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Review

Dust Sources and Impact: A Review

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Abstract: Dust from coal and rocks takes more life than the obvious accidents recorded in the mining and construction industry do. Among all proven fossil fuel reserves, coal accounts for 94%, whereas oil and natural gas account for 6% only. With the constant population growth, urbanization, industrialization, and the current technology age, the demand for power would continue to surge, thus coal use would remain inevitable and so would Coal Workers' Pneumoconiosis (CWP) persist. Also, with the high demand for rocks and their related products, coupled with polishing and tilling from the construction and real estate developers silicosis would be a setback that needs to be looked at more keenly. Research has identified specific factors such as duration of dust exposure, coal rank, stages of CWP, and types of work and coal mining categories, to be significantly associated with the high risk for CWP. Arid and semi-arid regions are the main global dust sources, where particles can be lifted into the atmosphere, transported, and deposited far away from their sources. The Sahara and the Sahel regions of Africa, Arabian Peninsula, Gobi Desert, Inner Mongolia Plateau, Alxa Plateau, Hexi Corridor, Tarim Basin, Taklimakan Desert, and the edge of deserts are the main sources of fugitive dust. The coordinates 351-541N and 731-1351E located in Northern China is the second largest source of atmospheric dust in the world. Dust particles influence the cloud formation processes, optical properties, precipitation rates by behaving as cloud condensation nuclei with the altered chemical properties affecting climate through modified direct radioactive forcing properties and therefore, indirectly influence the global atmospheric radiation budget. Conversely, atmospheric mineral dust rich in especially Phosphorus (P) and Iron (Fe) is transported from the Bodélé Depression in Chad to the deficient Amazon rainforest and contributes considerably to the fertilization of its soils.

Keywards: Dust, Pneumoconiosis, Silicosis, Meningitis belt, Bodélé Depression

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Introduction

Dust is a generic term that describes the suspension of fine particles of solid matter in a gas, or a deposit of such particles[1]. Dust particles transported in suspension in the Earth's atmosphere come from various sources such as soil lifted by wind (an aeolian process), volcanic eruptions, and pollution, and are mostly smaller than 100 μm[2]. Grains larger than about 20 μm settle back onto the surface quite quickly when the turbulence associated with strong winds decreases, but smaller and finer particles can remain in suspension for days or even weeks unless washed out by rain[3].

Dust is one of the main causes of hazards in the mining process in coal mines. It can lead to coal dust explosions and CWP. At the same time, it causes huge casualties and property losses[4].

Arid and semi-arid regions are the main global dust sources, where particles can be lifted into the atmosphere, transported, and deposited far away from their sources[5]. Dust events are closely related to human activities and climate change. The removal of the vegetation covers due to human activities such as tilling the soil, quarrying and, sand winning generates massive dust when the wind blows, and the impact depends solely on the velocity of the wind. The magnitude of the impact depends on the amount and the physical and chemical properties of atmospheric dust that are largely controlled by dust sources[6].

Most dust source activities take place along the so-called dust belt, which include the World's most remote areas in the Sahara, the Middle East, Central Asia, and China[7], where the population density is low and so is the observational data availability[8].

Airborne pollutants may generate the occurrence of health hazards, as well as damage to things and works. As far as humans are concerned, dust pollutants may cause or contribute to an increase in mortality or serious illness or may pose a present or potential hazard to human health[9]. Hazardous dust compositions can escape to the environment by accident, but several air pollutants are released from industrial facilities and other activities and may cause adverse effects on human health and the environment[9].

Air pollution in coal mines is mainly due to fugitive emissions of particulate matter and gases including methane, and oxides of nitrogen, among others. Mining operations have generated a substantial quantity of airborne respirable dust, which has led to the development of respiratory diseases in mine workers. Fugitive dust on longwalls has always been an issue of concern for production, safety, and the health of workers in the underground coal mining industry globally, especially in Australia, China, the US, and other major coal producing countries[10]. Many open cast mines have been excavated for the production of coal. From a safety point of view, open cast mining is preferred over underground mining. However, the air pollution due to surface mining and mineral processing, with their salient feature can pose a threat to the environmental quality[11] and the health of mine workers as well as that of the people residing near the mines[12].

All arid regions of the earth are susceptible to dust generation, but large basins of interior drainage (endorheic basins) dominated by lacustrine sediments have been identified as particularly important dust sources[13].

CWP is a preventable but difficultly curable occupational lung disease[14]. In China, the sum of deaths caused by mine accidents was less than 1500 in 2012, but the number of people who died due to pneumoconiosis was more than 1800[4]. Currently, water sprays are widely employed for dust prevention and suppression in the mining process in coal mines, but dust suppression efficiency is too low to meet the actual demand[15-17].

For silicosis, on the other hand, epidemiological and experimental studies have implicated silica not only as causing chronic inflammatory lung diseases, but also as a potential carcinogen, and the International Agency for Research on Cancer concluded that there was sufficient evidence in humans and experimental animals for the carcinogenicity of silica in the forms of quartz and cristobalite[18].

Therefore, understanding the physical and chemical properties of coal and silica is very imperative to solving and better preventing, controlling, and managing the affairs of mines to amply protect and isolate mine workers from these carcinogenic hazards.

1.1. Physical and Chemical Properties of Coal

Although coal is mainly carbon, coal mine dust contains hydrogen, oxygen, nitrogen, trace metals, inorganic minerals, and crystalline silica. **Table 1** presents examples of the trace elements, common minerals, and elemental contaminants that exist in coal and some of their characteristic effects. The rank of coal increases from peat to lignite, sub-bituminous to bituminous, and anthracite. As the coal rank increases, the proportion of carbon to other chemicals and mineral contaminants increases. In general, anthracite coal mining has been associated with higher rates of pneumoconiosis than that found in bituminous miners[19, 20]. Anthracite coal mine dust contains more surface free radicals than bituminous coal, which may explain its higher cytotoxicity and pathogenicity[21-23]. In addition, anthracite has a higher crystalline silica content than bituminous coal[24]. However, experimental evidence suggests that silica particles from bituminous mines may be coated with clay, rendering them less active[24]. Respirable coal mine dust has a relatively large surface area due to its small aerodynamic size and porous nature. Organic aromatic compounds present in the coal atmosphere, such as benzene, methylene, phenol, and phenanthrene can be adsorbed onto the surface of coal mine dust and may affect its biological activity[25].

Table 1 Constituent of coal, examples and their characteristic effects[25]

Some coal constituents	Examples	Characteristic Effect
Trace elements	Boron, cadmium, copper, nickel, iron, antimony, lead, and zinc.	Cytotoxic and carcinogenic
Common mineral	Kaolin, mica, pyrite, silica	Carcinogenic, fibrinogenic, and cytotoxic
Elemental contaminant	Titanium, calcite, sulphur, sodium, magnesium	

1.2. Physical and Chemical Properties of Silica

The Earth's crust is made up of about 28% silicon and many other minerals and metals. Silica can exist in either a crystalline or amorphous form[25]. **Table 2** presents the two main forms of silica and their properties. Crystalline silica is very toxic but there are uncertainties and controversies about whether or not amorphous silica is toxic. Some schools of thought classify it as non-toxic, while others say its toxicity is negligible.

Table 2 Forms of silica and their properties

Silica form	Examples	Properties
Crystalline (polymorphs)	Quartz Tridymite Cristobalite Coesite Stishovite	All the crystalline (SiO_2) forms are fibrogenic and biologically toxic. Orderly lattice structure: all the crystalline forms are arranged as tetrahedral crystals except stishovite which has an octahedral structure. Biologic reactivity decreases in the order quartz > tridymite > cristobalite > coesite > stishovite [25, 26]
Amorphous	Natural and synthetic	Less fibrogenic Randomized structure [25, 26]

The surface of silica becomes hydrated to form silanol groups (-SiOH) in the presence of water. This surface SiOH confers the high reactivity of crystalline silica to biological membranes. Research enabled the postulation of theories concerning the reactivity and toxicity of silica[25].

The first theory postulated was that; the -SiOH groups are hydrogen donors, while most biologic macromolecules contain lone-pair electrons on oxygen or nitrogen that serve as hydrogen acceptors. The formation of hydrogen bonds would result in strong interaction between silica and biologic membranes, resulting in possible damage[25].

The second theory postulated was that; silica has a negatively charged surface and at neutral pH (7.0), 1 in 30 -SiOH groups becomes negatively charged ($-SiO^-$). The negatively charged silica particles then react vigorously with scavenger receptors on alveolar macrophages thereby activating the generation of reactive oxygen species and inflammatory cytokines[27, 28].

The third theory postulated was that; cleavage of the silica crystal, as would occur in silica flour milling, rock drilling, and sandblasting, results in the generation of $Si^{\cdot}$ and $SiO^{\cdot}$ radicals on the fracture planes, which can induce oxidant damage[27, 29, 30].

2. Sources and Classification of Dust

2.1. Sources of Dust

Dust emanates from various sources due to climatic factors, and industrial and mining activities. Dust can also be generated from anthropogenic sources. Seasonal changes as well as ocean and desert winds influence some dust sources. Loose soils, unpaved roads, and haul roads are the basic and common ones so far as dust sources are concerned.

2.1.1. Opencast Mines and Coal as a Fossil Fuel

Opencast and mineral processing, with their salient feature, can pose a threat to environmental quality[11]. Spontaneous combustion of coal contributes enormously to the production of dust particulates.

In urban areas, significant quantities of anthropogenic particulates are released from fossil fuel combustion in domestic heating systems, industries, and vehicles[31]. Dust pollution in cold region surface mines, its prevention, and control was conducted by Wang et al.,[32] and found that the dust concentration in the pit exceeds the national regulatory limit of 50 μg/m for PM_{10} and 35 μg/m for $PM_{2.5}$. According to the air quality index, PM_{10} was the primary pollutant at the bottom of the pit where coal mining was occurring. The order of the factors influencing dust concentration was as follows: coal production > boundary layer height > wind speed > temperature difference > temperature > humidity. Kim et al.,[33] studied the anthropogenic contribution of magnetic particulates in urban roadside dust using a total of 1353 roadside dust samples collected from Seoul, Korea for 13 months. By using Thermomagnetic data and Intensive Electron Microscopy they identified a predominance of carbon-bearing iron-oxides, indicating that anthropogenic particulates mostly originated from fossil fuel combustions.

Direct emissions from stacks, chimneys, tailpipes, and fossil fuels also result in fugitive dust from mining and extraction activities as well as disposal of non-combustible ash and pollution control residues that remain after combustion[34].

2.1.2. Desert

Natural deserts and semi-arid lands are evident to be the principal supplier of atmospheric dust[35]. They cover approximately 33% of the world's land area, having inhomogeneous geographical distribution and distinct features[36]. Overland, patches of large-radius aerosols appear over deserts and arid regions, most prominently, the Sahara Desert in North Africa and the Arabian Peninsula, where dust storms are common. Fig. 1 shows (a) a dust storm over Libya; (b) a thick dust plume over Kuwait and the north-western tip of the Persian Gulf; (c) a pale brown plume of dust sweeping out of Argentina's Pampas; and (d) dry, windy weather sending clouds of dust across south-eastern Australia.

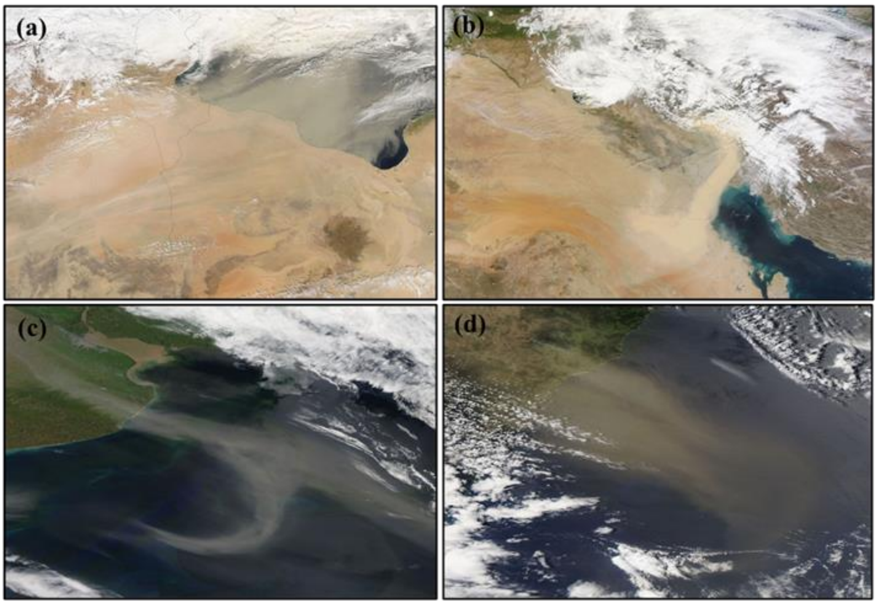

Fig. 1 (a) Dust storm over Libya (b) thick dust plume over Kuwait and the north-western tip of the Persian Gulf (c) pale brown plume of dust sweeping out of Argentina's Pampas and (d) Dry, windy weather sending clouds of dust across south-eastern Australia (Source:[37])

China

Arid and semi-arid regions in China are the main source of dust storm incidence in central Asia[38]. There are two schools of thought concerning the origin of the dust storm in China. One group believes that the dust storms originate from the deserts and Gobi[39] while the other researchers suggest that the dust storms come from degraded grasslands, farming lands, and the outer edge of the deserts[6, 35].

The coordinates 351-541N and 731-1351E located in Northern China are the second largest source of atmospheric dust in the world. In winter and spring every year strong winds from the Northern China region lift and transport a considerable large amount of dust fraction eastward for thousands of kilometers across the Pacific and beyond to the west coast of the United States, affecting the large geographical region[35].

Over the past three decades, dust storms with high frequencies were recorded in the main deserts and the Gobi deserts in Northern China except for the newest Hulun Buir Desert on the east edge of the Inner-Mongolia Plateau. The most severe dust storms were recorded in the west part of the Inner Mongolia Plateau, Alxa Plateau, Hexi Corridor[38, 40], and the Tarim Basin[41, 42]. In the Taklimakan Desert, dust storms are experienced mainly in spring and summer[38]. Apart from the volcanic, cosmic, industrial, and other man-made dust sources[43], other researchers argue that Gobi alluvial and lacustrine sediments and wadies developed at the outer edge of deserts[44].

By analyzing ground-surface and dust samples, Derbyshire et al.[45] and Sun et al.[39] reported that piedmont alluvial fans and Gobi are the main dust storm sources in China.

Africa

It has been estimated that 55% of the global dust emissions originate from the North African Desert[46]. The Sahara and the Sahel are the world's largest dust source regions, emitting several hundred tera-grams of mineral dust yearly[47]. The World's most important dust sources are located in the Sahara with the most active dust source originating from the Bodélé depression in Chad (Fig. 2), which is considered to produce half of the mineral aerosols emitted from the Sahara[48]. Similarly, Ginoux et al.,[46] also described the Aïr Massif in Niger as shown in Fig. 2 as a dust hot spot in the Sahara. Schepanski et al.[49] explained that active dust sources in the Sahara move in rugged and complex terrain around the mountain ranges of the Saharan Desert. Fig. 2 shows the location and the dust hot spot in North Africa and outlines the main meteorological factors (West African Monsoon and Harmattan winds) affecting the area.

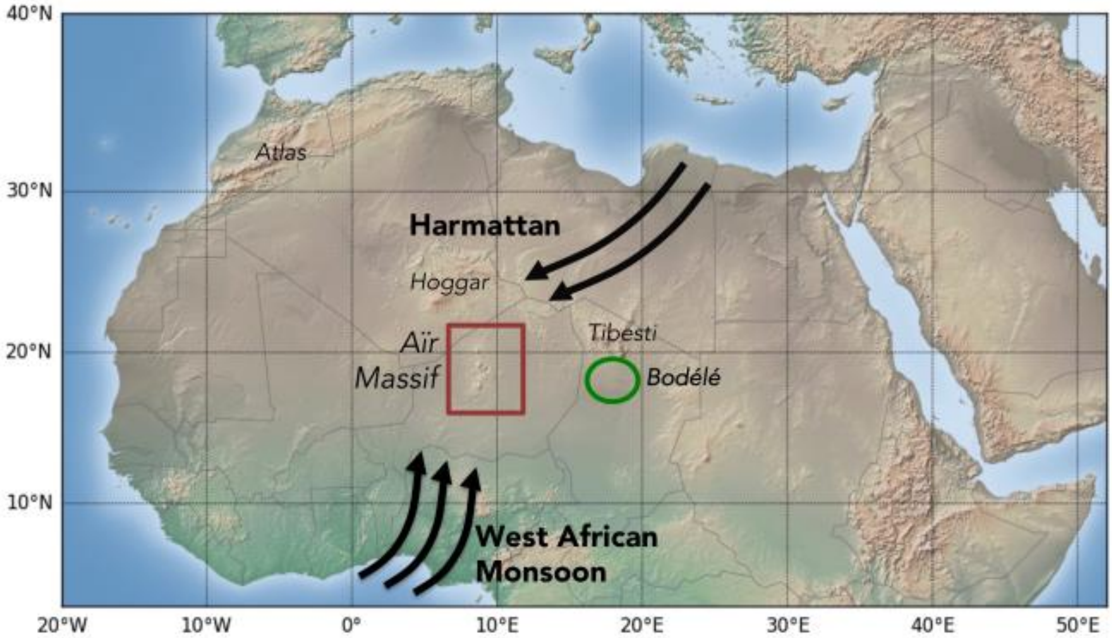

Fig. 2 The Bodélé Depression, and the main Saharan mountain ranges, as well as the location of the West African Monsoon and Harmattan winds

Most of the dust from the Sahel and Sahara is carried over large distances and transported west and southwest across the Atlantic Ocean[50]. During the boreal summer, dust is transported by the trade winds from northern Africa towards the Caribbean Sea, whereas during winter it takes a more southerly route towards the Amazon Basin[47].

2.1.3. Soil

Dust aerosols originate as soil particles lofted into the atmosphere by wind erosion. The soil is most susceptible to erosion in dry regions, where particles are only loosely bound to the surface by the low soil moisture[51].

Dust originating in the Sahara and Sahel is regularly noticed to cross the Atlantic[52], with the largest export occurring during years of low rainfall in the source regions[53].

Asian dust particles are mainly minerals derived from the soil and chemically modified by NO_x and SO_x from the industrialized region of China by mixing with the dust during long-range transport[54].

Approximately half of the present atmospheric dust is estimated to be anthropogenic in origin [55], due to soil degradation by agriculture, overgrazing, galamsey (illegal mining), sand winning, and deforestation to mention but a few. Charlson et al.[56] reported that model calculations reflect that 50 ± 20% of total atmospheric dust mass originates from disturbed soils such as those affected by cultivation, deforestation, erosion, and frequent shifts in vegetation due to droughts and rains.

2.1.4. Roads

Fugitive dust normally emanating from dust from vehicle traffic systems such as unpaved/shoulder roads, railways, and airports (runways), as well as dilapidated, disused, and disturbed lands such as mines and construction and industrial sites, have significant impacts on safety, health, quality of life, and the cost of maintenance[57]. Shearing forces created at the interface between the surface and vehicle tires produce dust on unpaved surfaces as a result of turbulence created by moving vehicles[58]. Excessive dust generation from unpaved mine haul roads is a problem common to most surface mining operations and especially so in semi-arid and arid areas[59].

Fig. 3 shows examples of dust created by tracks on haul roads and dust created on unpaved roads.

Fig. 3 Left: Example of haul road dust from mine haul tracks, Middle: Light fleet vehicle in the red outline showing the degree of obstruction from dusty haul rods and Right: Dust from an unpaved road

2.1.5. Sea Salt

The presence of the chemical concentrations of the common elements in ice from the interior of Greenland and Antarctica can be explained in terms of simple relations among sea salts and terrestrial dust. Murozumi et al.,[60] revealed that the amounts of pollutant lead, sea salts, and silicate dust in snows are more concentrated in winter than in summer snows, while silicate dust are more concentrated in spring than in winter snows.

2.1.6. River and Other Water Bodies

A study conducted by Schepanski et al.,[49] suggests that 31% of the global dust is emitted from hydrological sources such as ephemeral water bodies. And for North Africa, this number rises to 92% of total dust emission being derived from hydrologic sources. An airborne campaign reported by Schepanski et al.,[61] focusing on dust emission in Mauritania determined dry river valleys as the sources of mineral dust.

Dust storms caused by degenerated ecological environments were found in the western Inner Mongolia Plateau. The account of Wang et al.,[62] from the 1950s to 2000s explained that many natural lakes and rivers dried, and wadis and dried lakebeds increased by about 500 km^2 in the western Inner Mongolia Plateau region which in turn caused dust devils[62].

2.2. Classification of Dust

Dust is classified as fine, dry particulate matter and can be made up of pollen, minerals, soil, and many other particulates found in the local environment. The parameters that play an important role in eliciting health effects are size, shape, density mass/number, and composition of particles[9].

Dust can be classified into various groups and sub-groups by taking into account its general physical and chemical characteristics. **Table 3** presents some of the categories under which dust can be grouped for classification.

Table 3 Classification of dust[63]

Classification	Characteristics
Dust property[64]	Inorganic dust: minerals, metals, anthropogenic (e.g., human-produced fossil fuel), Soil
	Organic dust: vegetation (e.g., immature/mature peat organic matter), Animals, Anthropogenic (e.g., from lightening triggered fires) Natural Sea salt
	Compound dust: salts e.g.,
Size[65]	Macroscopic: > 10 μm
	Microscopic dust: >0.25 μm and < 10 μm (e.g., PM_{10})
	Super microscopic dust: < 0.25 μm (e.g., $PM_{2.5}$)
Ingredient	Coal source (e.g., PM), Cement, Asbestos, Rock,
Explosive Dust[66]	Coal dust and grain dust
Toxic Dust	Carcinogenic ability e.g., from coal and silica dust

Hazardous Dust[67]	Occupational health related diseases (e.g., Pneumoconiosis, Silicosis, Fibrosis), Deformation of the human body, and Genetic mutation and variation.
	The explosion of coal mines may release PM and other toxic fumes.
	Impairs workplace visibility resulting in incidents and accidents.
Mine Dust	Size: coarse dust, fine dust, ultra-fine dust

3. Impact of Coal Dust

Hazardous chemicals escape into the environment by several natural and/or anthropogenic activities and may cause adverse effects on human health and the environment[9]. Air pollution caused by dust generation has both acute and chronic effects on human health, affecting several different systems and organs.

Comprehensive quantification of the overall dust burden and impact on a regional scale is necessary if climate and climatic change predictions are to be upgraded[35].

3.1. Health Impact

The health impact caused by dust ranges from minor upper respiratory irritation to chronic respiratory and cardiovascular disease, lung cancer, acute respiratory infections in children and chronic bronchitis in adults, aggravating pre-existing heart and lung disease, or asthmatic attacks. Furthermore, short and long-term exposures have also been linked with premature mortality and reduced life expectancy[9].

Meningitis

Meningitis (the inflammation of the protective membranes covering the brain and spinal cord, generally referred to as meninges) is a severe acute infectious disease caused by several microorganisms, including viruses, bacteria, parasites, and fungi[68]. Even though many causes of meningitis exist, the epidemic form of the disease is caused by the bacterium *Neisseria Meningitidis*[69]. Humans who serve as intermediate host (carriers) transmit these bacteria through contaminated fresh respiratory droplets or throat secretions.

Epidemics of meningococcal meningitis are concentrated in sub-Saharan Africa during the dry season, a period when the region is affected by the Harmattan, a dry and dusty north-easterly trade wind blowing from the Sahara into the Gulf of Guinea[69]. The Epidemics and seasonal upsurges of the endemic disease occur in the latter part of the dry season after the onset of the Harmattan, a ground-level stream of dry and dusty desert air, which is part of the African continental trade wind system that sweeps south-westward between the end of November and the middle of March, and usually subside at the onset of the rains[69]. Cheesbrough et al.[70] and Dukić et al.[71] explained that, environmental factors including humidity, high temperatures, and dusty atmospheric conditions play a key role in the seasonality of epidemic meningitis as well as location. Thomson et al.[72] and Yaka et al.[73] also proposed that climatic factors play an important role in both spatial distribution and the year-to-year changes in the occurrence of meningitis to a large extent. But, Palmgren[74] reported that due to the absence of in vivo studies the correlation between climate and dust on the pathogenesis and transmission of *Neisseria Meningitidis* is unknown. Subsequent researches conducted by Cuevas et al.[75] explained that the optimal climate for transmission of the disease is the savannah climate south of the Sahel, with an annual precipitation index of 300-1,100 mm, extremely dry but warm winter seasons, and relatively abrupt onset of the rainy season. Lapeyssonnie[76] a French physician described a geographically well-defined area in Sub-Saharan Africa with an exceptionally high incidence of meningococcal meningitis as the meningitis belt. **Fig. 4** depicts the classical meningitis belt in Sub-Saharan Africa with other countries that are at epidemic risk in Africa.

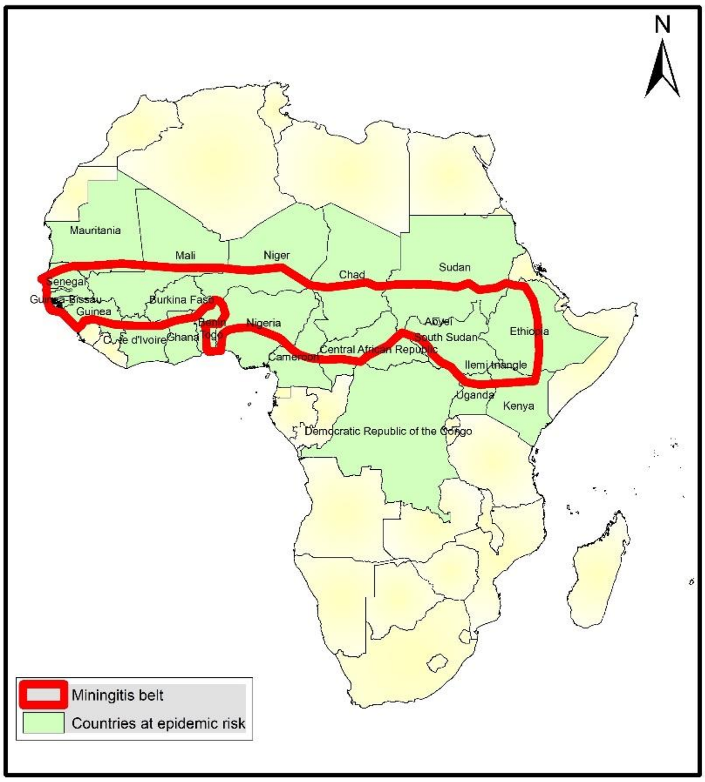

Fig. 4 Classical meningitis belt in Africa represented by the red outlined region within the yellow highlighted area, and with the yellow highlighted area representing countries at epidemic risk red outlined (Source: Modified from[77])

Meningitis is a global disease recorded in most countries of the world. To further explore the association of the environment with the epidemics, it is desirable to identify geographical areas outside Africa that share the environmental features of the meningitis belt[75]. The incidence of the disease is however lower in countries outside the meningitis belt. In Europe it ranges between 0.2 and 14 cases per 100,000 and 0.2-4 per 100,000 in USA[78]. In most countries, the disease is endemic with small outbreaks, mainly in crowded settings like schools and military establishments. Infrequently epidemics of serogroup A meningitis have been recorded outside Africa, for example, in China[79], Nepal[80], India[81], and Moscow[82].

3.1.1. Impact of Particulate Matter (PM)

PM or, more appropriately, the atmospheric aerosol is currently a subject of extensive research. PM is a complex atmospheric heterogeneous mixture of inorganic and organic particles differing in size, origin, and chemical composition that exist in either the solid or liquid state[83]. Among all air pollutants, fine particulate matter $PM_{2.5}$ is the most harmful pollutant concerning human health and may induce a sequence of diseases[84, 85]. It has been estimated that nearly 80% of premature deaths resulted from air pollution attributed to exposure to $PM_{2.5}$ pollution[86]. Exposure to high levels of PM can generate various human health problems, such as respiratory diseases[87] and cardiovascular diseases[88]. PM can cause atmospheric visibility impairment by scattering and absorbing light[89]. It can also influence climate directly by scattering and absorbing solar radiation and indirectly by modifying clouds' microphysical properties of albedo and lifetime[90].

Fine PM may also contain condensates of volatile organic compounds, volatilized metals, and products of incomplete combustion. The PM emitted from coal combustion is composed of three constituents as presented in **Table 4**.

Table 4 Constituents of PM emitted from coal combustion

Content	Characteristics
1. Unburnt coal	*Produced from the incomplete combustion of coal, the mass fraction of which can exceed 90% of the total PM, can drop to less than 1% under good combustion conditions. The unburnt carbon, also termed soot, consists of grape- or chain-like agglomerates of primary carbon-enriched particles, which are in the chemical form of polycyclic aromatic hydrocarbons (PAH), existing as a potential carcinogen and mutagen to humans[91] due to their polarity[92, 93].
2. Inherent mineral matter	*Particle size less than 10.0 Am, may escape the burning char, and transfer into PM without phase change[92].
3. Volatile matter	*Most of the heavy metals within coal initially vaporize in the flame zone; the resultant metallic vapor then undergoes homogeneous nucleation to form an ultrafine aerosol having a size of 10 to 30 nm. In the post-flame, the combustion gases cool rapidly, the condensed aerosol grows continuously by heterogeneous coagulation; the resultant agglomerates have a mean size of about 1.0 to 2.0 Am[94].

3.1.2. Coal Workers' Pneumoconiosis (CWP)

CWP commonly referred to as "black lung disease," are nodular interstitial lung diseases which are caused by long-term inhalation of coal dust[14], and in severe cases may lead to progressive massive fibrosis[95]. Over time, continued exposure to the coal dust causes restrictive impairment, scarring in the lungs, and impaired ability to breathe. It may be acute (cause death within months) or chronic (cause death after many years), depending on the extent and severity. CWP an occupational lung disease is most common among coal miners.

In countries where coal is mined, exported as a commodity, and employed as part of the main resource for energy generation, CWP is considered a public health problem due to its irreversibility, and high cost of diagnosis and management since the disease is incurable.

Coal is a combustible, carbonaceous, sedimentary rock composed mostly of carbon and hydrogen[96]. The coal forms with greater combustion capacity have the highest tendency of causing CWP, due to having the most surface free radicals[25]. Coal mine dust is a complex and heterogeneous mixture containing more than 50 different elements in and around the coal seam that include carbon, quartz, silicates (such as kaolinite and mica)[97], and other trace elements such as boron, cadmium, nickel, iron, antimony, lead, and zinc, among others[98].

Initially, CWP was thought to be a variant of silicosis due to their similarities in chest radiographs and coal dust was considered innocuous[14].

Mo et al.[14] after conducting a research survey using meta-analysis identified specific factors such as duration of dust exposure, coal rank, stages of CWP, types of work, and coal-mining categories, which were significantly associated with the high risk for CWP.

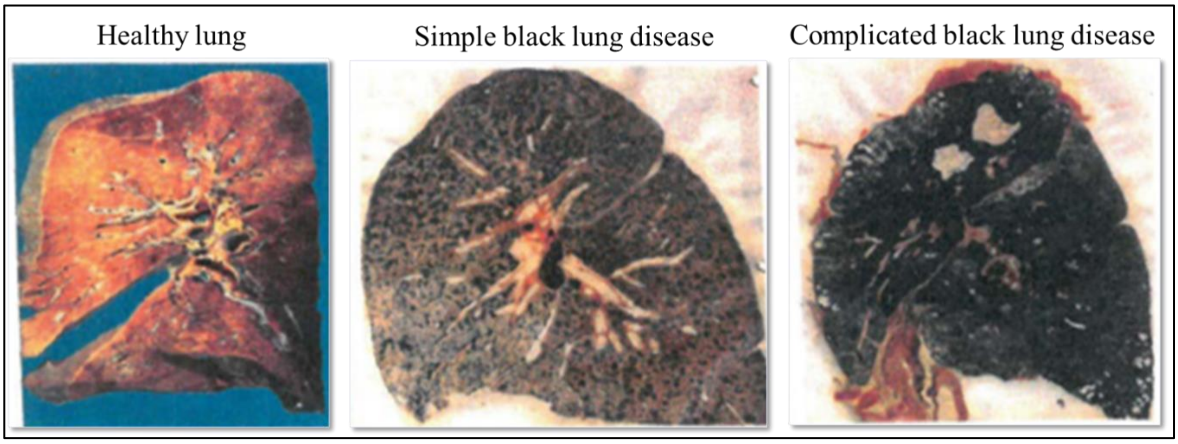

Fig. 5 Healthy lung, simple black lung disease, and complicated black lung disease (Source: Modified from[99])

Fig. 5 shows a healthy lung, a simple black lung disease, and a complicated lung disease. In the most complicated form of the black lung disease, the volume of the lungs shrinks and causes damage to adjacent lung tissue making breathing difficult anddecreasing gas exchange[99]. Complicated black lung disease can develop within 5 years with massive fibrosis in underground miners.

3.1.3. Silicosis

Silicosis is an interstitial lung disease caused by inhalation of crystalline silica (a common mineral found in many types of rock and soil). Over time, exposure to silica particles causes permanent lung scarring, called pulmonary fibrosis. Silicosis is characterized by fibrosis, which causes the thickening of alveolar walls and hypoxia of pulmonary capillary blood. Silicosis can result if mine workers are exposed to crystalline silica. Freshly broken silica is more toxic than aged silica likely because of extensive free radical generation[99].

It has been established that the coal mine dust inhaled by miners contains coal and silica-based rock dust. The coal mine dust that produces elevated toxicity to the lungs possesses a high concentration of silica dust demonstrated to be at least twenty-fold more toxic than coal dust to human lungs[99].

The use of advanced and highly efficient mining equipment elevates the production of both coal and silica dust because there is less specificity in mining narrow coal seams. Drilling into a typical quartz-containing rock surrounding coal seams (e.g., driving tunnels to the seam and drilling the roof to bolt supports to rock above to prevent collapse) long has been recognized to cause silicosis[97].

Fig. 6 depicts the comparison between three tissues to draw inference from the devastating damage that crystalline silica renders to the lung of miners even at age 40. The image showing the progressive massive fibrosis is indicative of excessive exposure to silica dust from mining.

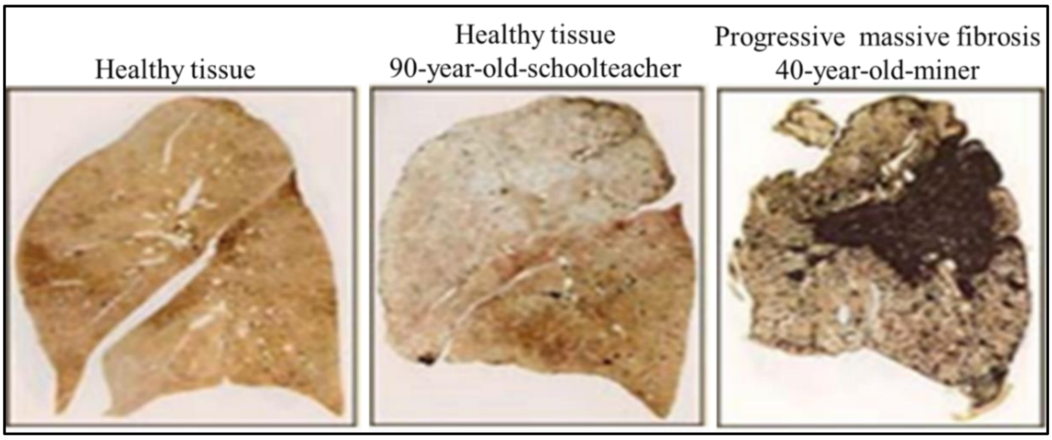

Fig. 6 Healthy tissue, Healthy tissue of 90-year-old schoolteacher and Progressive massive fibrosis of 40-year-old-miner (Source: Modified from United Mine Workers of America's website)

Acute Silicosis

Acute silicosis may involve a variety of different mechanisms of injury when compared to chronic silicosis. In lungs affected by acute silicosis, electron microscopy reveals hypertrophic type II pneumocytes lining the alveoli which may produce excessive amounts of proteinaceous material and surfactant protein making the alveoli infiltrated with protein-containing material[100]. Excessive free-radical formation leads to silicotic lung disease in the acute setting. Freshly fractured silica may contain higher proportions of free radicals than intact silica due to the abundance of cleaved particle surfaces where reactive oxygen species such as peroxides and hydroperoxides tend to form[101], and thus may generate a stronger inflammatory response[102, 103], altered activated transcription factors leading to cell and/or DNA damage[104]. Acute silicosis has been historically associated with sandblasting and rock drilling due to the production of freshly fractured silica particles[105].

Chronic Silicosis

Chronic silicosis is the most common form of silicosis and is characterized by the development of distinct, discrete, nodular, whorled lesions in the lung which are hyalinized and frequently contain silica inclusions[106]. These lesions are present more in the upper lobes, and the pleura may be thickened and contain candle-wax lesions[107]. The pulmonary silicotic lesions are usually manifested within 10 or more years of exposure to dust containing 18-30% of crystalline silica.

3.2. Mining

Miners breathing air from either surface or underground mines over an extended number of years can develop acute, chronic, and massive lung inflammatory diseases where breathing becomes difficult[37, 108]. Apart from the health-related impact mentioned in **3.1** (i.e., **3.1.1., 3.1.2. and 3.1.3.**) and the fact that dust of all kinds especially coal dust and silica influence the environment and climate and reduce the life expectancy rate, investment and profit become an important area.

Mine dust affects the budget of both surface and underground mines. This is because managers of mines spend huge sums of money to procure advanced equipment to reduce dust generation and emission. Similarly, dust control formulations both in the form of sprays or barriers are purchased to mitigate the emission. Health related risk management of mine staff is fundamentally an area where a mine's budget allocation is directed.

3.3. Environment (Climate Change)

Dust particles or aerosols indirectly influence the global atmospheric radiation budget and so changes in the atmospheric aerosol load as a result of natural causes or human activities would contribute to climate change[55]. Dust particles influence the cloud formation processes, optical properties as well as precipitation rates by behaving as cloud condensation nuclei[109]. Apart from clouds impacting the Earth's radiation budget, clouds are an essential part of the global water cycle[49].

The altered chemical properties of Asian dust particles can also affect climate change through modified direct radiative forcing properties[110]. Given the significance of radiative forcing associated with soil dust coupled with its large anthropogenic component, the impact of dust on both global and regional climate is of great interest[51]. Although long considered to be of marginal importance to global climate change, tropospheric aerosol contributes substantially to radiative forcing, and anthropogenic sulphate aerosol in particular has imposed a major perturbation to this forcing. Both the direct scattering of short-wavelength solar radiation and the modification of the shortwave reflective properties of clouds by sulphate aerosol particles increase planetary albedo, thereby exerting a cooling influence on the planet[56].

3.4. Fertilization of the Amazon Rainforest

The Amazon rainforest covers a vast area of 5500000 km^2 (between approximately 50°W and 80°W longitude and 5°N and 17°S latitude)[111] and represents about half of the planet's remaining rainforest and an ecosystem that plays a crucial role in regulating the Earth's climate[112]. Atmospheric mineral dust plays an important role both in the climate system[113] and in the maintenance of ecosystems through the biogeochemical interactions of macro and micronutrients that fertilize the oceans and continents[114-123]. Prospero and Carlson[124] suggested that a considerable amount of dust discovered in the Central Amazon Basin is of Saharan origin and is transported across the Atlantic under steady state conditions in the 850 to 700 mb layer. Several research works have reported that the Bodélé Depression in Chad has been identified as the single biggest source of atmospheric mineral dust on earth and contributes considerably to fertilizing the Amazon rainforest through nutrient exportation[112, 123, 125]. The mineral dust contains micronutrients such as Fe and P that have the potential to act as a fertilizer, increasing primary productivity in the Amazon rain forest as well as the equatorial Atlantic Ocean, and thus leading to N_2 fixation and CO_2 drawdown[125]. Phosphorus (P) is the principal fertility factor influencing tree growth across the Amazon Basin. However, 90% of soils in the Amazon Basin are P deficient[112]. It has been suggested that the long-term productivity of the Amazon rainforest depends highly on the atmospheric deposition of dust that may come from a distant ecosystem such as the Saharan desert with P which may be referred to as the out-of-basin P. This out-of-basin P input is comparable to the hydrological loss of P from the basin, suggesting an important role of African dust in preventing P depletion on timescales of decades to centuries[112]. Some authors claim that an association between Saharan dust dispersion and the development of the rainforest exists based on remote sensing evidence, which is a modern view[111], and suggests that, that the Bodélé may be a more significant micronutrient supplier than previously proposed.

The dust from the Bodélé Depression aggregate from eroded, friable low-density sediments from lake bed deposits, shoreline sediments (with beach ridges and a delta), fluvial and Aeolian sediments[126]. These sediments accumulate on the bed of palaeolake Megachad (**Fig. 7**), are primarily authigenic, having been formed within the lake, and are not the product of previous cycles of weathering, erosion, transport, and deposition as has been implied in some reports[7, 127].

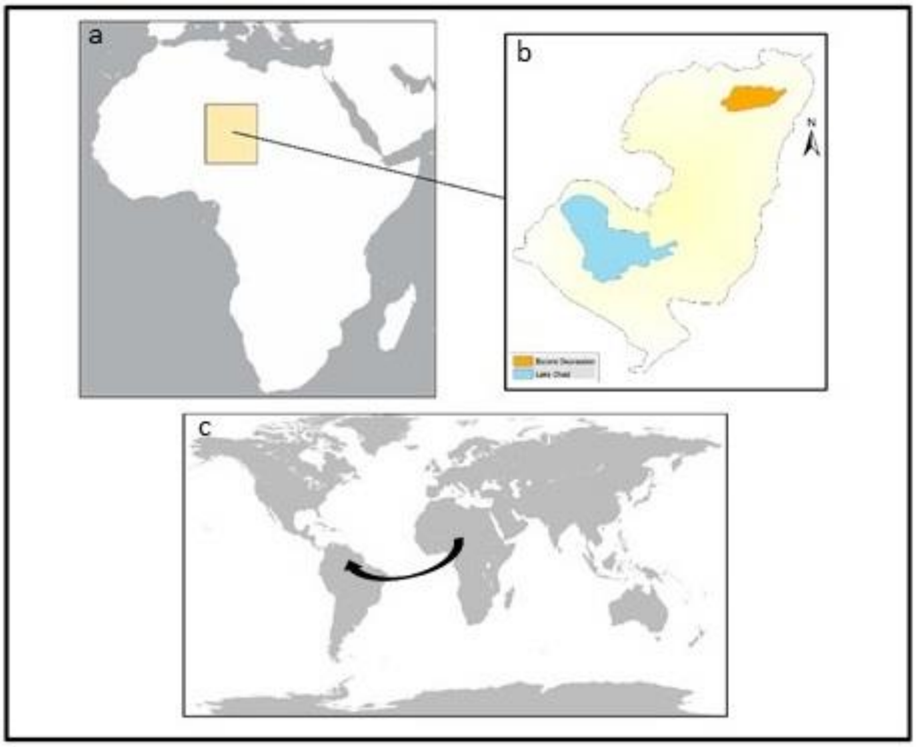

Fig. 7 (a) Map of Africa with inset box (b) showing the extent of palaeolake Megachad, Lake Chad, and the Bodélé Depression, (c) path of dust from Chad across the Atlantic to South America during the winter months modified from[128]

5. Conclusions and Recommendations

Among all proven fossil fuel reserves, coal accounts for 94%, whereas oil and natural gas account for 6% only[129]. For this reason, the use of coal remains inevitable, thus the safety of miners must be the topmost priority for all mining industries. The incidence of CWP and silicosis have increased in industrial operations due to the mechanization and use of sand blasting, drilling, pulverizing, cutting, grinding tools, and other pneumatic equipment[104].

Aerosol effects must be taken into account in evaluating anthropogenic influences on past, current, and projected future climate as well as in formulating policy regarding controls on the emission of greenhouse gases and PM. Resolution of such policy issues requires integrated research on the magnitude and geographical distribution of aerosol climate forcing and the controlling chemical and physical processes[130].

The regulatory agencies in China and other countries that generate productive dust, especially from coal and silica need to step up their effort in implementing more rigorous policies to protect coal miners, especially those in locally owned mines. The information should be very useful to occupation regulatory agencies in designing appropriate policies to reduce this highly preventable disease among coal workers[14]. Also, a well thought policy must be made to limit the number of years frontline coal mining workers are engaged by seeking advice from experts in the health sector.

Apart from coal dust emanating from mines, storage, or during transport, most of the fugitive dust originate from unpaved roads, arid and semi-arid regions, the desert (Sahara and the Sahel), the sea, rivers, and other water bodies, among others.

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