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Evaluation of Air Quality in Sudanese Gold Mining Fields

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Abstract: This study intended to provide a base line and describe the current air quality in Sudanese Gold mining fields. It covers 21 gold marketing centers in 5 states; namely Northern, River Nile, Gadaref, Red Sea and Kurdofan state. The main objectives of the survey is the detection of any significant concentrations that exceed Occupational Safety and Health norms and specifying the key emission sources, and also identification and assessing of the health hazards and environmental impacts. The tests were carried out by using electronic portable devices to measure the concentrations of pollutants in air. The measured pollutants were: Dust or Particulate Matter (PM), Nitrogen Dioxide (NO_2), Volatile Organic Components (VOCs), Sulphur Dioxide (SO_2), Ammonia (NH_3), Carbon Monoxide (CO) and Ozone (O3). National Ambient Air Quality Standards (NAAQSs) and Sudanese Standards for Ambient Air Pollutants were used for comparison purposes. In addition to that, Air Quality Index (AQI) was applied for the average concentrations of each pollutant. It was found that, all gold marketing centers suffered from very high concentration of $PM_{2.5}$ and $PM_{10.}$ 90.5% of those centers had higher NO_2 concentration than the standards, 37% of it was increased by 200% and 42% of it was increased by 150%. In addition to that, 48% of gold marketing centers had higher SO_2 concentration than the standards. On the other hand, concentrations of other pollutants obtained were found within the allowable limits. Finally, it was concluded that all those centers are contaminated with one or more air pollutants. Therefore, it was recommended to improve the environmental conditions by mitigating emissions from point sources. Supervisors have been advised to assume their responsibilities in controlling the use of Personal Protective Equipment (PPE) in addition to the dissemination of safety culture through psychological approach.

Keyword: *Air pollution, Gold mining, Particulate matter, Nitrogen dioxide.*

1. INTRODUCTION

Many African countries are going through a phase of difficult economic conditions and a high rate of unemployment and poverty in their communities. Over the years, artisanal gold mining has been a source of income generation of many communities [1]. Mining is an activity that employs many people in rural areas because the barriers to entry are minimal, with low technology, capital and limited specialized skills needed. Miners can earn higher incomes in mining than through other traditional activities. Artisanal mining may contribute to poverty alleviation and provides many opportunities. It is an activity associated with many negative social impacts [2].

Artisanal gold mining activities has increased tremendously over the Sudanese arid and semi-arid environment of the country and has resulted in significant environmental and socioeconomic impacts [2]. Miners are exposed to chemical contaminants, unsanitary conditions, prostitution, alcoholism and drug addiction. Women and children are generally the most affected by these hazards [3].

Artisanal mining is associated with a number of environmental impacts, such as deforestation, land degradation; open pits that pose animal traps, health hazards, mercury pollution, dust and noise pollution. A large proportion of artisanal miners are unaware of the laws governing mining activities and the environment impact of water pollution [3].

Mining activities and mining service companies discharge particulate matter into the ambient air. The grievances of the affected communities on air quality have been the airborne Particulate matter, emissions of black smoke, noise and vibration. Airborne particulates of major concern in the mining areas include respirable dust, Sulphur Dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO) and black smoke. The activities That produce this particulate matter include site clearance, road building, open-pit drilling, blasting, loading, haulage, vehicular movement, ore and waste rock handling [2]. The impacts of the air pollutants on receptors differ from one to another based on emission type, expose duration and the dose of expose. Air pollutants are emitted from a range of both synthetic and natural sources that Had serious impacts on human health and environment, the different sources of emissions and Its impacts are summarized in Table 1 that are rearranged from many sources. [4] [5] [6].

Research Methodology

In this study, the data was collected from 5 states to cover gold marketing centers. Electronic portable devices were used to measure the concentrations of pollutants in air. National Ambient Air Quality Standards and Air Quality Index were applied on measured emissions to determine and compare the risk rating of gold marketing centers emissions.

Period of Data Collecting: from Mar.2018 to May.2018

Study of Area: data were collected from 21 gold marketing centers in five states as shown below:

River Nile state (4 centers): Dar Mali, Al-Obeidia, Al-Shriek and Abu-Hamad.

Northern state (7 centers): Al-Gaab, Dalgo, Shada, Al-Khanag, Sawarda, No.1 Halfa and Al-Dabaa.

Gadaref state (3 centers): Al-Khiary, Shawar and Wd Bushara.

Red Sea state (3 centers): Mouk, Wadi Ushar and Norai.

Southern Kurdufan (4 centers): Togoola, Al-tayar, Gardood and Higairat.

Table 1. Sources of air pollutants and its impacts [4, 5] [6]

Air Pollutants	Source of Emissions	Impact on Human Health		Environmental Impact
PM	- Stationary sources. - Mobile or transportation-related source. - Combustion processes. - Biomass burning.	- Coughing and wheezing. - Decrease lung function. - Emergency room visits. - Death. - Respiratory system diseases. - Silicosis. - Carcinomas.	Acute Chronic	- Black smoke. - Acid smut.
NO_2	- Automobiles - Combustion processes	- Effects on Asthmatics. - Hospital admissions. - Mortality. - Respiratory system diseases	Acute Chronic	- Photochemical smog. - Acid rain HNO_3. - (With VOC+CO) » Ground Ozone level.
SO_2	- Combustion of Hydrocarbon Fuel	- Coughing and wheezing. - Decrease lung function. - Emergency room visits. - Death. - Respiratory system diseases. - Cardiovascular disease (Sensitive people).	Acute Chronic	- Acid rain H_2SO_4. - Fog
CO	- Transportation. - Incomplete combustion. - Forest fires. (Natural Source)	- Headache & Dizziness - Hallucinations - Loss of consciousness. - Personality and memory changes & loss of vision. - Cardiovascular problems. - Brain: mental confused. - Nervous system. - Heart diseases.	Acute Chronic	- Climate change and Global warming. - With other pollutants » Ground Ozone level.
NH_3	- Agriculture and Animals. - Industrial process. - Vehicles.	- Corrosive injury to the mucous membranes. - Burn the skin at direct contact. - Irritation of respiratory tract. - Cough asthma & lung fibrosis. - Irritation of eye membranes.	Acute Chronic	- Formation of PM. - Visibility degradation. - Deposition of Nitrogen to sensitive ecosystem.
O_3	- Photochemical production. ($VOCs + NO_x$), (Secondary pollutant). - Troposphere. (Natural)	- Eyes and lung irritation. - Coughing and shortness of breath. - Respiratory system diseases.	Acute Chronic	- Smog. - Damage plants and trees.

Devices:

1. **Aeroqual for gases.**

The Aeroqual handheld monitors have been specifically designed to incorporate Aeroqual's in-depth knowledge of accurate ambient gas measurement and can be used with a wide range of gas sensor heads. The sensor heads are interchangeable and therefore multiple heads can be used on the same base unit as shown in Fig 1. [7].

Fig .1. Device for measuring gases (Aeroqual)

2. Aerocet 831 for particular matter and total suspended particular matter.

The AEROCET 831 is a small, lightweight, battery operated, handheld mass profiler. This instrument simultaneously monitors PM1, PM2.5, PM4 and PM10 levels. The multifunction rotary dial provides simple and efficient operation. The internal battery pack provides 8 hours of continuous operation. The AEROCET 831 stores up to 2,500 sample events, which can be viewed on the display or exported to a computer via the USB port. [8] Fig 2.

Fig. 2. Device for measuring particular matter (Aerocet)

Table 2. Specifications of operating conditions and accuracy for Aerocet and Aeroqual devices

Device	**Unit**	**Accuracy**	**Operating Conditions**	
			Temp. ^{0}C	**RH%**
Aerocet	$\mu g/m^3$	± 10%	0 – 50	0 – 90
Aeroqual	ppm or mg/m3	± 0.01 ppm	-5 – 45	0 – 95

Procedures:

- MS Excel was used for calculations.
- NAAQS and AQI were applied for analyzing and diagnosing the results [9].

The U. S. Environmental Protection Agency (EPA) has provided a scale called the Air Quality Index (AQI) for rating air quality. This scale is based on the National Ambient Air Quality Standards (NAAQS). [10] An individual score (Individual Air

Quality Index, IAQI) is assigned to each pollutant and the final AQI is the highest of these six scores. The final AQI value can be calculated either per hour or per 24 hours.

Equation 1: Air Quality Index [11]

$$AQI = \frac{(PMobs - PMmin)(AQImax - AQImin)}{(PMmax - PMmin)} + AQImin \quad (1)$$

Where:

PM_{obs}: observed 24-hour average concentration.

PM_{max}: maximum concentration of AQI color category that contain PM_{obs}.

PM_{min}: minimum concentration of AQI color category that contain PM_{obs}.

AQI_{min}: maximum AQI value for color category that corresponds to PM_{obs}.

AQI_{min}: minimum AQI value for color category that corresponds to PM_{obs}.

Results and Discussions

$PM_{2.5}$ and PM_{10}

The measured levels frequently and largely exceeded international and national norms, for all particle sizes including PM2.5 that cannot be filtered by the human respiratory system. River Nile and Northern states are the most serious suffered from the concentration of $PM_{2.5}$ compared with others states as shown in Fig 3. On the other hand, Kurdufan state was recorded the highest concentration of PM_{10} that it is considered very dangerous to all receptors Fig 4. While Gadaref state and Red Sea state suffered from the lowest concentration of $PM_{2.5}$ and PM_{10} compared with the others states under study, even that they still exceed the maximum permissible exposure limits (PEL).

Sucking air through a filter showed this to be mostly desert dust. The high amount of dust in the air can often be seen at the level of haze. In addition, people who are more sensitized such as asthma sufferers or individuals with other respiratory problems will be more adversely affected. Only Inside the rooms the concentration measured were in general lower and fell within the limits.
During dry windy season and due to grading and crushing activities have the potential to produce dust that can be transported off site by wind. To control airborne fugitive dust, the company shall apply water, encourage plantation of trees and any other grass type that could protect and prohibit the movement of dust.

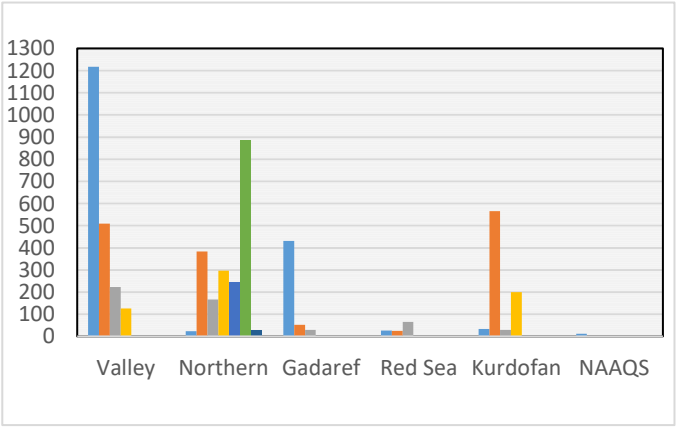

Fig .3. Average concentrations of particular matter 2.5 micron in all states under study

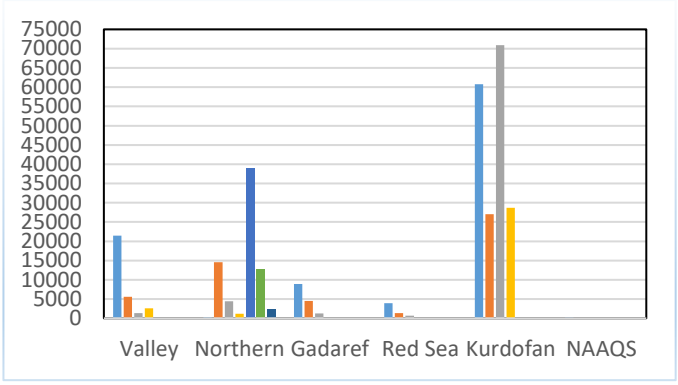

Fig .4. Average concentrations of particular matter 10 micron in all states under study.

NO_2 and SO_2:

High levels of contamination were measured of both Nitrogen dioxide and Sulfur dioxide in most gold marketing centers. 90.5% of those centers had higher NO_2 concentration than the standards, 37% was increased by 200% and 42% was increased by 150% Fig 5. In addition to that, 48% of gold marketing centers had higher SO_2 concentration than the standards Fig 6. The main source is combustion processes of separation mercury from gold, mercury purification, vehicles engines and cooking processes.

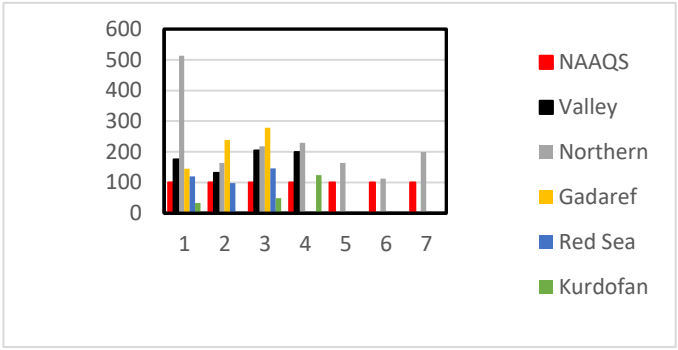

Fig .5. Average concentrations of nitrogen dioxide in all locations.

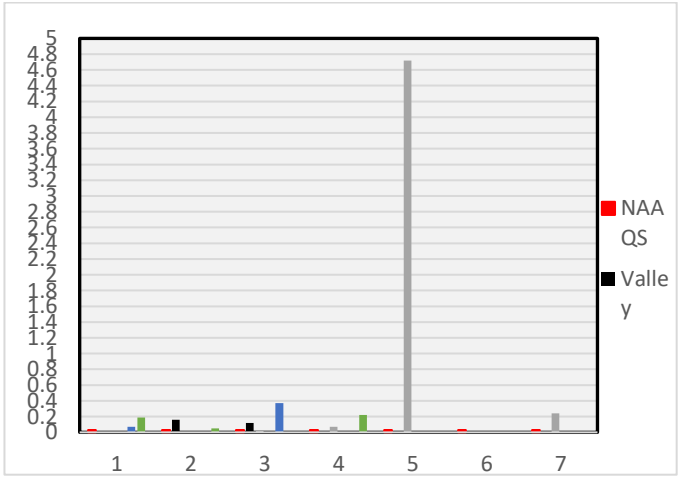

Fig .6. Average concentration of sulfur dioxide in all states under study.

Ammonia (NH_3); Carbon Monoxide (CO) and Ozone (O_3)

All of these emissions are remarkably low within the allowable limits as it shown in Fig 7.

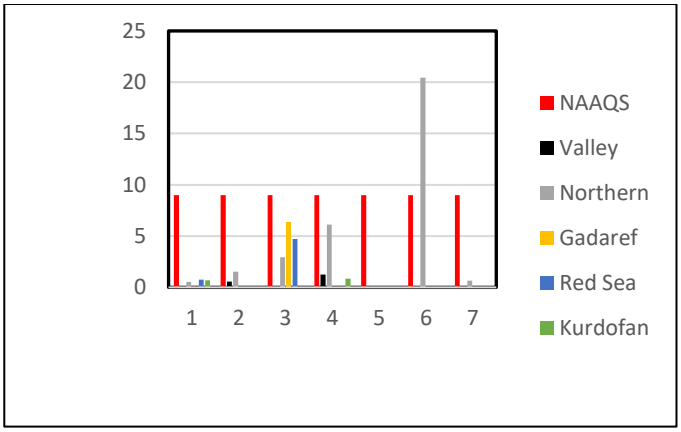

Fig .7. Average concentrations of carbon monoxide at all locations.

VOC emissions can be expected from fixed roof tanks, ponds and pits, and some from combustion processes. However, VOC components were not found in significant quantities.

Air Quality Index (AQI)

Air quality index (AQI) was calculated to demonstrate the health effects of emissions on people in the target population. To calculate AQI, an average concentration level of $PM_{2.5}$, PM_{10}, NO_2, SO_2 and CO at different locations were obtained and shown in Fig 3, Fig 4, Fig 5, Fig 6 and Fig 7; respectively. The observed average concentrations of pollutants were applied in Equation 1 to get AQI for the target population according to the sampling design (Table 3) and (Table 4).

Table 3. Average air quality index of nitrogen dioxide, sulfur dioxide, carbon monoxide and ozone at all gold marketing centers.

	AQI			
State	**NO2**	**SO2**	**CO**	**O3**
Nile River	0 good	0 good	3 good	0 good
Northern	0 good	0 good	28 good	0 good
Gadaref	0 good	0 good	11 good	0 good
Red Sea	0 good	0 good	15 good	0 good
Kurdofan	0 good	0 good	3 good	-

For SO_2: People with asthma are most at risk.

For CO: People with heart diseases are most at risk.

Table 4. Average air quality index of particular matter 2.5 and 10 micron at all gold marketing centers.

	AQI	Notes			AQI
State	**PM2.5**	**Sensitive groups**	**Health effects statements**	**Cautionary statements**	**PM10**
Nile River	Beyond AQI**	6	6	6	Beyond AQI**
Northern	340 Hazardous	6	6	6	Beyond AQI**
Gadaref	221 Very Unhealthy	5	5	5	Beyond AQI**
Red Sea	110 Unhealthy for Sensitive Groups	3	3	3	Beyond AQI**
Kurdofan	257 Very Unhealthy	5	5	5	Beyond AQI**

Sensitive groups:

(3) + (5) + (6) People with respiratory or heart disease, the elderly and children are most at risk.

Health Effects [4]:

(3) Increasing likelihood of respiratory symptoms in sensitive individuals, aggravation of heart or lung disease and premature mortality in persons with cardiopulmonary disease and the elderly.

(5) Significant aggravation of heart or lung disease and premature mortality in persons with cardiopulmonary disease and the elderly; significant increase in respiratory effects in all population.

(6) Serious aggravation of heart or lung disease and premature mortality in persons with cardiopulmonary disease and the elderly; serious risk of respiratory effects in all population.

Cautionary Statements:

(3) Sensitive group should limit prolonged exertion.

(5) Sensitive group should avoid any outdoor activity and others should avoid prolonged exertion.

(6) Sensitive group should remain indoors and everyone should avoid any outdoor exertion.

** Beyond AQI means above 500, fellow recommendation for Hazardous

CONCLUSION

It was concluded that all gold marketing centers are contaminated with one or more air pollutants. Most centers are controlled and managed individually or by groups so the role of government almost fades away. In addition, the environmental conditions should be improved by mitigating emissions from point sources. Supervisors have been advised to assume their responsibilities in controlling the use of Personal Protective Equipment (PPE) in addition to the dissemination of safety culture through psychological approach.

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