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Assessment of the Concentration of Settleable Particulate Matter Using Geographic Information Systems in the Central Ecuadorian Highlands

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Abstract

INTRODUCTION: Pollution is the most obvious factor in the deterioration of environmental quality. This issue affects different media and is closely related to the destructive effects on the environment, the accelerated greenhouse effect, the deterioration of ecosystems, and environmental quality.
OBJECTIVES: Determine and characterize the sedimentable particulate matter due to anthropic and natural incidence Using Geographic Information Systems in the Central Ecuadorian Highlands.
METHODS: 22 monitoring points were established, these collected sedimentable particulate matter (SPM) through the passive gravimetric method that consists of particulate matter (PM) being deposited by gravity in Petri dishes with filter paper inside for one month. The samples were analyzed and compared with the maximum permissible limits (LMP) of the standards: international (WHO) and national (Agreement 097-A).
RESULTS: Showed that all samples comply with the regulations established in Agreement 097-A reformed in 2018 (1 mg / cm2 / month), however, 21 of the 22 samples collected do not comply with WHO regulations being above the maximum permissible limit that is (0.5 mg / cm2 / month), being the SPM a factor that affects air quality in the area.
CONCLUSION: A map of concentration and dispersion of the SPM was elaborated with the help of Geographic Information Systems (GIS) where 3 types of ranges to the concentration of the MP were categorized: high, medium, and low, also the areas with the highest degree of concentration of particulate matter were identified, turning out to be the north and south of the study area.

Keywords: Particulate matter (PM), sedimentable particulate matter (SPM), monitoring stations, air pollution.

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1. Introduction

Assuming nature as a subject of rights (1) presupposes, with the positive affirmation of its rights in which pollution is the most obvious factor in the deterioration of environmental quality. This issue affects different media (soil(2–4), water(5), air(5,6)) and is closely related to the destructive

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effects on the environment, the accelerated greenhouse effect, the deterioration of ecosystems, and environmental quality. Air quality is defined by a set of factors that affect your condition. The changing industrial environment generates atmospheric emissions of certain pollutants that must be controlled to mitigate negative impacts on the environment, health, and human well-being. Numerous epidemiological and observational studies have shown that poor air quality due to air pollutants has an impact on cardiovascular health (7).

A study by the United Nations (UN) in 2014 indicates that, for the first time in history, more than half of the planet "lives in cities", this implies different problems one of them air pollution. This problem is one of the most critical considering its high impact on public health (8). Accompanied by the development of various activities such as the oil industry, the service industry, agribusiness, and the increase in the number of automobiles, they lead to the massive consumption of fossil fuels; At the same time, inadequate agricultural activities can affect the production of large amounts of pollutants, when related to environmental conditions, damage human health, ecosystems and physical resources (9).

Cajabamba is an urban parish of Colta Canton, Chimborazo Province, Ecuador. It is surrounded by different anthropic activities such as flour factories, block factories, and metalworking which are emitters of dust, smoke, and gases, in addition to the pollution emitted by the automotive sector, this affects the quality of the air which is affected by particulate matter, which will represent a considerable level of air pollution, In addition, the municipality in charge has not carried out any study on this subject. For all this, it is necessary to prepare a study and identify the level of sedimentable particulate matter (SPM) being able to obtain relevant information for the benefit of the community and the environment.

Among the studies that can be found in Ecuador on air quality in rural regions, the one conducted by Lima et al. (9) stands out. They analyze the air quality and its impact from sawmills in the area, continuing with the analysis of air quality the objective of this research is to determine the air quality in the parish and compare it with national and international standards, concerning sedimentable particulate matter. This monitoring will allow to establishment of general and specific ideas to understand the air quality in the area, as well as to compare the maximum permissible limits of the SPM(10).

The results will benefit the inhabitants of the area, the owners of the different industries, the local environmental control authorities, and the municipal so that they can plan the dissemination of the problems associated with air pollution. It will also serve to raise awareness among the inhabitants about the control of their emissions, with relevant information for their protection and determining control alternatives to them.

1.1. Sources of air pollution

Sources of pollution are all activities, processes, or operations that may produce air pollutants. They can be classified into:

- Stationary sources are characterized by being stationary or located at a fixed point, such as power plants, chemical plants, refineries, and factories.
- Mobile sources are those that encompass all forms of transportation and motor vehicles.
- Area sources are all those activities that together affect air quality, such as the use of wood, printing presses, dry cleaners, or agricultural activities.
- Natural or biological sources are the result of animal and plant life phenomena, such as emissions from volcanoes, oceans, and soil erosion.

Among the main sources of anthropogenic air pollution are heating plants, thermal power plants, waste incinerators, the chemical industry, transport, and open-pit mining among others. Its harmful action has been of such a dimension that the increase in the level of air pollution in cities has come to affect the surrounding areas, including forest ecosystems (11).

In this regard, the hotel industry contributes to environmental pollution (11), due to the large amounts of water it consumes in its various areas, and like other industries, it generates environmental pollution due to the mobilization of its workers (12) and guests who use their cars or other means of transportation.

1.2. Particulate matter (PM) and Sedimentable particulate matter (SPM)

- Particulate matter (PM)

It is a set of solid and liquid particles emitted directly into the air, such as diesel soot, track dust, agricultural dust, and particles resulting from production processes. These suspended particles (MP) are a complex mixture of chemicals and/or biological elements, such as metals, salts, carbonaceous materials, volatile organics, volatile compounds (VOCs), polycyclic aromatic hydrocarbons (PAHs), and endotoxins that can interact with each other forming other compounds (12).

Some of these particles are large or dark enough to be seen by the human eye, such as grains of sand, soot particles or cigarette smoke, others are not, so the use of a technical support such as an electronic microscope is necessary (13). Likewise, epidemiological tests show adverse health effects due to prolonged exposure to particulate matter, this is due to its size; the smaller its diameter, the greater its damage to health. It was specified that fine particles (PM2.5) can penetrate the respiratory system all the way to the pulmonary alveoli, crossing their cell wall directly into the bloodstream (10).

- Sedimentable Particulate Matter (SPM)

Also called "coarse dust" is that fraction of particulate matter, whatever its size, that is captured in a specific unit of surface, during a specific unit of time. It is expressed as a mass of solid material (mg), deposited in one unit area (cm2) for one unit of time (days). The (SPM) consists of solid or liquid particles, about 10 μm in size or more, that can temporarily suspend themselves in the air, so they settle as dust and settle in different (14).

1.3. Sources of air pollution

Particle size is directly related to the likelihood of causing health problems. Small particles smaller than 10 microns in diameter are the biggest problem because they can penetrate deep into the lungs and some can even reach the bloodstream (15).

Exposure to these particles can affect the lungs and heart, these problems include:

- Premature death in people with heart or lung disease
- Nonfatal myocardial infarctions or irregular heartbeat
- Aggravated asthma or reduced lung function
- Increased respiratory symptoms, such as airway irritation, coughing, or shortness of breath.

1.4. Classes of particulate matter

For a better study, it is common to measure the fractions of particulate matter: particles smaller than 10 micrometers (μm), PM10, and particles smaller than 2.5 μm, PM2.5, which vary widely concerning their concentration and chemical composition according to time and place (12). By their diameter, the particles are classified into:

- Total suspended particles (TSP) diameter up to 100 μm.
- Inhalable or respirable (PM10), whose diameter is less than 10 μm.
- Fine, with a diameter not exceeding 2,5 μm (PM2,5)
- Thick, with a diameter of less than 10 μm (PM10)

1.5. Classes of particulate matter

Within the formation process, pollutants can be classified as primary and secondary, where the primary pollutants are emitted directly from processes such as smoke from the exhaust pipes of motor vehicles, the eruption of a volcano, or sulfur dioxide from a factory in its production process; on the other hand, secondary pollutants are not a direct emission as the previous case, but rather, they are formed from chemical reactions of primary pollutants in initial atmospheric conditions present in the air (16). Table 1 presents the formation of the types of PM that can be found in the atmosphere, the chemical reactions that give rise to them, their composition, solubility, emission sources, half-life in the atmosphere, and travel distance.

Table 1. Characterization of the MP present in tropospheric air.

	Fine particulate matter	**Coarse particulate matter**
It is formed from:	Gases	Large solids, droplets.
It is formed through:	Chemical reactions or vaporization. Evaporation of mist droplets and clouds in which they have dissolved.	Mechanical disruption (crushing, grinding, abrasion of surfaces, etc.). Spray evaporation. Powder suspension.
They are composed of:	Sulfate, nitrate, ammonium, elemental carbon. Organic compounds such as PAHs. Metals such as lead, cadmium, vanadium, nickel, copper, zinc, manganese, and iron.	Dust re-suspended from the ground and streets. Coal ash and oil. Oxides of crustal elements (silica, aluminum, titanium, and iron). Salt, calcium carbonate, pollen, fungal spores, mold.
Sources:	Combustion of coal, oil, gasoline, diesel, or wood. High-temperature processes such as foundries and steelworks.	Re-suspension of industrial dust and soil on roads and streets. Soil suspension in mining, unpaved roads. Biological sources. Construction and demolition. Combustion of coal and oil.
Half-life in the atmosphere:	Days to weeks	Minutes to hours
Travel distance	100 to 1000 km	1 to 10 km

Fountain: (4)

1.6. Air quality regulations according to WHO

Particulate matter is a common indicator of air pollution. It affects more people than any other pollutant. The main components of particulate matter are sulfates, nitrates, ammonia, sodium chloride, soot, mineral dust, and water. It consists of a complex mixture of solid and liquid particles of organic and inorganic substances suspended in the air (17). The WHO maximum permissible limit for SPM for sedimentable particulate matter is an exposure of 30 days (1 month) and the maximum allowable concentration is 0.5 mg/cm2/month (17).

1.7. Air quality regulations in Ecuador

Agreement 097-A, in annex 4 details ambient air quality, maximum permissible limits, methods, and procedures for the determination of air pollutants in Ecuadorian territory, which was published as an integral part of book VI "TULSMA" and entered into force as of 2015. The maximum permissible limit according to Agreement 097-A (Ecuador) for sedimentable particulate matter is an exposure of 30 days (1 month) and the maximum allowable concentration is 1mg/cm2/month (18).

2. METHODOLOGY

2.1. Area of Study

The present study was developed in the urban parish of Cajabamba, Colta canton, Chimborazo province, in the Andean region of Ecuador, at an altitude of 3212 meters above sea level (Figure 1). In the sector, the average temperature is 13 ° C, with an annual rainfall that varies from 500mm to 800mm and a relative humidity of 50% (19).

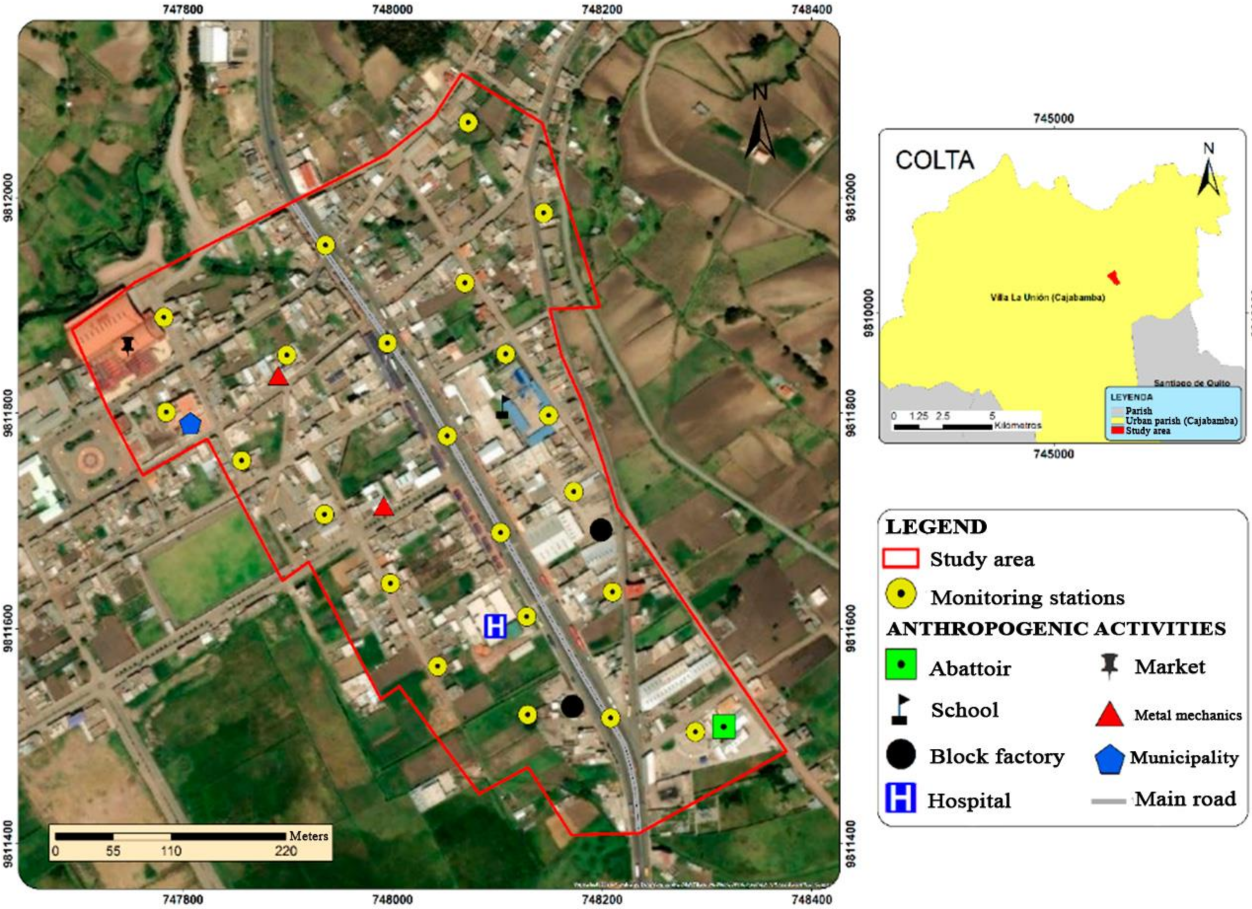

Figure 1. Monitoring stations in the study area.

For SPM sampling, 22 monitoring stations were implemented. The sample was collected continuously for 30 days, following the provisions of Book VI, Annex IV of TULSMA, to evaluate the concentration of sedimentable particles at the monitoring sites (Table 2).

Table 2. Monitoring stations.

Point	Latitude (N)	Length (E)
P-01	747782	9811889
P-02	747784	9811801
P-03	747936	9811956
P-04	748072	9812070
P-05	747856	9811756
P-06	747899	9811854
P-07	747995	9811865
P-08	748069	9811921

P-09	748144	9811986
P-10	747935	9811706
P-11	748052	9811779
P-12	747998	9811642
P-13	748103	9811689
P-14	748108	9811855
P-15	748043	9811565
P-16	748210	9811634
P-17	748149	9811798
P-18	748128	9811611
P-19	748173	9811727
P-20	748129	9811520
P-21	748208	9811517
P-22	748289	9811504

2.2. Determination of sedimentable particulate matter

For the analysis of SPM, the passive method proposed by Almiron *et al*., (20). Which proposes to place filter paper in Petri dishes previously dried, weighed, and determined its area. The set time for monitoring is 30 days. The result is achieved by calculating the final and initial weights and dividing for the area where the sample was collected; obtaining values in units of mg/cm2 for 1 month (Equation 1).

$$PAS = \left(\frac{Pf - Pi}{\acute{A}rea}\right) 1mes \qquad (1)$$

Where:

PAS: Sedimentable atmospheric dust

Pi: Weight of filter paper after leaving the laboratory

Pf: Weight of filter paper after I will be exposed to the sampling period

Filter paper area: $A = \pi \times r^2$(21).

Geostatistical model

Spatial distribution analysis was developed with ArcGIS 10.x software, which uses intelligent data models to represent continuous variables in space. This program includes several tools; but for our data interpolation analysis we used the Spatial Analyst and Geostatistical Analyst tools. To program the interpolation, PM2.5 values were considered, which was obtained by sampling for 24 consecutive days. In addition, wind speed values were used which for the city of Riobamba was 2.1 m/s, and wind direction in most cases blows mainly from north to south (N-S).

Morphological analysis of sedimentable particulate matter

To know the shape of the fine SPM particles, the optical microscope was used where the particles captured on the filter paper of each monitoring point were photographed in the microscope at a resolution of 100x.The filter paper samples were placed on the sample holder to take their respective photograph, and thus obtain the best image conditions where the shape of the microparticles can be appreciated.(22).

Statistical analysis

Normality tests were performed to verify the assumptions of the ANOVA analysis by grouping the SPM data associated with each sampling point. A one-way ANOVA ($p<0.05$) was performed to detect statistical differences between treatments and Tukey's mean tests. MINITAB V17 software was used for this statistical analysis.(23).

3. RESULTS AND DISCUSSION

3.1. Sedimentable particulate matter

In the study area, 22 monitoring stations were implemented randomly, to cover the entire study area. The sampling was carried out over 30 days, from January 20 to February 19, 2022. The SPM in the study area was obtained through the different concentrations obtained at each sampling point and calculated by applying "equation 1".

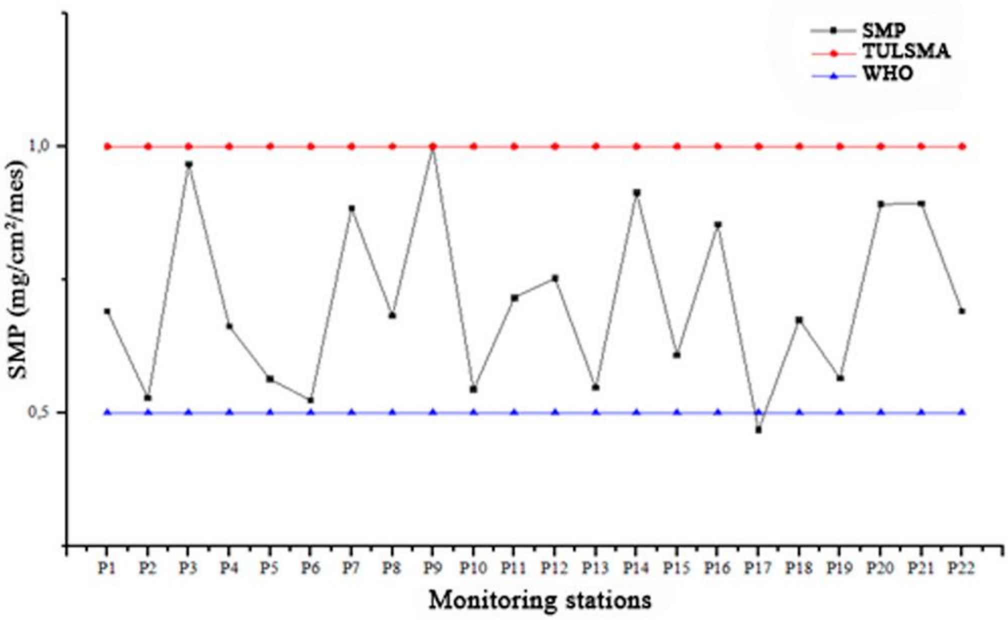

Figure 2. Concentration of SPM in the parish of Cajabamba. Comparison of SPM values with WHO LSPM and Agreement 097-A.

Figure 2 shows the SPM values obtained at each monitoring station. These values, when compared with the maximum permissible limits established by the WHO (0.5mg/cm^2/month), show that most of them exceed this threshold except for season 17. However, when compared with the maximum permissible limit of Agreement 097-A (1mg/cm^2/month), it is observed that station 9 reaches this limit, while the other values remain below this figure. In the case of higher concentrations, these coincide with the dry period in the study area. However, in general, the fractions that contribute most to suspended particles are of geological origin and are associated with resuspended dust (24). To address this problem, it is necessary to incorporate monitoring and control elements both from the point of view of air pollution and its effects on people's health. This would take research to another level to establish sector-specific risk mitigation measures (25).

The results indicate that air quality can be seriously compromised, as the concentration of SPM in urban areas exceeds the maximum permissible limit proposed by the WHO (26). This could be due to the circulation of automobiles since the Cajabamba parish is crossed by an important road artery such as the E35 or Troncal de la Sierra. On the other hand, from the point of view of people's health, these values are worrisome, because the SPM can easily enter the airways and can even reach the lungs, reaching the pulmonary alveoli (27).

The data obtained after weighing indicate that the SPM has a mean value of 0.7098 mg/cm^2, with a maximum of 0.9997 mg/cm^2 and a minimum of 0.4674 mg/cm^2. The dispersion of the data is around the mean, with a standard deviation of 0.1619 and a variance of 0.0262. The coefficient of variation was 22.81, which indicates a high variability (Table 3).

Table 3. Descriptive statistics of SPM in the parish of Cajabamba.

Area of Study	N	Stocking	Standard error Ẋ	SD	Variance	Coef Var	Minimal	Maximum
Cajabamba Parish	24	0,7098	0,0345	0,1619	0,0262	22,81	0,4674	0,9997

The difference in results is due to the high vehicular traffic that travels on the main road, which is an important initiator of the impact caused by vehicle emissions. On the other hand, it is important to indicate that in the study area, it was possible to observe different activities of an anthropic nature such as the presence of block factories. (28) and metalworking. In addition, the study area is surrounded by agricultural areas, which becomes a factor in PM pollution.

The data obtained after quantification indicate that the highest concentration of SPM is distributed in the northern and southern areas of the study area. This difference in values concerning the mean indicates that 9 monitoring stations had higher concentrations, while 13 stations showed values lower than the average SPM concentration. Reason why it becomes an indicator of importance and impact when making decisions and defining local plans to improve air quality in the sector.

3.2. Morphological characterization of SPM

The morphological analysis of the SPM samples collected at the monitoring stations is presented in Figure 3. The images reveal that the samples analyzed are characterized by their diversity in terms of shapes, colors, and sizes. In terms of morphology, two types of particles were observed: (a) natural; mineral dust particles that have a rough surface and sometimes form structural aggregates with irregular shapes and sizes; and (b) anthropogenic; which usually have a spherical morphology and a smooth surface, revealing slow burning processes or other processes developed at high temperature (29).

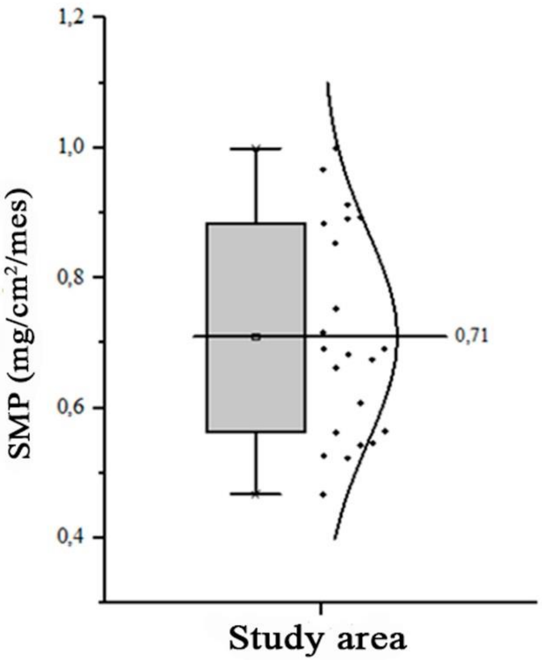

Figure 1. Concentration of SPM in the parish of Cajabamba.

The morphological part and abundance of SPM are attributed to high levels of pollution at this site (30). The morphological part of the material is also associated with the presence of Fe, Si, Al, O, and Ca which come from sources of natural and anthropic origin (31). This type of information provides significant data on the morphology, size, shape, and sources of contamination.

The image (a) shows the presence of brown organic particles similar to clay. In addition, there is a deformed filament of black color, the result of the combustion of the engines of vehicles that circulate on the main road. These particles have been collected to assess their size, using a 1x1 mm grid. Image (b) also presents brown and crystalline particles, as well as some black particles, which could be the product of the combustion of hydrocarbons such as soot and charcoal, although to a lesser extent (32). Image (c) shows more clearly the presence of brown particles (organic material), and the presence of crystals (quartz) and black particles (combustion products). Sample (d) highlights the presence of large amorphous particles of a yellowish brown color which can be of vegetable origin such as small pieces of wood or some vegetable origin, dust particles (clays) and black particles (by combustion) are also visualized.(33).

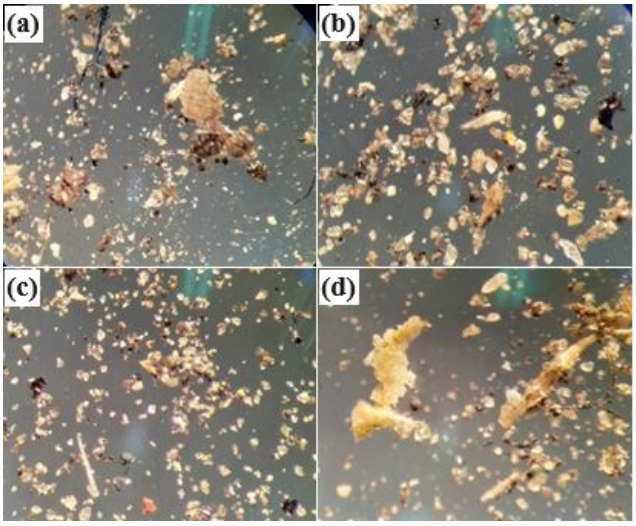

Figure 2. SPM images were obtained from the Optical Microscope (100x) in the Cajabamba parish.

In short, this type of particle comes from both natural and artificial emissions. Artificial sources include dust from unpaved roads, the transport of raw materials such as sand and clay to produce handmade bricks and blocks, and possibly remnants of metallurgy. Emissions of sedimentable particles occur due to the action of the wind on the earth's surface, which causes its aggregation and subsequent precipitation. In these particles, they find main minerals such as calcite, quartz, dolomite, kaolinite, illite, and feldspars (34).

As previously analysed in the samples obtained, the particles are considered primary because they are emitted directly into the atmosphere. Although most SPM emissions are of natural origin, it is necessary to consider the existence of a limited number of anthropogenic sources of particulate mineral material.

In this study, particles from combustion processes are generated by mobile and stationary sources. Mobile sources are considered the most relevant in this research because the Cajabamba parish is part of an important road artery (E35) being cars the generators of VOCs in the environment. These substances are toxic to both humans and nature.

As for the stationary sources generating particulate matter found in the area, block factories are included (35) and metalworking, in addition to burning some waste carried out by some people in the territory.

This assertion finds support in the study of Romero et al. (36), on urban climates and air pollution in Santiago de Chile. In their research, the authors mention that there is an increase in air pollution levels, which can have harmful effects on people's health.

3.3. Statistical Geostatistical analysis of SPM concentration and dispersion

The spatial distribution of SPM for the study area through the kriging method shows a similar trend (Figure 5). The resulting map of the model shows a spatial distribution ranging from 0.56 (low) to 1.00 (high). It is important to indicate that for the elaboration of this map, various sources of meteorological data were used, such as wind speed and direction, which allowed for estimating how the wind behaved during the capture of the SPM in the study area.(25).

The meteorological data that were used were from 3 meteorological stations which allowed a triangulation of data around the study area. It should be noted that 2 of the weather stations are from the Escuela Superior Politécnica de Chimborazo (San Juan and ESPOCH) and are located north of the study area, data from the INAHMI station "M5186" located in the Colta canton south of the study area were also used.

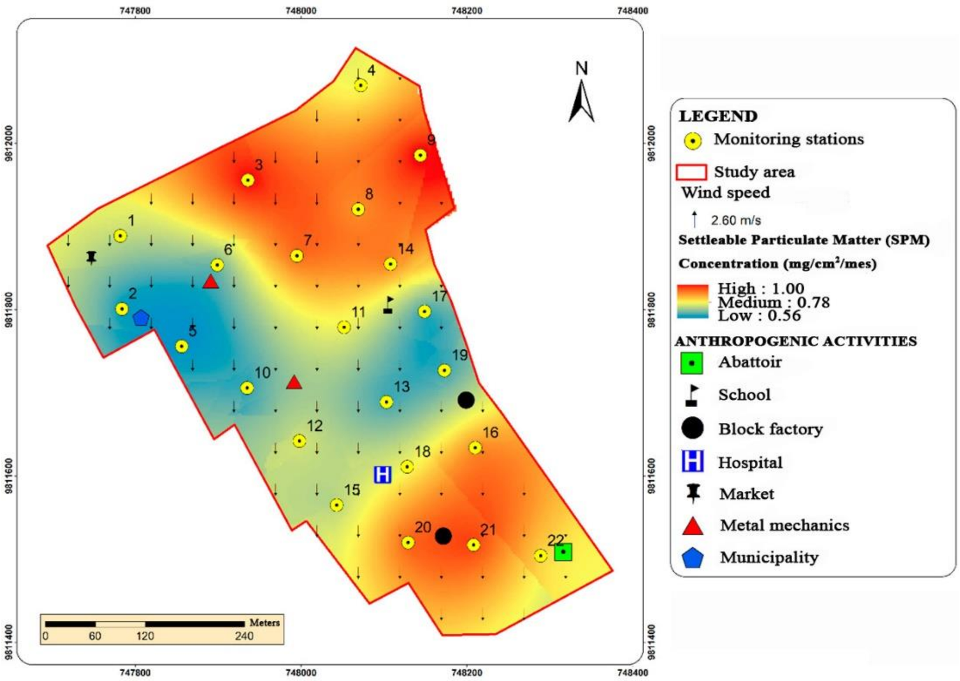

Figure 5. Map of concentration and dispersion of the SPM.

During the investigation, the analysis of the wind direction and speed was carried out where the predominant direction was in the south direction, while the average wind speed was 2.6 m / s. These values served as the basis for generating the SPM dispersion map where the north and south were the ones with the highest concentration of particulate matter. It should be noted that the study area especially the northern part is surrounded mainly by agricultural areas, flour factories, and constructions, while in the southern area, there is the presence of block factories and these may be a source of PM in the area (37).

In the centre of the study area, there are the lowest concentrations of SPM because the anthropic activity is diminished, in addition to the buildings themselves can act as artificial barriers in the area. The SPM dispersion map allowed us to identify critical concentration radii of approximately 200m around. This radius of deposition is conditioned by the topography and direction of the wind in the sector and it is also not common to discharge pollutants at height, rather the emission is a few meters from the surface (38). Hence nOur values coincide with those described by Hinojosa et al., (39), in their study on the Distribution of PM2.5 air pollution in Mexico City: Spatial analysis with land-use regression model.

CONCLUSIONS

The evaluation of SPM in the study area does not exceed the thresholds contemplated in Agreement 097-A, however, it exceeds the maximum permissible limits established by the WHO (0.5 mg / cm2 / month), it is evident that air quality is affected, and that it could have long-term consequences on the health of the inhabitants.

The characterization of the SPM showed spherical, rounded, irregular shapes, which indicate incomplete combustion, or another process generated at high temperatures. In this way, it is announced that emissions from fixed sources are mainly caused by the presence of block factories, agricultural fields, and the flour factory that is close to the study area, while emissions from mobile sources are caused by vehicles circulating in the area. This type of particle represents one of the greatest health risks especially of the surrounding population.

The concentration and dispersion map identified 3 categories: high (1 mg/cm2/month), medium (0.78 mg/cm2/month), and low (0.56 mg/cm2/month), where the northern and southern areas are the ones with the highest concentration of SPM.

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