed above in detail. The major reason of the real pollution is fossil fuel burning and the emissions from the burning directly in contact with the atmosphere without any use of air pollution control devices in industries and use of low-quality fuel.

Use of air pollution control devices like scrubbers, cyclones separators, air bag filters can reduce the air pollution. Recently the standards are set by the Pakistan EPA but still there is no implementation of these standards. The standard only is implemented on some industrial state like Sunder Industrial Estate and Quaid-E-Azam Industrial Estate. The Government should pay attention to the air pollution studies and facilitate the researchers to monitor and set their goals to provide the public with a clean environment.

REFERENCES

1. Lohman, U and Feichter, J.: Global Indirect Aerosol Effects: a review, Atmospheric Chemistry and Physics 5, pp. 715 – 737, 2005.
2. Capes, J. G., Murphy, C. E., Reaves, J. B., Mc Quaid, J. F., Hamilton, J. R.: Secondary Organic Aerosol from Biogenic VOCs Over West Africa during African Monsoon Multidisciplinary Analysis (AMMA), Atmospheric Chemistry and Physics 9, pp. 3841–3850, 2009.
3. Kanakidou, M., Seinfeld, J. H., Pandis, S. N., Barnes, I, Dentener, F. J., Facchini, M. C., Van Dingener, R., Ervens, B., Nenes, A., Nielsen, C. J., Swietlicki, E., Putaud, J. P., alkanski, Y., Fuzzi, S., Horth, J., Moortgat, G. K., Winterhaltor, R., Myhre, C. E. L., Tsigaridis, K., Vignati, E., Stephanou, E. G. and Wilson, J.: Organic Aerosol and Global Climate Modeling: a review, Atmos. Chem. Phys; 5, pp. 1053 – 1123, 2005.
4. ISO: Air Quality–Particles Size Fraction Definitions for Health Related Sampling (ISO7708), 1995.
5. Liotta, P. H., and Miskel, J. F. (2009). The 'Mega-Eights': Urban Leviathans and International Instability. *Orbis***53**, 647-663.
6. Bhutto, A. W., Bazmi, A. A., and Zahedi, G. (2012). Greener energy: Issues and challenges for Pakistan—Solar energy prospective. *Renewable and Sustainable Energy Reviews* **16**, 2762-2780.
7. Vafa-Arani, H., Jahani, S., Dashti, H., Heydari, J., and Moazen, S. (2014). A system dynamics modeling for urban air pollution: A case study of Tehran, Iran. *Transportation Research Part D: Transport and Environment* **31**, 21-36.
8. Freije, A. M. (2015). Heavy metal, trace element and petroleum hydrocarbon pollution in the Arabian Gulf: Review. *Journal of the Association of Arab Universities for Basic and Applied Sciences* **17**, 90-100.
9. Wilson, J. G., Kingham, S., Pearce, J., and Sturman, A. P. (2005). A review of intraurban variations in particulate air pollution: Implications for epidemiological research. *Atmospheric Environment* **39**, 6444-6462.
10. Calderón-Garcidueñas, L., Kulesza, R. J., Doty, R. L., D'Angiulli, A., and Torres-Jardón, R. (2015). Megacities air pollution problems: Mexico City Metropolitan Area critical issues on the central nervous system pediatric impact. *Environmental Research* **137**, 157-169.
11. Hu, H., Ha, S., Roth, J., Kearney, G., Talbott, E. O., and Xu, X. (2014). Ambient air pollution and hypertensive disorders of pregnancy: A systematic review and meta-analysis. *Atmospheric Environment* **97**, 336-345.
12. Hyder, A. A., A. A. Ghaffar, D. E. Sugerman, T. I. Masood and L. Ali (2006). "Health and road transport in Pakistan." Public Health **120** (2): 132-141.
13. Mohmand, J., Eqani, S. A. M. A. S., Fasola, M., Alamdar, A., Mustafa, I., Ali, N., Liu, L., Peng, S., and Shen, H. (2015). Human exposure to toxic metals via contaminated dust: Bio-accumulation trends and their potential risk estimation. *Chemosphere* **132**, 142-151.
14. Kamal, A., K. Qamar, M. Gulfraz, M. A. Anwar and R. N. Malik (2015). Chemosphere **120** (0): 59-67.
15. von Schneidemesser, E., Stone, E. A., Quraishi, T. A., Shafer, M. M., and Schauer, J. J. (2010). Toxic metals in the atmosphere in Lahore, Pakistan. *Science of The Total Environment* **408**, 1640-1648.
16. Wahid, A., Maggs, R., Shamsi, S. R. A., Bell, J. N. B., and Ashmore, M. R. (1995). Air pollution and its impacts on wheat yield in the Pakistan Punjab. *Environmental Pollution* **88**, 147-154.
17. Kamal, A., Malik, R. N., Martellini, T., and Cincinelli, A. (2014b). PAH exposure biomarkers are associated with clinico-chemical changes in the brick kiln workers in Pakistan. *Science of The Total Environment* **490**, 521-527.
18. Ortolano, L., Sanchez-Triana, E., Afzal, J., Ali, C. L., and Rebellón, S. A. (2014). Cleaner production in Pakistan's leather and textile sectors. *Journal of Cleaner Production* **68**, 121-129.
19. Shah, F., Gul Kazi, T., Imran Afridi, H., Khan, S., Fatima Kolachi, N., Balal Arain, M., and Ahmed Baig, J. (2011). The influence of environmental exposure on lead concentrations in scalp hair of children in Pakistan. *Ecotoxicology and Environmental Safety* **74**, 727-732.
20. Xu, Y., J. Li, P. Chakraborty, J. H. Syed, R. N. Malik, Y. Wang, C. Tian, C. Luo, G. Zhang and K. C. Jones (2014). "Atmospheric polychlorinated naphthalenes (PCNs) in India and Pakistan." Science of The Total Environment **466–467** (0): 1030-1036.
21. Stone, E., Schauer, J., Quraishi, T. A., & Mahmood, A. (2010). Chemical characterization and source apportionment of fine and coarse particulate matter in Lahore, Pakistan. *Atmospheric Environment, 44*(8), 1062-1070.

22. Pak-EPA, 2007. Ambient Air and Water Quality Investigation in Quetta. http://www.environment.gov.pk/pub-pdf/Ambient%20AW%20Quetta.pdf.
23. Pak EPA/JICA (2001). Three Cities Investigation of Air and Water Quality with analytical comments (Lahore, Rawalpindi and Islamabad). Pakistan Environmental Protection Agency and Japan International Cooperation Agency. Islamabad.
24. EPA, (2006). Pakistan Clean Air programme(PCAP). Islamabad.
25. Ghauri, B., Salam, M., & Mirza, M. I. (1994). An assessment of air quality in Karachi, Pakistan. *Environmental Monitoring and Assessment, 32*(1), 37-45.
26. Smith, D. J. T., Harrison, R. M., Luhana, L., Pio, C. A., Castro, L. M., Tariq, M. N., . . . Quraishi, T. (1996). Concentrations of particulate airborne polycyclic aromatic hydrocarbons and metals collected in Lahore, Pakistan. *Atmospheric Environment, 30* (23), 4031-4040.
27. Hussain, T., Khan, I.-U.-H., & Khan, M. A. (1992). Study of environmental pollutants in and around the city of Lahore, Pakistan. II. Concentrations of cadmium in blood of different groups of people. *Science of The Total Environment, 119*(0), 169-178.
28. Sabiha, J., Tufail, M., & Khalid, S. (2008). Heavy metal pollution from medical waste incineration at Islamabad and Rawalpindi, Pakistan. *Microchemical Journal, 90* (1), 77-81.
29. Shah, M., & Shaheen, N. (2008). Annual and Seasonal Variations of Trace Metals in Atmospheric Suspended Particulate Matter in Islamabad, Pakistan. *Water, Air, and Soil Pollution, 190*(1-4), 13-25.
30. Syed, J. H., Malik, R. N., Liu, D., Xu, Y., Wang, Y., Li, J., Jones, K. C. (2013). Organochlorine pesticides in air and soil and estimated air–soil exchange in Punjab, Pakistan. *Science of The Total Environment, 444* (0), 491-497.
31. Khan, S., Khan, M. A., & Rehman, S. (2011). Lead and Cadmium Contamination of Different Roadside Soils and Plants in Peshawar City, Pakistan. *Pedosphere, 21*(3), 351-357.
32. Waqas, M., Khan, S., Chao, C., Shamshad, I., Qamar, Z., & Khan, K. (2014). Quantification of PAHs and health risk via ingestion of vegetable in Khyber Pakhtunkhwa Province, Pakistan. *Science of The Total Environment, 497–498*(0), 448-458.

33. Kamal, A., Malik, R. N., Martellini, T., and Cincinelli, A. (2014a). Cancer risk evaluation of brick kiln workers exposed to dust bound PAHs in Punjab province (Pakistan). *Science of The Total Environment* **493**, 562-570.

34. Dumka, U. C., Manchanda, R. K., Sinha, P. R., Sreenivasan, S., Moorthy, K. K., & Suresh Babu, S. (2013). Temporal variability and radiative impact of black carbon aerosol over tropical urban station Hyderabad. *Journal of Atmospheric and Solar-Terrestrial Physics, 105–106*(0), 81-90.
35. Alamdar, A., Syed, J. H., Malik, R. N., Katsoyiannis, A., Liu, J., Li, J., Jones, K. C. (2014). Organochlorine pesticides in surface soils from obsolete pesticide dumping ground in Hyderabad City, Pakistan: Contamination levels and their potential for air–soil exchange. *Science of The Total Environment, 470–471*(0), 733-741.

36. Abbasi, N. A., Jaspers, V. L. B., Chaudhry, M. J. I., Ali, S., and Malik, R. N. (2015). Influence of taxa, trophic level, and location on bioaccumulation of toxic metals in bird's feathers: A preliminary biomonitoring study using multiple bird species from Pakistan. *Chemosphere* **120**, 527-537.
37. Jaffery, S. H. I., Khan, M., Ali, L., Khan, H. A., Mufti, R. A., Khan, A., Khan, N., and Jaffery, S. M. (2014). The potential of solar powered transportation and the case for solar powered railway in Pakistan. *Renewable and Sustainable Energy Reviews* **39**, 270-276.
38. Chen, B. H., Hong, C. J., and He, X. Z. (1992). Indoor air pollution and its health effects in China - a review. *Environmental Technology* **13**, 301-312. Assessment, A. Global. "Air Pollution Impacts on Crops and Forests.
39. Ahmad, M. N., P. Büker, S. Khalid, L. Van Den Berg, H. U. Shah, A. Wahid, L. Emberson, S. A. Power and M. Ashmore (2013). "Effects of ozone on crops in north-west Pakistan." Environmental Pollution **174** (0): 244-249.
40. Wahid, A., Maggs, R., Shamsi, S., Bell, J., and Ashmore, M. (1995a). Air pollution and its impacts on wheat yield in the Pakistan Punjab. *Environmental Pollution* **88**, 147-154.
41. Wahid, A., Maggs, R., Shamsi, S., Bell, J., and Ashmore, M. (1995b). Effects of air pollution on rice yield in the Pakistan Punjab. *Environmental Pollution* **90**, 323-329.
42. Janhäll, S. (2015). Review on urban vegetation and particle air pollution – Deposition and dispersion. *Atmospheric Environment* **105**, 130-137.

43. Bell, J. N. B., Power, S. A., Jarraud, N., Agrawal, M., and Davies, C. (2011). The effects of air pollution on urban ecosystems and agriculture. *International Journal of Sustainable Development & World Ecology***18**, 226-235.

44. Agrawal, M., Singh, B., Rajput, M., Marshall, F., and Bell, J. N. B. (2003). Effect of air pollution on peri-urban agriculture: a case study. *Environmental Pollution***126**, 323-329.

45. Wahid, A. (2006a). Influence of atmospheric pollutants on agriculture in developing countries: A case study with three new wheat varieties in Pakistan. *Science of the Total Environment***371**, 304-313.

46. Wahid, A. (2006b). Productivity losses in barley attributable to ambient atmospheric pollutants in Pakistan. *Atmospheric Environment* **40**, 5342-5354.

47. US-EPA, 2015 http://www.epa.gov/criteria-air-pollutants/naaqs-table.

48. Cakmak, S., Dales, R., Kauri, L. M., Mahmud, M., Van Ryswyk, K., Vanos, J., Liu, L., Capes, J. G., Murphy, C. E., Reaves, J. B., Mc Quaid, J. F., Hamilton, J. R.: Secondary Organic Aerosol from Biogenic VOCs Over West Africa during African Monsoon Multidisciplinary Analysis (AMMA), Atmospheric Chemistry and Physics 9, pp. 3841–   3850, 2009.

49. Kim, K.-H., E. Kabir and S. Kabir (2015). "A review on the human health impact of airborne particulate matter." Environment International **74** (0): 136-143.

50. Subhani, M., I. Mustafa, A. Alamdar, I. A. Katsoyiannis, N. Ali, Q. Huang, S. Peng, H. Shen and S. A. M. A. S. Eqani (2015). "Arsenic levels from different land-use settings in Pakistan:Bio-accumulation and estimation of potential human health risk via dust exposure." Ecotoxicology and Environmental Safety**115** (0): 187-194.

51. Kamal, A., K. Qamar, M. Gulfraz, M. A. Anwar and R. N. Malik (2015). Chemosphere **120** (0): 59-67.

52. Xu, Y., J. Li, P. Chakraborty, J. H. Syed, R. N. Malik, Y. Wang, C. Tian, C. Luo, G. Zhang and K. C. Jones (2014). "Atmospheric polychlorinated naphthalenes (PCNs) in India and Pakistan." Science of The Total Environment **466–467** (0): 1030-1036.

53. Wei, G.-L., D.-Q. Li, M.-N. Zhuo, Y.-S. Liao, Z.-Y. Xie, T.-L. Guo, J.-J. Li, S.-Y. Zhang and Z.- Q. Liang (2015). "Organophosphorus flame retardants and plasticizers: Sources, occurrence, toxicity and human exposure." Environmental Pollution **196** (0): 29-46.

54. Guaita R, Pichiule M, Mate T, Linares C, Diaz J. (2011). "Short-term impact of particulate matter (PM2.5) on respiratory mortality in Madrid: Int J Environ Health Res 21:260–74.

55. Fallah Shorshani, M., M. André, C. Bonhomme and C. Seigneur (2015). "Modelling chain for the effect of road traffic on air and water quality: Techniques, current status and future prospects." Environmental Modelling & Software **64** (0): 102-123.

56. Ouyang, W., B. Guo, G. Cai, Q. Li, S. Han, B. Liu and X. Liu (2015). "The washing effect of precipitation on particulate matter and the pollution dynamics of rainwater in downtown Beijing." Science of The Total Environment **505**(0): 306-314.

57. Cahoon, L. B. (2015). 10-Coal Use as a Cause of Water Quality Impairment. Food, Energy, and Water. S. Ahuja. Boston, Elsevier**:** 261-275.

58. De la Torre, F. R., A. Salibián and L. Ferrari (2007). "Assessment of the pollution impact on biomarkers of effect of a freshwater fish." Chemosphere **68** (8): 1582-1590.

59. Vallero, D. (2014). Chapter 14 - Air Pollution's Impact on Ecosystems. *In* "Fundamentals of Air Pollution (Fifth Edition)" (D. Vallero, ed.), pp. 341-368. Academic Press, Boston.