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EFFECTS OF PARTICULATE MATTER ON HUMAN HEALTH, THE ECOSYSTEM, CLIMATE AND MATERIALS: A REVIEW

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Abstract. *Airborne particulate matter has now become an issue in the global environment due to the health problems and environmental degradation it causes. This has necessitated that most developing countries try to set standards for coarse and fine particles due to their noticeable impacts on the environment. This paper is a critical review of how particulate matter in the atmosphere affects visual air quality, human health, soiling and damage to materials, vegetation/animals, soil/water bodies and direct/indirect radiative forcing. The challenge in this paper is to describe the comprehensive effects of this pollutant so as to identify its minimization in the environments with the view of developing its effective control strategies for adequate air quality management.*

Key words: *particulate matter, health, environment, adverse impact, absorption*

1. INTRODUCTION

Anthropogenic aerosol particles have substantially increased the global mean burden of aerosol particles from pre-industrial times to the present day (Lohmann and Feichter, 2004). The process of cleaning, painting and repairing exposed surfaces has become an economic burden. Atmospheric aerosol plays a key role in climate and atmospheric chemistry (Capes *et al*, 2009). Recently, considerable attention has been paid to air quality degradation caused by particulate matter. Many studies have shown that fugitive dust is the major source of the total suspended particulates (TSP) and aerosol particles less than 10μm (PM_{10}) (Chow *et al*, 1992; Watson *et al*, 1994). The ambient air concentration of particulate matter is universally high in developing areas because of higher road dust loading contributed from ongoing construction/industrial activities (Yang *et al.*, 2001). PM_{10} can easily be transported through the upper respiratory tract into the bronchioles and alveoli of the lung, causing direct health hazards. Most recent studies focus their at-

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tentions on finer particulates ($PM_{2.5}$) because of their ability to penetrate deep into the respiratory system. Aerosol particles are likely to have a long residence time in the atmosphere and can undergo dispersion and transport processes. As particulate matter is transported from a source to a potential receptor, the pollutant disperses into the surrounding air causing various effects to the floral/fauna inhabitants and the environment.

Primary aerosols are emitted directly into the atmosphere while Zhang *et al*, (2004) defined secondary ambient aerosols as aerosols that are caused by oxidation of gaseous compounds such as sulphur dioxide (SO_2), oxides of nitrogen (NO_x) and volatile organic compounds (VOCs) that lead to the formation of sulphate (SO_4^{2-}), nitrate (NO_3^-), ozone (O_3) and low volatile organic compounds like peroxyacetyl nitrate (PAN). Secondary organic aerosol (SOA) is also an important component of ambient particulate matter. It frequently comprises a large fraction of the total organic carbon aerosol (OC), often greater than 50% on a carbon mass basis (Kanakidou *et al*, 2005). Particulate matter is characterized with major health effects that include effects on the breathing and respiratory systems, the aggravation of existing respiratory and cardiovascular diseases, the alteration of the body's defense systems against foreign materials, damage to lung tissue, carcinogenesis and premature mortality. These health effects are more noticeable in the elderly and children (Henry and Henke, 2004). Frequently, plant damage is observed on the fruit and on their flowers, either of which significantly lower the value of the crop. Fluorine affects plants at even lower concentrations. The fluorine-contaminated shrubs, trees or grass are subsequently eaten by cattle or other animals (Henry and Heinke, 2004). Halvorsen and Ruby (1982) estimated the costs that are due to damage from atmospheric pollution in most developing countries at billions of dollars.

Health problems and environmental degradation have been attributed to air-borne particulate matter (EPA, 1996b). Particulate matter suspended in the atmosphere plays a major role in the reduction of visibility. Particulates with a diameter less than 10μm (PM_{10}) and particularly of diameter less than 2.5μm ($PM_{2.5}$) are characterized by optimum sizes that scatter light with wavelength in the visible range. This is one of the reasons PM_{10} and $PM_{2.5}$ are acceptable measures of visibility degradations even though they are commonly used for assessing health effects (Pope *et al*. 1995). However, PM_{10}, a specific indicator of anthropogenic fine dust, represents the thoracic fraction of the ambient particles while $PM_{2.5}$ is an alveolar fraction of the ambient particles (ISO, 1995). Meteorological factors like rainfall, ambient temperature and wind speed were reported to affect aerosol emission, transportation, chemical reaction and deposition (Qin and Oduyemi, 2003).

Air quality criteria are observed as a cause-effect relationship observed experimentally and epidemiologically, when human beings, plants and animals are exposed to various ambient levels of specific pollutants. Hence, air quality standards are based upon air quality criteria for specific pollutants. The standards prescribe the pollutant levels that cannot be exceeded during a specific time period in a specific geographic location. Standards for air pollution are concentrations over a given time period that are considered to be acceptable in the light of what is scientifically known about the effects of each pollutant on health and on the environment. They can be used as a benchmark to see if air pollution is getting better or worse.

An exceedence of a standard is a period of time (which is defined in each standard) when the concentration is higher than that set down by the standard (UKNAQA, 2008). The major health effects that are associated with airborne particles include increased

mortality, and the aggravation of existing respiratory/cardiovascular diseases (NZME, 1994). Efforts are underway by developed countries to design a standardized method for measuring PM_{10} and $PM_{2.5}$ so that the exact concentrations of particulate matter will be linked to the human symptoms and effects on vegetation, materials and visibility (Position Paper, 1998). However, the EPA (1996a) reported that there is an urgent need for the standardization of $PM_{2.5}$ measurement techniques in particulate matter measurements due to its relation to human health. Table 1 below shows the various standards and their exceedence in Nigeria, the World Health Organization, South Africa and developed nations (the United States and the United Kingdom).

Table 1. PM_{10} and $PM_{2.5}$ Standards for Various Nations

		Nigeria	WHO ($\mu g/m^3$)	World Bank	USEPA	UKEPA	South Africa
PM_{10}	Annual	–	20	–	–	40	60
	24-Hour	–	50	80	150	50	180
$PM_{2.5}$	Annual	–	10	–	15	25	–
	24-Hour	–	25	–	35	–	–

***** Daily average of daily value for particulate matters in the Federal Ministry of Environment (Nigeria) is 250 $\mu g/m^3$. Source: Sonibare (2009b)

2. Effects on Human Health

Particulate matter has recently become an issue of increasing importance in pollution studies due to its noticeable effects on human health. Various studies on air pollution effects on health have indicated a strong relationship between air pollutant concentrations and observed health effects. There is also strong evidence that fine particles (dp < 2.5 μm) play an important role in the observed health effects (Stern *et al.*, 1984). Coarse particles (2.5 μm < dp < 10 μm) are effectively removed in the upper part of respiratory track while fine particles (dp < 2.5μm) are deposited on the bronchi walls in the bronchi tree (Akeredolu, 1996). Particles smaller than 0.1μm experiences Brownian Motion as a result of which they get collected in the bronchi. However, particles lying between 0.1 -1 μm are too large for Brownian Motion and too small to be trapped in the upper part of the trachea. Hence, they get deposited in the lungs, thus increasing airway resistance (Akeredolu, 2006). Figure 1 shows the respiratory system of a human being showing the extent of the penetration size – fractionated total suspended particulates (dp < 100 μm), coarse particles (2.5 μm <dp <10 μm) and fine particles (dp < 2.5 μm). Particle behavior in the lung is dependent upon the aerodynamic characteristics of particles in flow streams. The aerodynamic properties of particles are related to their size, shape and density. The deposition of particles in different regimes of the respiratory system depends on their sizes. The nasal openings permit very large dust particles to enter the nasal region, along with much finer airborne particulates. Particles in the atmosphere range from less than 0.01 μm to more than 50 μm in diameter (Akeredolu, 1996). Table 2 shows the specific air pollutants including the particulate matter and their associated health effects while Table 3 reports the effects of heavy metal constituents of particulate matter on human health.

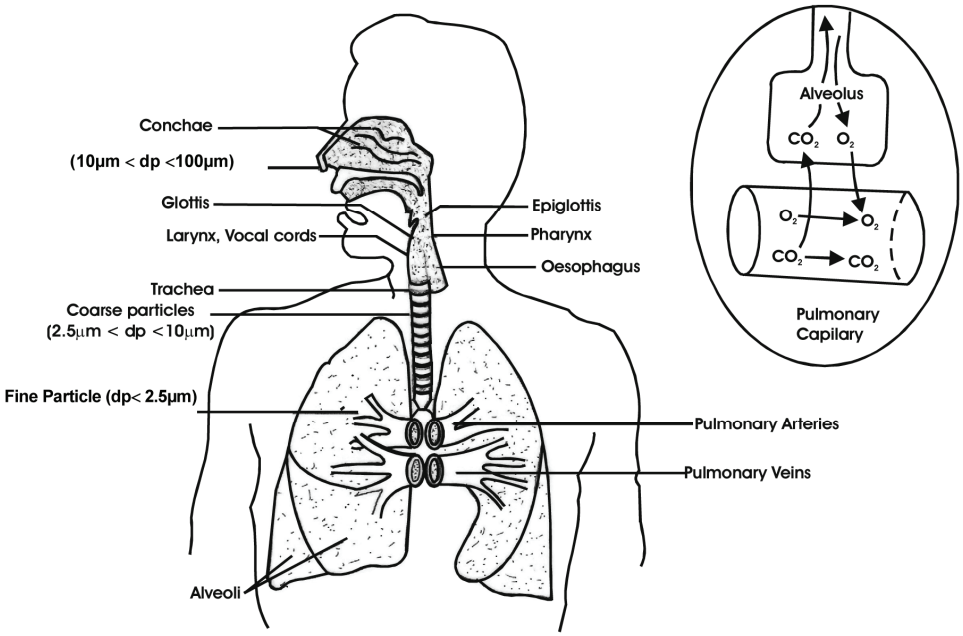

Fig. 1. The respiratory system showing the extent of penetration of particulate matter
Source: Stern *et al.* (1984).

Table 2. Specific air pollutants and associated health effects

Pollutants	Effects
CO	Reduction in the ability of the circulatory system to transport O_2 Impairment of performance on tasks requiring vigilance
	Aggravation of cardiovascular diseases
NO_2	Increased susceptibility to respiratory pathogens
O_3	Decrement in pulmonary function Coughing; chest discomfort Increased asthma attacks
Peroxyacyl nitrates,	Eye irritation
Aldehyde	
SO_2/particulates	Increased prevalence of chronic respiratory disease Increased risk of acute respiratory disease

Source: Stern *et al.* (1984).

Table 3. Effects of heavy metal constituents of particulate matter on human health

Heavy metal	Environmental sources	Minimum risk level	Chronic exposure toxicity effects
Lead	Industrial and vehicular emissions, paints and burning of plastics, paper etc	Blood lead levels below 10 micrograms per deciliter of blood	Impairment of neurological development, Suppression of the hematological system (anemia), kidney failure, immunosuppression etc
Mercury	Electronic and Plastic wastes, pesticides, pharmaceutical and dental waste.	Below 10 microgram per deciliter of blood; oral Rfd 4 mg/kg/day	Gastrointestinal and respiratory tract irritation, renal failure, neurotoxic
Cadmium	Electronic, Plastic, batteries - diet and water.	Below 1 microgram per deciliter of blood	Local irritation of the lungs and gastrointestinal tract, kidney damage and abnormalities of skeletal system.
Arsenic	Herbicides and pesticides, electronics, burning of waste containing the element, contaminated water.	Oral exposure of 0.0003 mg/kg/day	Inflammation of the liver, peripheral nerve damage - neuropathy, cancer of the liver, skin and lungs, irritation of the upper respiratory system- pharyngitis, laryngitis, rhinitis, anemia, cardiovascular diseases.

Source: Kimani (2007)

3. VEGETATION AND ANIMALS

Vegetation reacts with air pollutants over a wide range of pollutant concentrations and environmental conditions (Stern *et al.*, 1984). Air pollutants enter the plant systems through direct and indirect pathways. The outer surfaces of a leaf are covered by a layer of epidermal cells which help in moisture retention. Between the epidermal layers are the mesophyll cells which comprise the spongy and palisade parenchyma. The leaf has a vascular bundle which carries water, minerals and carbohydrate throughout the plant. The stomatas of leaves are controlled by guard cells which can open and close and hence change air spaces in the interior of leaves. Particulate matter enters into leaves through stomata by diffusing into and out of leaves. The indirect pathway occurs through the root system. The deposition of air pollutants on soils and surface water can cause alteration of the nutrient content of the soil in the vicinity of the plant. This changes the soil conditions and hence leads to an indirect effect of air pollutants on vegetation and plants (Levith,

1972) Extensive tissue collapse or necrosis results from injury to the spongy or palisade cells in the interior of the leaves (Heck and Brandt, 1977). Urban vegetation can directly or indirectly affect the local and regional air quality by altering the urban atmospheric environment. Trees affect local air temperature by transpiring water through their leaves, by blocking solar radiation (tree shade) and therefore reducing radiation absorption and heat storage by various anthropogenic surfaces which include buildings and roads.

During dry seasons, trees predominantly reduce local air temperatures by increasing within and below - canopy air temperature due to reduced turbulent exchange with above-canopy air (Heisler *et al.*., 1995). Reduced air temperature due to trees can improve air quality because the emission of many pollutants and/or their precursors is temperature dependent. Decreased air temperature can also reduce ozone (0_3) formation in the atmosphere (Cardelino and Chameides, 1990). Physical mass, water transpiration and thermal/ radiative properties of trees can also affect wind speed, relative humidity, turbulence and surface albedo. The emission of volatile organic compounds (VOC_S) from trees can contribute to the formation of ozone (0_3) and carbon monoxide (CO) (Brasseur and Chatfield, 1991). Since VOC emissions are temperature dependent and trees generally lower air temperatures, increased tree coverage can lower VOC emissions and consequently ozone (0_3) levels in urban areas (Cardelino and Chameides, 1990).

Heavy metals on vegetation and in bodies of water have been found to be toxic to animals and fish (Stern *et al.*, 1984). Gaseous and particulate fluorides have caused injury and damage to a wide range of animals (domestic, wild and fish). Abnormal intake of arsenic results in severe colic (salivation, thirst, vomiting), diarrhea, bloody feces, a garlic-like odor on the breath, cirrhosis of the liver and spleen (Stern *et al.*, 1984). Cattle feeding on herbage containing 25-50 mg/kg lead resulted in the excitable jerking of muscles, frothing of the mouth, the grinding of teeth and paralysis of the larynx muscles. Molybdenum poisoning in cattle often lead to emaciation, diarrhea, anemia, stiffness and fading of hair color. Vegetation containing 280 mg/kg of Molybdenum affects cattle. Mercury in fish has been found in the water of developed countries (the United States and Canada). Mercury in the water is converted into methyl mercury by aquatic vegetation. Small fish consume such vegetation, which in turn are eaten by large fish and eventually by human beings. Food with more than 0.5 ppm of Hg (0.5 mg/kg) cannot be sold in the United States for human consumptions.

4. VISIBILITY REDUCTION

Visibility degradation is one of the most readily perceived impacts of fine particulate matter. Fine particles absorb and scatter light and therefore reduce visibility (Seinfeld and Pandis, 1998). For example, in many parts of the United States, the visual range has been reduced to 70 % from natural conditions. In the eastern part of the US, the current range is 14-24 miles versus a natural visibility of 70 miles. In the western US, the current range is 33-90 miles versus a natural visibility of 140 miles. Fine particles with a diameter between 0.3-1.0 μm make the major contribution to visibility reduction (EPA, 1996b, Trijonis *et al.*, 1991, Eldering *et al.*, 1993, Kerker and Aden, 1991). The most immediate and obvious impact of urban air pollution is its impairment of visibility. Most cities in the world like Lagos are experiencing high levels of visibility degradation due to high emis-

sion intensity and adverse meteorology (Oluwafemi, 1996). This high emission intensity is as a result of fine particles that interact more strongly with visible radiation due to their diameter being similar to that of light wavelengths (Hyde *et al.*, 1983).

Light from a target object passing through a homogenous, uniformly illuminated atmosphere is attenuated according to the Beer- Lambert law as:

$$I = I_o e^{b_{ext} l} \tag{1}$$

I = light intensity at a distance l, from the target (at $l = 0$, $I = I_o$) (Oluwafemi, 1996).

Waggoner *et al.* (1981) and Akeredolu (1996) defined L_v (the distance at which the target object is no longer distinguishable) as:

$$L_v = 3.92 / b_{ext} = \frac{1.2 \times 10^3}{C} \tag{2}$$

L_v is in kilometers, C is the concentration of fine particles in $\mu g/m^3$.

The changes in the appearance of objects in the distance is controlled by the extinction coefficient (b_{ext}) which varies with the wavelength. This alteration includes changes in the colouration of distant objects as well as their contrast. However, the extinction of light from a target object varies from a combination of the absorption and scattering of light by both gases and airborne particles i.e.

$$b_{ext} = b_{sg} + b_{sp} + b_{ag} + b_{ap} \tag{3}$$

Where s, a, g and p refer to as scattering, absorption, gases and particles respectively.

Scattering by gaseous species is usually called Rayleigh Scattering. It is wavelength-dependent ($b_{sg} \propto \lambda^{-4}$) and has a value of $1 \times 10^{-5}\ m^{-1}$ at a wavelength of 550 nm for a particle-free atmosphere at sea level which corresponds with a visual range of $\simeq$ 400 km at this wavelength. The only common polluting gas that absorbs visible light is NO_2; hence, there is a significant contribution to b_{ext} from b_{ag} due to this pollutant.

In most urban atmospheres, visual degradation is largely associated with the presence of aerosol particles. This is because aerosols interact with visible light in a different manner to gases. Hence, aerosol appears bright against a blue sky when an observer is looking towards the sun and dark when the sun is behind the observer. The colour of the haze is due to the combined wavelength dependence to the component of b_{ext}. Hanel (1976) observed that relative humidity has considerable effects on the extinction properties of the aerosol as a result of absorption and water uptake capacities of the various mineral aerosol properties. Generally, fine particles were thought to be considered important in determining b_{sp}. In fact, Roberts *et al.* (1983) found that the value of b_{sp} increased when the coarse particle is excluded in Sydney brown hazes. High volume sampling and analysis for carbon on the filter paper revealed grey to black colouration of the filter paper. This black to grey colouration persists and is unaffected even when the aerosol collected exceeds $500\ ^0C$ which is an indication of the presence of sooty or micrographic carbon (Hyde *et al.*, 1983).

Visual air quality (visibility) is a valuable natural resource in terms of aesthetic value and economic benefits (Brookshire *et al.*, 1978). One of the primary reasons for the persistence of the visibility problem is the lack of methods that can quantitatively show

how different sources contribute to visibility impairment (Ying *et al.*, 2004). Previous studies have shown that secondary particulates that are formed in the atmosphere from the reaction of precursor gases contribute significantly to visibility impairment in polluted areas. The reduction of the visual range and the discolouration of the sky are caused by the scattering and absorption of light due to gases and suspended particles. In a pristine atmosphere, visibility is only limited by light scattering due to gas molecules (Rayleigh scattering), resulting in a visual range of approximately 300 km (Ying *et al.*, 2004). In polluted areas, anthropogenic pollutants significantly reduce the visual range. Past analyses have shown that light scattering associated with sulphate, ammonium ions, nitrate and carbon are the chief sources of visibility impairment (Ying *et al.*, 2004).
Visibility is usually quantified by the visual range, the light extinction coefficient or deciviews. Visual range (L_v) is defined as the greatest distance at which an observer can distinguish an object from its background. Visual range is linked to the light extinction coefficient b_{ext} through the Koschmieder equation:

$$L_v = \frac{K_c}{b_{ext}} = 3.912 \tag{4}$$

K_c is the Koschmieder constant which is equal to 3.912. Ying *et al.* (2004) reported a visual index, deciview (dV) as:

$$dV = 10 \times \ln\left(\frac{b_{ext}}{0.01 km^{-1}}\right) \tag{5}$$

Where 0.01 km^{-1} is the approximate extinction coefficient due to Rayleigh scattering in a pristine atmosphere. The deciview scale is near zero for a near pristine atmosphere and increases as visibility impairment increases.

Also, Ying *et al.* (2004) estimated the aerosol extinction coefficient $b_{a,ext}$ and the aerosol scattering coefficient $b_{a,scat}$ for the dimensionless scattering and extinction coefficients for the homogeneous and core-and-shell configuration, as:

$$b_{a,ext} = \sum_{i=1}^{n}\sum_{j=1}^{m} \pi r_{i,j}^{\ 2} N_{i,j} Q_{b,i,j} \tag{6}$$

$$b_{a,scat} = \sum_{i=1}^{n}\sum_{j=1}^{m} \pi r_{i,j}^{\ 2} N_{i,j} Q_{s,i,j} \tag{7}$$

where i refers to the emissions source for primary particles, j refers to size, n is the number of primary particle source categories, m is the number of particle sizes. N and r are the number concentration and radius of particles respectively. Q_s and Q_e are the dimensionless scattering and extinction coefficients respectively.

5. Soiling and Damage to Materials

An important part of particulate matter pollution is the soiling of man-made surfaces. Hence, the processes of cleaning, painting and repairing exposed surfaces become an

economic burden. Acid particles can severely deteriorate artwork and historic monuments (cultural heritage) and result in the reduction of their aesthetic appearance and life span (Hamilton and Mansfield, 1993; Nazaroff and Cass, 1991). Chemical degradation of materials due to deposition of atmospheric acid particles is an important aspect of material damage (Butlin *et al.*, 1992; Cobourn *et al.*, 1993). Airborne particulate matter are generally of two classes, the fine particulates (Particles <2.5 μm) and coarse particulates (Particles between 2.5 and 10 μm). They differ not only in size but also in source, chemical composition, physical properties and their formation process. These particulate matters tend to soil cities due to surfaces that become dusty so that streets, sidewalks and floors have to be swept or dusted more frequently, and clothing must also be washed more frequently. In addition, the dust which is alkaline, damages painted surfaces such as walls, doors and automobiles.

The soiling of exterior building materials was investigated by Beloin and Haynie (1975) to be dependent on type of paints. For white paints, the soiling was found to be directly proportional to the square root of the particle dose of the particulate matter. Also, Michelson and Tourin (1967) related the frequency of repainting houses to atmospheric particulate concentrations. A linear relationship between repainting frequency and atmospheric particulates was obtained. The cost of repainting associated with loss of cleanliness was found to be proportional to the atmospheric particulate level raised to an exponent.

The degree of soiling damage is influenced by the optical and chemical compositions of airborne particulate matter. Walling (1965) observed that a diesel particulate is about 3.5 times blacker than the average urban particulate. Hence, diesel smoke tends to stick to surfaces more than average particulates. He compared the reflectance of diesel soot with known reflectance of average urban particulates. He concluded that only 1/3 to 1/4 of the mass of diesel soot compared with urban particulates was required to achieve a stain of equivalent darkness. Hence, diesel soot is expected to have a greater affinity to surfaces than generated atmospheric particulates. The liquid components of diesel particulates allow it to adhere to a surface more readily than dry average particulates. Diesel soot has a greater propensity to smear and is more difficult to remove than dry particulates due to its liquid components. The soluble organic fraction (SOF) of diesel soot from light-duty engines was reported by Kageyama and Kinehara (1982) to vary from 10 to 80 percent by mass, depending on engine operating conditions.

Soiling is an optical effect which is essentially the darkening of reflectance that results from the deposition of airborne particulate matter to external building surfaces. DETR (1999) summarized the factors that affect the degree of soiling as: the blackness per unit mass of smoke, the particle size distribution, the chemical nature of the particles, substrate-particle inter-facial binding, surface orientation and the micro-meteorological conditions. Similarly, different types of particulate emission have different soiling characteristics. Newby *et al.* (1991) and Mansfield *et al.* (1991) reported that diesel emissions have a much higher degree of soiling relative to petrol or domestic coal emissions. This is due to higher particulate elemental carbon (PEC) content as reported by QUARG (1993). PECs have a high optical absorption coefficient. Hence, a PEC particle landing on a surface is more likely to adhere than other particulate matter.

5.1. Dose-response functions for soiling damages from particulates

Building soiling damages were estimated by Rabl *et al.* (1998) as the sum of the repair cost and amenity loss. He quantified amenity loss to be equal to cleaning cost for a zero discount rate. Thus, the total damage costs are twice the cleaning cost. The annual soiling damage was calculated from the relation:

$$S_i = a * Pi * \Delta PM \tag{8}$$

Where ($a = b * 2$)
S_i = Annual soiling damage at receptor location i.
P_i = Number of people in location i.
ΔPM = Change in annual average Particulate matter (PM) ($\mu g/m^3$)
a = Total cost per person per year to avoid soiling damage of 1 ($\mu g/m^3$) particles ($).
b = Cleaning cost per person per year from a concentration of 1 ($\mu g/m^3$) of PM ($).

From this calculation, the estimated soiling costs for PM_{10} using the dose-response approach for the years 1998 and 2010 baseline were estimated by Watkiss *et al.* (2001) to be £336.6 million/year and £176.7 million/year respectively. This implies an estimated reduction in damages from building soiling over the period from 1998 to 2010 of £159.8 million/year as in Table 4.

Table 4. Estimated benefits to materials from reductions in PM10

Date	Total Damage (£ Million)	Total Annual Benefit (£ Million) relative to the 2010 Baseline
1998	336.6	
2010	176.7	159.9*

*Change in benefit between 1998 and 2010.

The impact of particulate matter depends on the location and the population under consideration. For instance, a certain amount of particulate matter released upon a dense region like Lagos would be expected to result in far greater human health damage than if released in Ile-Ife. Banzhaf *et al.* (1996) use a contingent valuation to estimate unit damage cost for particulate matter. Frankhauser (1994) and Banzhaf *et al.* (1996) summarized the damage cost per ton (in $) of particulate matter, other criteria air pollutants and green house gases as shown in Table 5.

Table 5. Damage cost per ton (in $) of pollutants

Pollutants	Types of Pollutant	Damage Cost per ton (in $)	Source
CO_2	GHG	6.22	Frankhauser (1994)
CO_2	Criteria	0.99	Banzhaf *et al.*(1996)
Pb	Criteria	1,719.00	Banzhaf *et al.*(1996)
CH_4	GHG	129.00	Frankhauser (1994)
NO_X	Criteria	54.00	Banzhaf *et al.*(1996)
N_2O	GHG	1,075.14	Frankhauser (1994)
PM_{10}	Criteria	2,297.00	Banzhaf *et al.*(1996)
SO_X	Criteria	73.50	Banzhaf *et al.*(1996)

Portney and Weyant (1999) reported that an appropriate discount rate should be applied in environmental costs. Weitzman (2001) observed that the discount rate for the damage cost decreases over time as shown in Table 6.

Table 6. Sliding scale of discount rates

Period	Range in Years		
	From	To	Discount Rate
Immediate Future	1	5	4%
Near Future	6	25	3%
Medium Future	26	75	2%

The discount rates are used to determine discount factors. The discount factor is the present value of 1 $ received at a stated future date. The discount factor is calculated from the relation:

$$Discount\ Factor = \frac{1}{(1+r)^n} \tag{9}$$

r = is the discounted rate
n = is the number of years that the cash flow is being discounted.

6. RADIATIVE FORCING

Particulate matter influences the climate directly (through scattering and absorption of the solar radiation) and indirectly through the formation of cloud condensation nuclei (CCN). The direct aerosol contribution to radiative forcing is due to sulphate aerosols, fossil fuel soot and biomass burning (Penner *et al.*, 1993; 1994; Robock, 1991 and Hansen and Lacis, 1990). The radiative forcing due to sulphate aerosols is estimated to be -0.4 Wm^{-2} with a factor of two uncertainties. The effect of soot aerosols is +0.1 Wm^{-2} with a factor of three uncertainties and the contribution from biomass burning is estimated to be -0.2 Wm^{-2} with a factor of three uncertainties. Therefore, the total direct forcing is estimated to be -0.5 Wm^{-2} with a factor of three uncertainties.

Climate forcing is defined as the change imposed by certain forcing agents which include greenhouse gases and aerosol particles in the energy balance of the earth (in units of Wm^{-2}) that eventually alters global temperature (Haywood and Boucher (2000) and IPCC (2001)). However, the definition is only useful under the assumption that a general relationship exists between global mean forcing and the global mean equilibrium surface temperature response that is similar for all the different types of forcing.

Aerosol can interact both directly with solar radiation and terrestrially re-emitted infrared radiation, and indirectly alter the planetary albedo by modifying the properties of clouds. The first of these mechanisms is known as the "direct radiative forcing effect" of particles (Charlson *et al.*, 1992), whereas the latter is referred to as the "indirect radiative forcing effect" of particles (Twomey, 1991). Size distribution, the complex refractive index (chemical composition and state of mixing), solubility and change in size with relative humidity influence the magnitude of these effects.

6.1. Direct radiative forcing of tropospheric aerosols

Chylek and Wong (1995) and Haywood and Shine (1995) presented the expression that can be used to estimate the globally-and annually-averaged top-of-atmosphere forcing (ΔF) caused by an aerosol layer as:

$$\Delta F = -\frac{1}{2} F_o T^2 [1 - A_c][W_o \beta (1 - R_s)^2 - 2(1 - W_o) R_s]\tau \qquad (10)$$

Where F_o is the solar constant (F_o = 1360 Wm^{-2})

The associated factor of 1/2 reflecting the fact that any point on the globe is illuminated by sunlight only one-half of the time over the cause of the year.
F is the transmissivity of the atmosphere above the aerosol layer.
A_c is the fractional cloud cover.
W_o is the single scattering albedo.
β is the aerosol hemispheric up-scattering fraction i.e. the fraction of the incident light redirected back to space.
R_s is the surface albedo.
τ is the aerosol layer optical thickness.

The single scattering albedo, W_o is one of the most critical parameters in determining the sign and magnitude of the forcing. W_o is defined as the ratio of the aerosol scattering over the sum of scattering and absorption. Horvath (1998) identified aerosols in the accumulation mode as being the most important in terms of radiative forcing because they are the most efficient at scattering and absorbing solar radiation and they have the longest atmospheric lifetime. The shape of the aerosol particles which vary from one type of particle to another is also significant in computing aerosol forcing (Mishchenko *et al.*, 1997; Pilinis and Li, 1998).

6.1.1 Scattering of light due to aerosol particles

The scattering of light is defined as the redistribution of the incident light in non-parallel directions, at the same wavelength as the incident beam. The scattering of light by accumulation mode particles (particles whose diameters are of the order as the wavelength of the incident light) falls predominantly into the region of Mie scattering while that of the smallest parts of the accumulation mode falls into Rayleigh scattering. Mie scattering which is more pronounced in the forward direction is characterized by a certain fraction of up-scattered light that is reflected back into space (i.e. does not reach the earth's surface). Therefore, scattering due to aerosol particles produces a negative forcing (cooling effect). At greater solar zenith angles, a larger fraction of the forward scattered light does not reach the earth, thus contributing to a portion of light that is up-scattered. Light scattering of aerosol particles can be due to a large variety of aerosol types, among which carbonaceous and sulphate-containing particles of natural and anthropogenic origins are usually considered to be the most efficient.

6.1.2 Absorption of light due to aerosol particles

Absorption of light by air-borne particles involves a conversion of incident light into thermal energy, thus, producing a warming (positive forcing) of the aerosol and sur-

rounding air parcel. This leads to a decrease in the amount of light reaching the earth's surface, and subsequently leads to a cooling effect on the surface. However, aerosol particles emitted from anthropogenic sources absorb more and are usually concentrated in the lower troposphere, producing an overall warming of the earth's system (Andreae, 2001 and Jacobson, 2001). Absorbing aerosols may also reduce heat convection and contribute to cloud re-evaporation (Ackerman *et al.*, 2000). A layer of absorbing aerosol particles above the ocean may also reduce evaporation and disturb the whole hydrological cycle (Ramanathan *et al.*, 2001). Most studies identified that the absorption of light due to aerosol particles is caused by its elemental carbon constituent. However, recent studies revealed that aerosol particles released from biomass burning contain a large amount of polymeric organic compounds (Mayol-Bracero *et al.*, 2002; Zappoli *et al.*, 1999).

6.2. Indirect radiative forcing of the aerosols

The change in aerosol chemical composition and number concentrations which subsequently alter the microphysics, radiative properties and lifetime of clouds because aerosol particles serve as cloud condensation nuclei, is referred to as the indirect radiative forcing of aerosols. This indirect effect of the aerosols can be divided into the first and second indirect effects.

The first indirect effect is a result of an increase in CCN number concentration. For a given liquid water content, an increase in the CCN number due to pollution and burning leads to an increased amount of smaller droplets since the available water has to be shared between a greater numbers of droplet nuclei (Twomey, 1991). These smaller aerosols scatter more in the backward direction than larger aerosols causing a cloud albedo effect which subsequently results in a net cooling effect. The second indirect effect is a result of increased rainfall suppression and an increased cloud lifetime due to increased CCN concentration which prevent droplets from reaching a threshold radius of 14 μm (Albrecht, 1989). In order to produce rain, cloud droplets need to overcome a threshold radius of 14 μm. This second indirect effect was recognized by Haywood and Boucher (2000) and IPCC (2001) to be a major agent of climate change.

7. ACIDIFICATION – EUTROPHICATION

Acidic deposition is the combined total of wet and dry depositions, with wet acidic deposition being commonly referred to as acid rain (Stern *et al.*, 1984). The pH of rainwater is acidic due to the presence of sulphuric acid (H_2S0_4), nitric acid ($HN0_3$) and carbonic acid (H_2CO_3) dissolved or formed in the droplets. Dry deposition occurs when pollutants ($S0_2$, $N0_2$, $HN0_3$, particulate matter and acidic aerosols) are deposited when they contact and stick to the surface of bodies of water, vegetation, soil and other materials. If the surfaces are moist or liquid, the gases go directly into the solution; the acids formed are identical to those that fall in the form of acid rain. $S0_2$ and $N0_2$ can undergo oxidation forming acids in the liquid surfaces if oxidizers are present. The main cause of surface water acidification is deposition of an anthropogenic surplus, although nitrogen compounds contribute significantly in some areas (NEGTAP, 2001). Acid deposition is not limited to the acidity contained in precipitation. The acid gases $S0_2$ and $N0_2$ may also be deposited onto terrestrial surfaces by dry deposition (NEGTAP, 2001).

Pollutants emitted into the atmosphere such as SO_2, NO_x and CO_2 are oxidized to sulphate, nitrate and carbonate through gaseous and aqueous phase reactions. These particle species are removed by both wet and dry deposition to the earth's surface leading to effects such as acidification and eutrophication. The deposition of sulphate and nitrate particles is dependent on their size that is controlled by the aerosol dynamic process in the atmosphere. Eutrophication is becoming a serious threat to coastal environments and could become a global problem in the next decades. Water enriched with nutrients leads to higher production of organic matter and results in oxygen deficiency which kills marine life (Pelley, 1998), (Spengler *et al.*, 1989), (EMEP-WMO, 1997).

8. Control of Particulate Matter in the Atmosphere

Gross damage estimates are the first step that provides information on the benefits of pollution abatement to policy-makers. These involve the cost of medical expenses and low productivity as a result of health effects, the yield and growth effects on plants and animals, the material loss due to damage to materials and psychological costs that are suffered as a result of deteriorating air environment. Investigations on comprehensive studies of particulate matter effects should be undertaken. This review is one. Information on close-response and damage-function studies will assist the better estimation of the benefits of abatement techniques. Research should also be expanded in the area of different methods that can be utilized in the awareness of the social cost of particulate matter pollution. Policy formulation in the form of legislation will also assist in particulate matter pollution resulted from bush burning, discharge of particulate matter from industries through chimney heights and other refined methods of treating air waste.

9. Conclusion

Airborne particulate matter is characterized by diverse effects on human health, the ecosystem, climate and materials. These effects have been comprehensively reviewed in this paper together with their associated environmental impacts. The long range transport of this particulate matter within countries and between countries has raised awareness of researche that is aimed at reducing their effects in the last 2 decades. The estimates of economic costs of particulate matter pollution on human health and material degradation will help in the accurate assessment of economic damages resulting from particulate matter. Various control measures that could minimize the effects of the particulate matter have been identified.

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PREGLED UTICAJA ČESTICA NA LJUDSKO ZDRAVLJE, EKOSISTEM, KLIMU I MATERIJALE

L. A. Jimoda

Čestice koje se prenose vazduhom su u današnje vreme postale važna tema u diskusijama o globalnom ekosistemu s obzirom na broj zdravstvenih problema i negativan uticaj na okruženje. Ova činjenica zahteva da najrazvijenije zemlje sveta pokušaju da postave standard za grube i fine čestice zbog njihovog uočljivog uticaja na okruženje. Ovaj rad daje kritički pregled toga kako čestice u atmosferi utiču na kvalitet vazduha, ljudsko zdravlje, kako štete raznim materijalima, vegetaciji i životinjskom svetu, tlu i vodi i kako je moguća apsorpcija upadnih čestica na direktan i indirektan način. Izazov u ovom radu bio je da se opiše sveobuhvatni uticaji ovog zagađivača kako bi se odredila mogućnost njegove minimizacije u okruženju sa ciljem razvijanja efikasnih strategija za kontrolu adekvatnog kvaliteta vazduha.

Ključne reči: *čestice, zdravlje, okruženje, štetan uticaj, apsorpcija*