Chapter

An Analysis of Remote Sensing Data to Evaluate the Problem of Atmospheric Aerosol Pollution in Africa

Gerard Rushingabigwi, Celestin Twizere, Philibert Nsengiyumva, Jean De Dieu Ntawangaheza and Liguo Sun

Abstract

The particulate matter (PM) directly endangers the human health. Remotely sensed tiny atmospheric particles, aerosols, are presented in this research as atmospheric air pollutants. Globally overviewed for the first instances, and then a focus put on Africa and Asia, the selected aerosols are fine particulates ($PM_{2.5}$), black carbon (BC), and Sulfate (SO_4). According to the existing literature, the motivation to research on air pollutants came from the fact that the polluted air globally kills many people, by attacking cardiovascular system. The online accessible remote sensing's data has been mostly collected from the second version of modern era retrospective analysis for research and applications (MERRA-2), a model selected for its update as well as the fact that its data are directly assimilated from the most renown remote sensors: Moderate resolution Imaging Spectroradiometer (MODIS) and the advanced very high-resolution radiometer (AVHRR). MERRA-2 also compiles data from different aerosol robotic networks (AERONETs). With a vast region of interest, and considering the big temporal resolution, reduced spatio-temporal resolutions facilitated the focused research. Goddard interactive online visualization and analysis infrastructure (GIOVANNI) bridged our research objectives with the data; Geographical Information Systems (Arc GIS) is a main software tool. Map-based as well as time series results for $PM_{2.5}$ and other atmospheric air pollutants are presented; health dangers associated with the dust from erstwhile research highlighted. Finding that the annually-averaged mass concentration of the dust's PM2.5 is significantly greater than the mean recommended concentration, 25 $\mu g/m^3$, in all the seasons of the center of the research region of interest (Africa), this research recommends further research on dust aerosols mitigation strategies, during the seasons of heaviest air pollutants in particular.

Keywords: Africa, aerosols health effects, atmospheric air pollutants, dust's particulate matter

1. Introduction

1.1 Understanding aerosols and their sources

Aerosols, sometimes referred to as the dust clouds, if not the airborne tiny particles, are hazardously toxic to health: human, animals and plants, especially if uncontrolled.

The dust storm (dust and sand carried away by the wind from the very dry grounds) has too many effects. For example, anthropogenic dust storm, as illustrated in **Figure 1**, directly pollutes the breathable air, food and water. If the storm is naturally caused by the desert's dust, it causes the drought [1].

As presented in **Figure 1(a)**, most of sub-Saharan inhabitants unavoidably live with anthropogenic aerosols; the most remarkable are the dust and smoke aerosols, and sometimes do not worry about the associated dangers. **Figure 1(b)** shows the smoke of the accidentally burnt house, its equipment and furniture. Hazards caused by the smoke from biomass burning's fire, volcanic eruptions, home and industrial chimneys, road vehicles exhausts, etc., is very dangerous to both health and climate uncertainties, and that's where most constituents of the fine particulate matter ($PM_{2.5}$) come from.

In **Figure 2**, the primary sources of particulate matter as aerosols are deserts, erupting volcanoes and of course some human (anthropogenic) activities, it's a matter of the dust and many other aerosol particles that are windblown over either the sea, ocean or earth surface. The aerosol particles such as Soot, fly ash, black carbon (BC) and smoke are primarily produced during different combustion activities.

The secondary sources can otherwise be generically referred to as atmospheric chemistry source where gas-phase species can chemically transform before they condense, and they are technically referred to as aerosol precursor gases [2].

Aerosol science, however, is a sub-branch of physics or physical-chemistry which, until 1980s, has been so neglected that most people did not worry about aerosols dangers to the human breathing and blood circulation. The industrial revolution in the 19th century brought high-speed machinery; dust exposure increased dramatically, for instance dust from mines, which caused more cases of lung diseases. Thus, since then onwards, it's a very hot research topic to study the physicochemical properties of aerosol: how to sample (clustering), to control and avoid them. For instance, aerosols can play a role of polluting gases removal from the atmosphere, either by absorbing them on existing ones or launching new particles. The study of aerosols, however, is not easy because airborne particles behave very differently than the air in which they are suspended and also behave very differently among themselves depending on their sizes, shape and composition [3].

The atmosphere is such a complex dynamic natural system that sustaining life on earth is very essential as the atmospheric air interacts with water and land. Acidic rain is a result of air pollution. Therefore, it's very important for an air quality engineer to understand water pollution: air normally contains water vapor (varying from one to four per cent at surface), dust pollen, sea spray, volcanic ash and various industrial pollutants [3, 4].

1.2 Significance: direct and indirect aerosols effects on health

The aerosols transported by wind over a long distance directly pollute the quality of breathable air. For instance, the windblown dust from deserts entrains particulates which are hazardous to human health [5–7]. Particularly, the diseases such as pneumonia are attributed to that type of aerosol [8, 9].

(a)

(b)

Figure 1.
Anthropogenic Aerosols (a) dust storm in the inhabited village's road (source: Original photos taken on the road under construction in June 2020); (b) smoke due to the burning (source: Original photo of the building that was accidentally burnt on 06 September, 2020).

It has been ascertained that the dust endangers the respiratory, cardiovascular and nervous systems [10].

Referring to Pope et al., as cited by Dianat et al. ([11], p. 5155), "the prolonged health exposure to $PM_{2.5}$ was most strongly associated with mortality attributable to cardiac dysrhythmias, ischemic heart diseases, cardiac arrest, and heart failure."

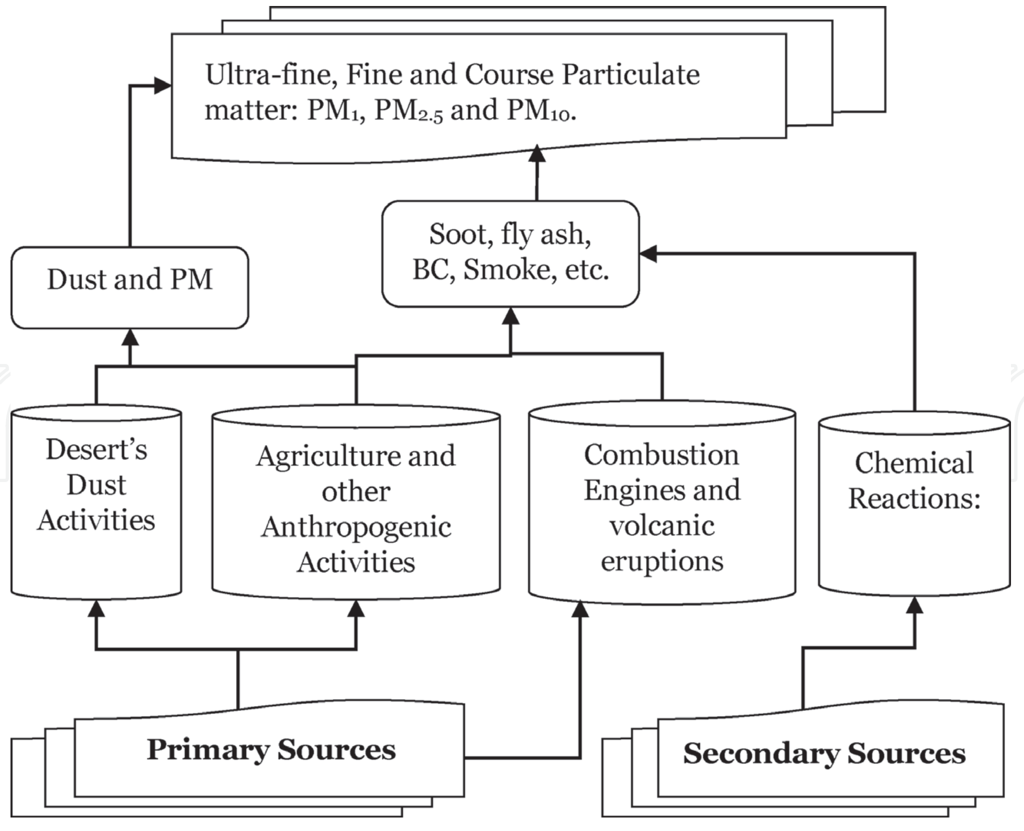


Figure 2.
Primary and secondary sources of particulate matter (PM).

Besides, an aerosol is collectively known as solid, gaseous or/and liquid particles suspended in the atmosphere, except all the hydrometeors which include the cloud droplets, ice crystals, raindrops, snowflakes, and the alike particles [12]; smoke is the famously known gaseous aerosol. Therefore, apart from the direct health effects (learned from erstwhile works in the same research field), the aerosol in general can also change the clouds properties: thus, they indirectly affect the lives on earth in causing drought, acidic rain, etc.

A research question: "how can results from the remote sensing data analysis instruct the community about the tropospheric aerosols hazards?"

1.3 Objectives

Africa and Asia are the global source of the Desert's Dust Aerosols; therefore, the main target is to continue the research works which will alert the world and inhabitants about the updates in aerosols which can endanger the earth.

Considering the formation, correlation, health effects; assessing the on-site (in situ) versus remote sensing data collection, the in-field collected data is reliable for research related with physical, biological, and social sciences. However, studying aerosols and air pollution by targeting very big areas, remote sensing data is better than in situ data [13].

The research objectives are:

- to limit the scope of research on the troposphere of African and Asian continents in different scenarios, and to study the air quality based on selected measurements under aerosols such as sulfates (SO_4), black carbon (BC), and the fine particulate matter ($PM_{2.5}$).

- to track the long-term emission of the selected remote sensing measurements over different seasons and sub-temporal resolutions in the years 1980–2020;

- to discuss the inherent health hazards that link the existing research works with findings of this research.

2. The research trends in aerosols as air pollutants

Particulate matter (PM), a type of aerosol, is a complex mixture of molecules differing in chemical composition, shape and size; PM can come from natural sources such as the wind erosion of rocks and soil, sea sprays, volcanic dust, etc. PM also come from anthropogenic sources, noting the fossil fuels combustion, industrial processes, and traffic emission [12, 14, 15].

Airborne particles can change their size and composition by condensation of vapor species or by evaporation, by coagulation with other particles, by chemical reaction, or by activation in the presence of water super-saturation to become fog and cloud droplets. Particulates are eventually removed from the atmosphere by two mechanisms: deposition at the Earth's surface (dry deposition) and incorporation into cloud droplets (wet deposition) during the precipitation in the form of rain [16].

2.1 Dust, particulate matter, black carbon

Dust, particulate matter (PM) and Black Carbon aerosols have the common characteristics, especially when it comes to polluting the atmospheric breathable air.

The heavy contribution of the deserts' dust to the global airborne particulates as well as numerous other effects of dust aerosol are very well documentable [17–19]; the effects become very dangerous to human health when the dust is characterized to the PM size [19].

The smoke as a gaseous aerosol broadly links with ecosystem, to mean the living organisms and non-living entities like atmospheric air as well as cloud and climate.

The literature reiterates that the global air polluting particles come from both the discipline of aerosols and atmospheric chemistry; in this research, the selected aerosol particles are the dust's fine particulate matter ($PM_{2.5}$), sulfates, as well as Black Carbon (BC). Cardiovascular problems and death caused by air pollution are globally reported, and air pollution kills more people than they die of viral diseases.

Due to the dust belt [17] as well as meningitis belt [20] which keep expanding, Africa is one of the best research areas, while targeting the source of different sized particulate matter, PM (PM_1, $PM_{2.5}$, PM_{10}), which are classified under solid aerosols, and breathable air pollutants in particular [21].

2.2 Sulfur dioxide

The sulfur Dioxide (SO_2) is produced from anthropogenic burning activities, and erupting volcanoes activities [22], and is recognized as a potential air pollutant; importantly, through chemical reaction, SO_2 plays a considerable role in the formation of sulfate aerosols. The role that sulfate aerosols may play in ambient particulate matter (PM) chemistry is so meaningful that the possible effects might be the product of acidic component formed by sulfur dioxide [23, 24]. Acid rain, for example, is one of main reasons why atmospheric sulfur dioxide and nitrogen oxides can be of interesting focus among the air pollutants [25–27].

For instance, it was found that rain in northwestern Europe was measured with the most increased acidity; the tendency appeared linked with certain gaseous pollutants, like SO_2, which chemically convert into strong acids in the atmosphere. Nonetheless, the trend seems to directly cause very little threat to human health.

Rather, the acidic rain can considerably damage some artificial architects, and seriously implicates to the ecosystem [25].

3. The data source, methodology, and roadmap

The collected data from multiple remote sensing instruments is trustworthy; this way of the data collection has challenged the existing methods (according to the published research works), especially when it comes to the data reliability.

Throughout the research, GIOVANNI is the core of research data collection; relying on MERRA-2 (in most cases). MERRA-2 is a remote sensing model which assimilates data from various remote sensors as well different ground aerosol robotic networks (AERONETs).

Additional software tools, such as Arc GIS, have been utilized to scientifically present the results, but the statistics was done at the level of GIOVANNI web browsing [28–31].

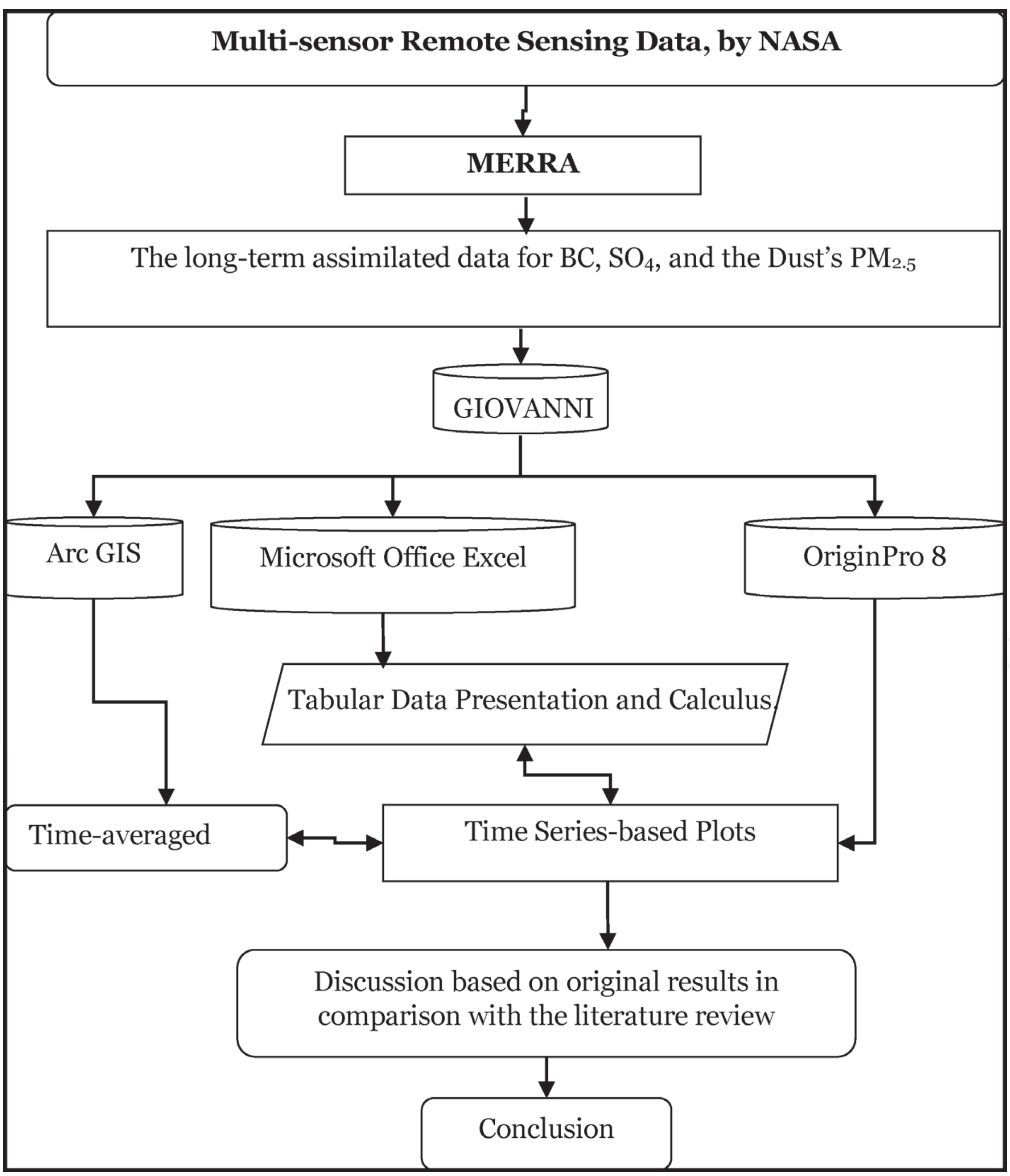


Figure 3.
The research roadmap.

3.1 The research data source and roadmap

The rough roadmap that was utilized to collect data and generate the results presented in this research is generalized and shown in **Figure 3**.

Different data types are available in various forms and formats: time averaged maps, scatter plots, time series, etc. In this research, both time averaged map based and time series data has been collected from GIOVANNI platform.

The collected data is then input to the analysis by the help of the software tools: ArcGIS/Arc Map to get the presentable map-based results; Origins, to generate different plots of results as functions of time.

That means that even though some results can directly be visualized online by the help of GIOVANNI, all the results presented in this research article have been further handled by additional software tools such as Arch GIS and Origins.

Microsoft Excel helps the research to do some necessary calculations, and elaborate the table-based results. Finally, a discussion is made on basis of the original results, in comparison with the existing literature review.

Thus, as seen in **Figures 3** and **4**, GIOVANNI is a bridge as an online platform designed by NASA Goddard Space Flight Center, to collect raw data from different satellites and remote sensors, the most notable are illustrated in **Figure 4**.

Though the remote sensed data can be collected from the most documentable remote sensors such as the Moderate-resolution Imaging Spectro-radiometer (MODIS), it has been challenging to directly detect dust from MODIS [32]. Therefore, the remote sensing model MERRA-2, an online model which directly assimilates the remote sensing data from the AERONETS, the MODIS and the advanced very high-resolution radiometer, AVHRR [32].

For the quality of data collected via GIOVANNI, data from different sources can be a good solution to the data reliability. For example, MERRA-2 is a model which treats the data from different sources, as earlier mentioned in this sub-section.

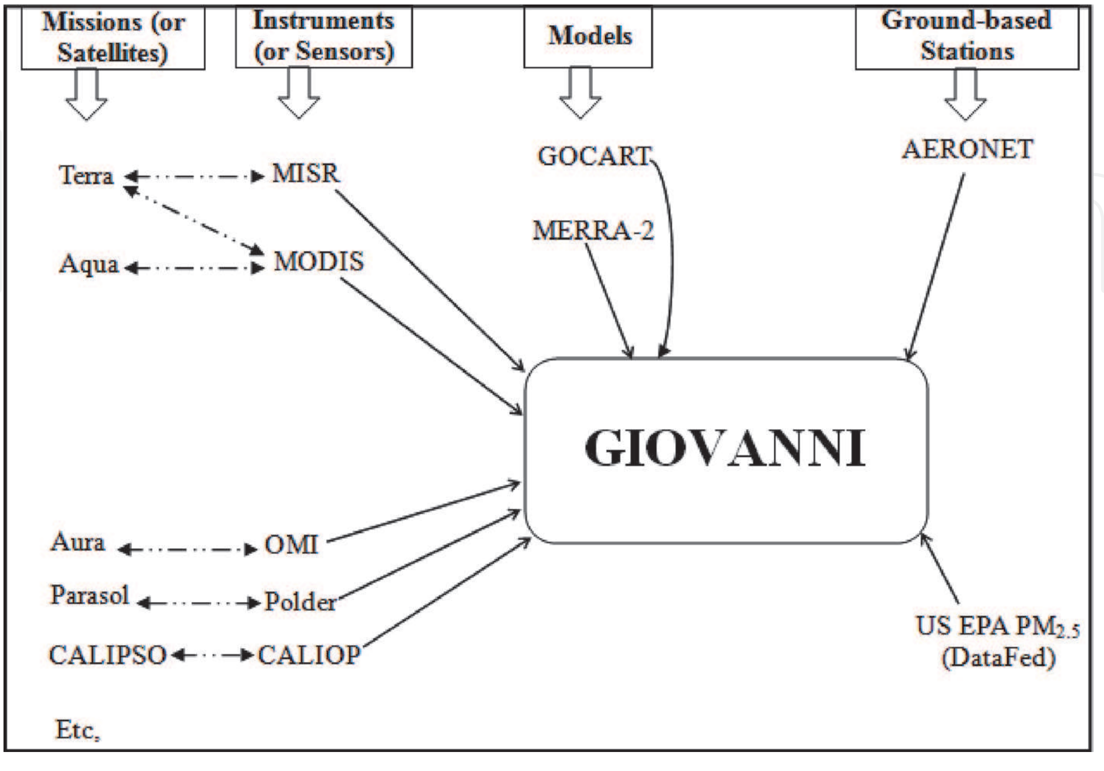


Figure 4.
A multi-sensor aerosol data bridge: GIOVANNI.

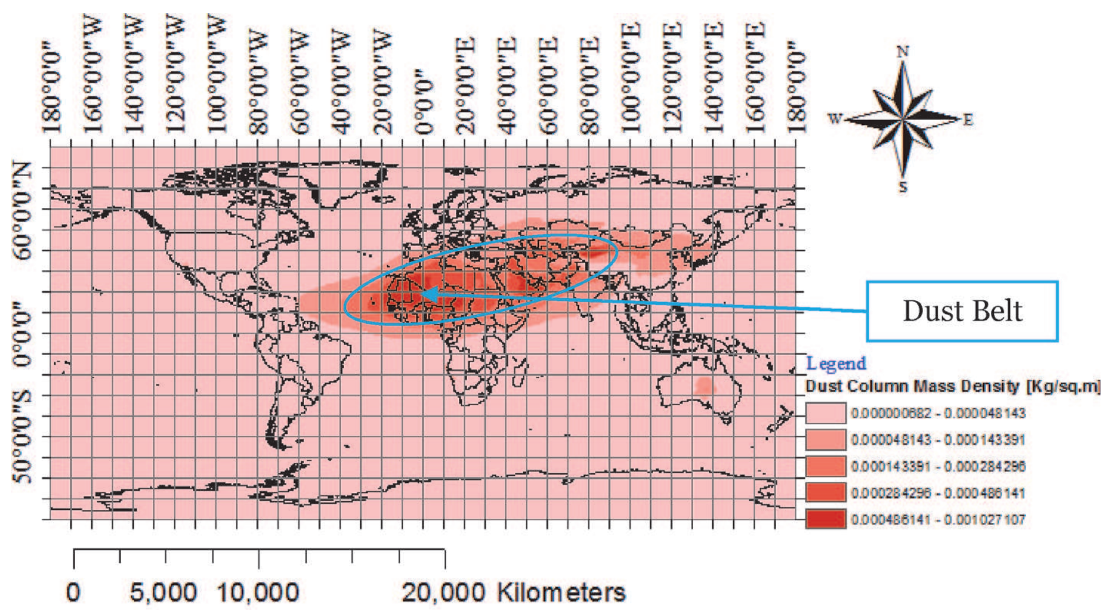
4. Analysis of remote sensing data: Air polluting aerosols effects on health

4.1 An overview for the big picture

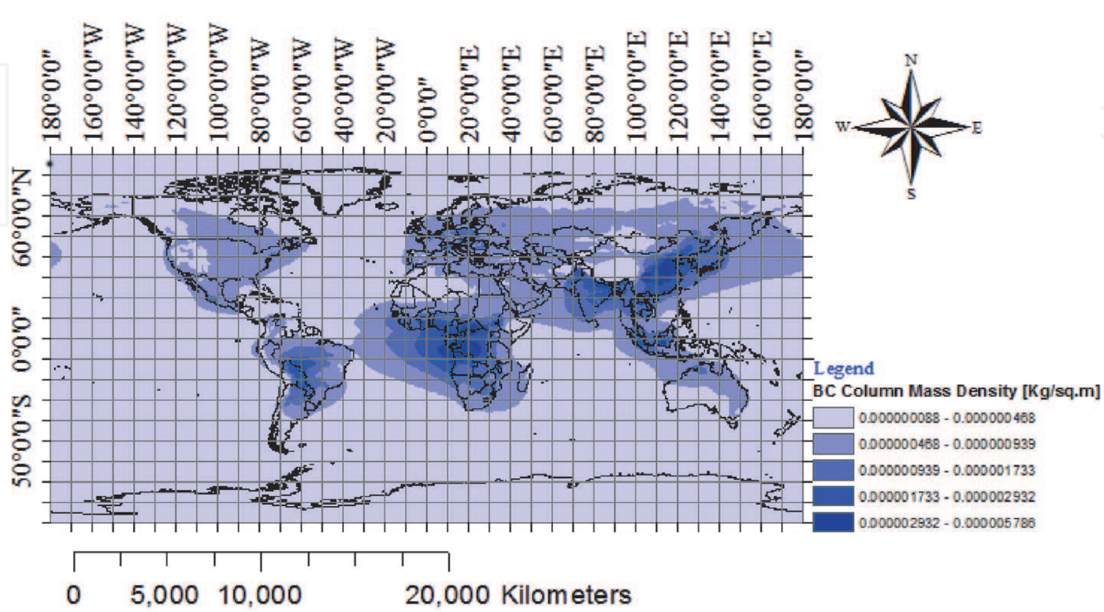
The desert's dust together with anthropogenic biomass burning's black carbon in the tropical regions are associated with many effects to climate and air quality.

Globally overviewed in **Figure 5(a)** and **(b)**, respectively, the dust as an air polluting aerosol expands all over the world from the world's dust belt that stretches from the Atlantic Ocean in the neighborhood of West-Northern Africa to the East and Middle Asia, and the atmospheric black carbon is abundantly stretched all over the mid-latitudes of the earth.

The Global overview of these selected aerosols and air pollutants, is an important input to research contents in the subsequent sections.



(a)



(b)

Figure 5.
The global overview of selected Aerosols and Air pollutants' column mass density: (a) dust, aerosol and air pollutant; (b) black carbon aerosol and air pollutant.

4.2 The results

The desert's dust together with anthropogenic biomass burning's black carbon in the tropical regions associate with both climate changes and air quality problems.

For example, the aerosol optical thickness (AOT), known as an extent to which aerosols obstruct the light energy transmission, via absorption or/and scattering of that light, AOT is distributed within a column of air to the top of the atmosphere [15]. The process of absorption and scattering makes up the extinction process, which means the loosing of the photon incoming energy [33].

It is according to the knowledge of the African Physical Geography as well as climates that five sub-regions had been created and those are described as region 1, 2, 3, 4 and 5.

- Region 1: 15°W, 9.5°E, (4–14) °N for the West Africa;
- Region 2: 10°W, 52°E, (24–40) °N for the North Africa and neighborhoods;
- Region 3: (9.5–30) °E, 10°S, 14°N for Central Africa;
- Region 4: (11–35) °E, (10–35) °S for the South Africa;
- Region 5: (30–52) °E, 28°S, 12°N for East Africa.

The purpose of those five subdivisions is to obtain most reliable remote sensing results, and the focus was put in the most central part of Africa.

The findings are presented in **Figure 5**.

In this research, four seasons are shortened as:

- DJF, for December, January, and February or the northern hemisphere's winter;
- MAM is standing for March, April, and May or the northern hemisphere's spring;
- JJA represents June, July, and August or the northern hemisphere's summer;
- SON for September, October, and November or the northern hemisphere's autumn.

From the existing research, the dust's particulates are one of the causes of pulmonary tuberculosis [34]; dry desert's dust in particular is one of the causes to Meningococcal meningitis ([35], p. 108–109).

In the research, **Table 1** reports the results for $PM_{2.5}$, in the 5 sub-regions of Africa, and it's found that the averaged mass concentration is very high as compared to 25 $\mu g/m^3$, the recommendable concentration [14].

Looking at the table, the vastest global Desert, Sahara, which keeps expanding [1] might be the reason for the increase of the global dust aerosol since the year 2000 onwards, most notably in the seasons of DJF and MAM, during the whole time series from the year 2000 to date.

Besides, the African Sahara Desert being the biggest contributors to global atmospheric particulate matter (PM) and air pollutants in particular, **Table 1** demonstrates the concentration of $PM_{2.5}$ in Africa.

	West-Africa				North-Africa				Central-Africa			
	DJF	**MAM**	**DJF**	**MAM**	**JJA**	**SON**	**JJA**	**SON**	**JJA**	**SON**	**JJA**	**SON**
2000	66.8	54	25.3	40.9	39.1	33.3	39.1	33.3	34.4	24.6	6.1	11.3
2001	69	38.8	29.1	39.8	39.1	33.4	39.1	33.4	31.6	21.1	5.9	12.0
2002	67.2	46.0	28.9	43.3	38.9	33.3	38.9	33.3	32.7	23.8	6.4	11.9
2003	45.1	43.2	31.3	42.8	37.6	35.5	37.6	35.5	23.3	25.9	6.2	11.2
2004	74.2	60.7	34.2	46.5	36.6	34.1	36.6	34.1	35.6	36.3	6.6	14.4
2005	75.6	44.8	36.4	43.9	38.6	33	38.6	33	34.2	26.2	6.7	12.5
2006	36.9	47.9	33.5	40	40.4	30.3	40.4	30.3	26.3	26.1	6.9	12.2
2007	84.6	54.1	31.6	44	39.4	32.3	39.4	32.3	35.4	27.7	5.7	13.4
2008	85.2	44.9	32.3	47.8	40.7	37.4	40.7	37.4	38.4	22.7	5.0	12.8
2009	59.1	42.2	39.1	42.3	37.3	31.6	37.3	31.6	29.9	27.9	6.1	12.7
2010	37.2	56	38.6	47.8	38.3	33.6	38.3	33.6	22.1	26.1	6.3	9.0
2011	58.8	37.8	34.4	42.9	40.3	31.5	40.3	31.5	28.7	25.5	12.2	12.7
2012	77.1	53.9	34.7	43.2	36.8	28.3	36.8	28.3	40.0	30.0	6.2	9.6
2013	57	25.4	33.2	46.1	38.9	30.3	38.9	30.3	32.0	20.1	5.6	10.5
2014	52.3	29.5	31.6	36.8	37.5	31.6	37.5	31.6	27.0	19.4	5.4	10.3
2015	62.9	54.5	34.3	38.7	37.8	30.3	37.8	30.3	33.6	33.7	6.5	11.0
2016	108.3	29	28	40.2	36.2	31.4	36.2	31.4	46.1	21.8	5.2	13.0
2017	67.2	41.3	30.8	41.8	36.3	30.5	36.3	30.5	36.8	27.1	9.4	17.5
2018	85.1	39.7	37	46.4	37.8	32	37.8	32	36.4	26.0	7.1	11.4
2019	63.6	41.3	10.9	N/A	32.4	39	35.1	N/A	37.0	25.5	6.1	N/A

	East-Africa				South-Africa			
	JJA	**SON**	**JJA**	**SON**	**JJA**	**SON**	**JJA**	**SON**
2000	4.5	4.6	3.7	2.5	1.6	1.8	2.1	2.1
2001	5.1	4.0	3.5	2.6	2.4	1.5	1.8	1.7
2002	5.1	3.8	4.0	2.7	2.2	1.3	1.8	1.8
2003	3.7	4.6	3.8	2.7	1.6	1.5	1.8	2.0
2004	5.2	5.1	3.7	2.7	2.7	2.4	1.9	1.8
2005	4.6	3.7	3.9	2.8	2.2	1.7	1.6	1.9
2006	4.3	4.4	3.8	2.6	2.0	1.6	1.9	1.8
2007	5.8	4.3	3.5	3.3	2.6	1.8	1.9	2.2
2008	7.3	4.6	4.0	3.6	2.2	1.3	1.6	2.1
2009	5.4	5.0	3.9	2.9	2.2	1.5	1.9	1.8
2010	4.5	4.5	3.8	3.2	2.0	1.5	1.9	2.0
2011	5.6	4.3	6.3	3.5	2.0	1.3	1.9	2.1
2012	7.8	6.6	4.5	3.0	2.7	1.8	1.9	2.0
2013	5.6	4.1	4.3	2.9	2.6	1.7	1.8	2.0
2014	5.7	3.3	3.9	2.8	2.1	1.6	1.9	1.9
2015	5.8	4.8	4.1	2.7	2.7	1.6	1.6	2.0
2016	6.5	3.8	3.8	3.2	2.7	1.7	1.7	1.9
2017	5.5	4.5	4.9	3.4	2.3	1.5	1.5	1.7
2018	6.8	4.9	5.3	2.9	2.4	1.8	2.1	1.9
2019	5.2	4.3	3.9	N/A	2.5	1.8	1.7	N/A

Table 1.
The dust's $PM_{2.5}$ mass concentration in $\mu g/m^3$ in five African sub-regions of interest [36].

Looking at some existing research works, "exposure to common air pollutants like fine and coarse particulate matter (PM2.5 and PM10), Nitrogen dioxide (NO2), and sulfur dioxide (SO2) were closely associated with asthma patients who visited Shanghai from January 22, 2014 to October 31, 2015 [37];" generally, the portion of nearly 90% of BC belongs to PM2.5 [38].

5. Discussion

It's expected that both the inhabitants of the region of interest (RoI), and visitors will understand furthermore the dangers of particulate matter, and will take precautions to comfortably live on earth because the atmosphere is shared resource: the dust belt's $PM_{2.5}$ unlimitedly spreads to the sub-Saharan, European, Asian, and Atlantic Ocean regions.

Most specifically, in this research, the direct effects of aerosols on heath are presented by results in **Table 1**, speaking of the central African focal region of interest: the dust's PM2.5 mass concentration is mostly above the highest recommended value for health which is 25 μg/m^3.

With a reference to the World's Dust Belt [17], the heavily concentrated particulate matter in the west, north and central African sub-regions is attributed to the Sahara Desert, and this has nothing to do with the population.

Apart from the world's dust belt which is due to deserts, the nature source of dust aerosols and linked air pollutant groups is also from volcanic eruption activities, and anthropogenic activities.

Therefore, inhabitants of arid regions are recommended to learn from China's policy, which turned a desert into crop and forestland, cited by Rushingabigwi et al. ([39], p. 1958), which would reduce the dust aerosols which are windblown all over the world.

6. Conclusions

Aerosol science, a sub-branch of physics or physical-chemistry which, until 1980s, has been so neglected that most people have not cared about the aerosols dangers to the human breathing and blood circulation. In this research, a quick overview of aerosols and air pollutants (solid and gaseous) has been made; the research has resulted in finding more about air polluting aerosols such as the dust's fine particulate matter, $PM_{2.5}$, an agent to many diseases leading to the mortality due to cardiac dysrhythmias, cardiac arrest, etc.

In this research, the west and north African sub-regions are characterized by the concentrations of PM2.5 above the standard, 25 μg/m^3, in all the seasons; the same thing applies to the Central African JJA season.

In any case, the atmosphere is such a complex dynamic natural system that sustaining life on earth is very essential since the atmospheric air interacts with water and land. Acidic rain due to atmospheric chemistry of sulfate aerosols reacting with the clouds Hydrogen, for instance, is a result of air pollution.

Black carbon (abundant in the African mid-latitude and the global mid-latitudes), together with dust aerosols (from deserts, volcanic activities, and anthropogenic activities), windblown from their sources to surrounding regions are certainly hazardous to the global ecosystem, especially when in the precipitation's clouds.

Therefore, for sustainability of the life on earth, this research can help policy makers to plan for the community welfare: it is expected that by publishing different research works in this area, more scholars will furthermore understand the real problem, and if supported by policy makers, smart systems will be developed for the welfare of end users.

Acknowledgements

The East Africa's Regional Centre of Excellence in Biomedical Engineering and E-health (CEBE), operating under the University of Rwanda College of Science and Technology (UR CST), is highly acknowledged for some financial support to this research.

We are very grateful with the University of Science and Technology of China (USTC), for the involvement of the University's Academic Staff Members in this research.

Last but foremost, the efforts made by all the team members of GES DISC, who contributed to enrich GIOVANNI with the useful and resourceful research tools are highly acknowledged: many thanks are addressed to NASA and fellow scientists for the supportive data that are made available online.

Conflict of interest

There exist no 'conflict of interest' in this manuscript.

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