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Influência das Características Geomorfológicas e Climáticas no Movimento de uma Pluma de Poluentes: Exemplo do Distrito Industrial de Pirapora, Minas Gerais, Brasil

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R E S U M O

Este trabalho apresenta uma análise da circulação de uma pluma de particulados atmosféricos emitidos no distrito industrial de Pirapora. A metodologia incluiu o estudo da direção e velocidade dos ventos; levantamento da extensão e direção da pluma em imagens de satélite e avaliação do condicionamento geomorfológico baseado em levantamentos de campo e dados SRTM. A dinâmica atmosférica regional histórica é marcada por ventos de nordeste (NE) e direciona a movimentação preferencial da pluma para sudoeste (SW). A geomorfologia atua no controle da dispersão por meio de dois corredores geomorfológicos (NE-SW) e (E-W), estes delimitados por barreiras orográficas nas cotas médias de 600m e 800m. Foi verificado no quadrante oeste (W) perfil de pluma com extensão de 128,5 km, sendo este o de maior risco ambiental devido à deposição de poluentes transportados por ventos de leste (E). As imagens de satélite associadas à dinâmica dos ventos e feições do relevo permitiram a identificação das áreas com maior possibilidade de degradação da qualidade do ar e acúmulo de material particulado. A quantidade e qualidade da sua deposição em animais, plantas e superfícies depende das propriedades particulares e condicionamento da pluma. Estes resultados são importantes no direcionamento dos estudos de contaminação nos compartimentos ambientais receptores (solo e vegetação) na área de deposição da pluma e poderão subsidiar ações de gestão ambiental, bem como auxiliar na tomada de decisões por parte dos gestores públicos.

Palavras-Chaves: material particulado, geomorfologia, movimentação atmosférica, risco ambiental.

Influence of Climatic and Geomorphological Characteristics on the Movement of a Plume of Pollutants :Example from Industrial District of Pirapora, Minas Gerais, Brazil

A B S T R A C T

This paper presents an analysis of the movement of a plume of atmospheric particulates emitted in the industrial district of Pirapora, Minas Gerais, Brazil. The methodology included the study of wind direction and speed, evaluation of plume extent and direction in satellite images and field observations and the geomorphological conditionins based on mapping and SRTM data. The regional atmospheric dynamics are marked by winds mainly from the NE and therefore the preferred plume orientation is SW. Two geomorphological corridors (NE-SW) and (E-W) with altitudes of 600 m and 800m controlled the plume dispersion in the direction of SW and E. The greatest environmental risk of deposition of pollutants carried by winds from the East is given by the plume distribution in around 128.5 km. The information of satellite images associated with wind dynamics and geomorphological features allowed the identification of different areas with different degree of air quality degradation and particulate accumulation. These results should subsidize environmental management actions, as well as assist in public managers decisions.

Keywords: particulate matter, geomorphology, atmospheric movement, environmental risk.

Introduction

One of the main environmental problems nowadays is the degradation of air quality, especially in urban and industrial areas. This is mainly due to the increase in the emissions of hazardous gaseous compounds and particulates into the atmosphere.

The visual impact of the pollutants in the atmosphere is one important aspect of the degradation of air quality. Stern (1986), stated that due to the visual impact and the concern with air pollution, programs aimed to reduce the emissions of particulates and smoke were initiated.

The sources of air pollutants can be natural or anthropogenic. Anthropogenic sources have different characteristics and varies among spatial and temporal scales.. Factors that can hinder the dispersal and dilution of the pollutants are related to the location of the emissions, volume of the material released and intensity of the production.

The pollutants released in the atmosphere undergo different process. They can be transported, diluted and chemically or physically modified during trajectory. Finally, they reach final deposition site (*i.e.* fall out, wash out) where they can cause damage to the environment, animals or human health (De Nevers, 2000).

Pollutant plumes originated in industrial areas can carry material over long distances. These compounds, composed by particulates, liquids and gases have a pattern of movement initially in a vertical way and latter horizontally. The pattern of dispersion of these plumes, especially from stationary sources, depend on the conditions of the atmosphere, winds dynamics and geomorphological features.

Several studies have used mathematical and deposition models to analyze the dispersion of pollutants in the atmosphere. These mathematical models are also used to calculate and predict future settings and stablish actions for air pollution monitoring and control (Moreira and Tirabassi, 2004; Albuquerque, 2010; Hoinaski, 2010; Machado, 2011; Tadano, 2012; Alves, 2013).

According to Medeiros (2003) and Cooper and Alley (2011) the dispersion process of pollutants in the atmosphere mainly depends on the topography of the region, weather conditions and characteristics. Meteorological aspects, such as wind speed and direction, are essential for understanding the horizontal movement of the pollutants in the atmosphere. Other important factor is the geomorphological features that can act as a barrier or directional channel interfering in the plume movement and influencing the deposition.

As highlighted by Ribeiro (2009), vertical and horizontal movement of the plume is sometimes difficult to visualize by photographs and airborne images, as it depends on the location of the observer,. One option is the use of remote sensing techniques. Remote sensing allows the observation of various surface features based on the spectral response of objects and is considered an important tool in environmental studies (Florenzano, 2002).

Tarana and Viswadham (1982) reported that "the remote sensing techniques can be applied to the study of smoke plumes in industrial sources" and the results point to the feasibility of the use of Landsat images in the detection and monitoring of large smoke extensions. The advances achieved in the last decades with improved spatial and temporal resolution expanded the possibility of smaller plumes extension studies.

In Brazil, research activities have been developed by INPE (National Institute of Space Research) in the Cerrado (Savannah) and the Amazon region (Almeida-Filho and Shimabukuro, 2004).

Due to the difficulty to obtain accurate meteorological data in smaller spatial density to apply computational dispersion models, the use of satellite images can be an important tool in the study of the dispersion of air pollution plumes.

The aim of this paper is to delineate and characterize the movement of a plume of particulates originated by the industrial district of Pirapora MG and to show its influence over the environment. The study covered mapping the extent and preferred direction of the plume, the study of the dynamics of the winds, geomorphological factors and analysis of satellite images (Landsat 5).

Material and Methods

Study Area - the area of study (Fig. 1) is located in the micro region between the cities of Buritizeiro and Pirapora in the North of Minas Gerais State. This region is marked by intense transformations land use beginning in the 1960's. In this period took place the installation of the industrial district of the Pirapora, that today is a production center of ferrosilicon and ilicon metal.

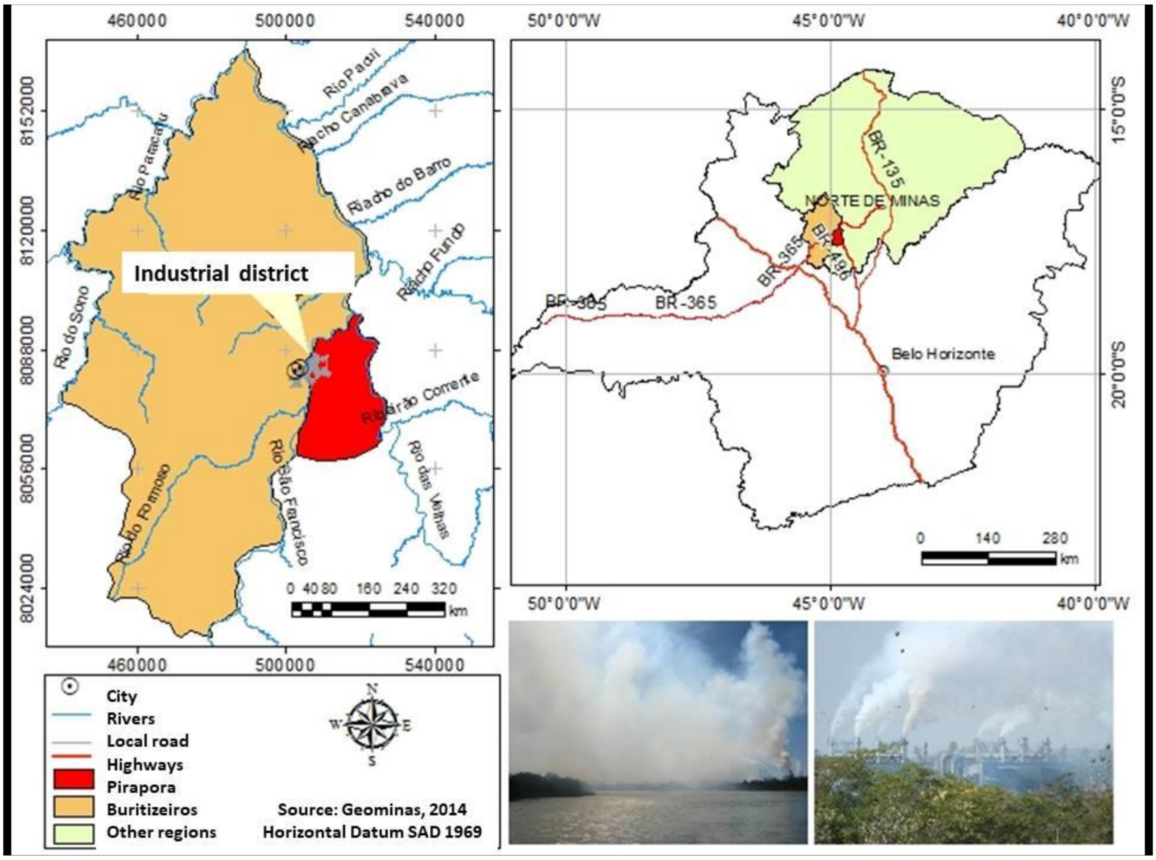

Figure 1. Location map of the study area, showing thee municipal and regional context. In detail, pictures of the particulates plume, seen from the São Francisco River South of the industrial district (emissions by the chimneys).

Silicon productions main environmental impact is the emission of air pollutants from the furnaces and metallurgy. According to FEAM (2010), from all emissions generated in a Ferroalloy/Metal Silicon plant, the ovens have the greatest impact and the installation of filters in chimneys is highly recommended. In the Pirapora industrial plant, only two, from a total of ten industries, have a filter system installed. Therefore, the emission from the industrial area is visible as a dense plume of particulates.

The studied area is inserted in the San Franciscano depression and the San Francisco Valley, bordered by elevated tabular surfaces and erosive slopes, formed by later geological units.

The climate is tropical with two well defined seasons and according to Köpen classification, of Aw type, rainy tropical, hot and humid, with dry winter and rainy summer, characterized by the average temperature in the coldest month, exceeding 18°C (CPRM 2001).

Methods - in this study, information about wind direction and speed, satellite images and SRTM data were used.

Landsat 5 scenes were used to identify and map the plume. The images used are from 1984 and 2011. A total of 215 images were used in the study and about 18% have clouds or a background noise which could not the used for the analysis and measurement of the extent of the plume.

According to INPE (2014), band 1 (0.45-0.52 µm presents the best sensitivity for smoke plumes from burning or industrial activity; band 3 (0.63-0.69 µm shows a good contrast between planted areas an urban regions and, band 4 (0.76-0.90 µm, have a sensitivity to morphological changes and allows the gathering of the information about geomorphology, soils and geology. All these bands attend the goal of this study, showinggood visibility of the air particulates and roughness of the ground in contrast to the characteristics of the surface. The false color mixture RGB 413 presents the best result in the identification of the plume.

The largest number of used images are from the last 10 years, especially from the period of dry weather (mainly July), where it is possible to obtain images with less interference. All images were treated with the software ArcGIS 10.1 using the "composite bands" option.

At the field the geomorphological units were characterized and latter it was applied the interpretation by satellite images. The characterization of the geomorphological units (i.e. depressions, hills) was done using a Digital Elevation Model (MDE) and topographic profiles prepared in Surfer 8.0 and ArcGIS 10.1. For elaboration of the MDE were processed SRTM (86 m) data and generated 10 m contour lines.

The study of the wind direction and speed was conducted based on seasonal data of the National Institute of Meteorology (INMET) located in Pirapora (Tab. 1).

Table 1. Weather stations near the studied area

Station (Code)	Beginning of Operation	Lat/Long	Height
Pirapora - MG (OMM: 83483)	23/12/1912	-17.349167º/-44.921667º	505.24 m
Pirapora - A545 (OMM: 86759)	04/07/2007	-17.258064º/-44.835600º	505 m

Wind diagrams (Roses) were prepared from monthly data and schedules using Excel, and WRPLOT View 7.0.

Results and Discussion

The wind is the principal force that transports compounds in the atmosphere. The dispersion of pollutants in the atmosphere depends on the wind magnitude and velocity, its orientation and changes, which are metereological determinants in the study of air pollution (Woods, 2009; Alves, 2013).

Wind velocity, frequency and orientation - the meteorological data of Pirapora region used in this study demonstrated a predominant wind direction from the northeast (NE; 31.70%), determining displacement in the Northeast-Southwest (NE-SW) direction. Winds from the South and Southwest (SW) are also quite significant, corresponding respectively to 14.31 and 7.98% of the cases.

Over the past 53 years the velocities varied between 1 - 1.99 m/s (70.14%), followed by a class between 2 - 2.99 (26.99%; Fig. 2). These two classes of speeds correlated positively, with the preferred wind direction of NE, which indicates a greater potential for dispersal of pollutants.

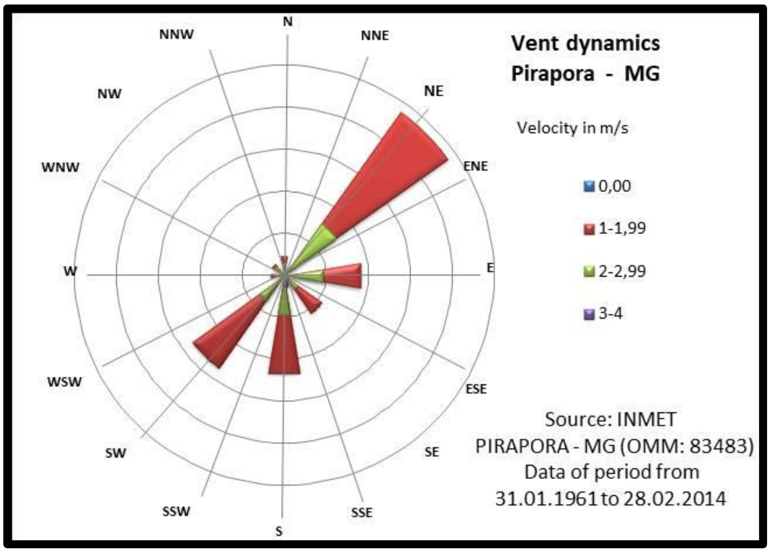

Figure 2. The diagram is showing the wind directions between 1 January 1961 and 28 February 2014. Remark the principal direction from NE, SW and S (Pirapora weather station).

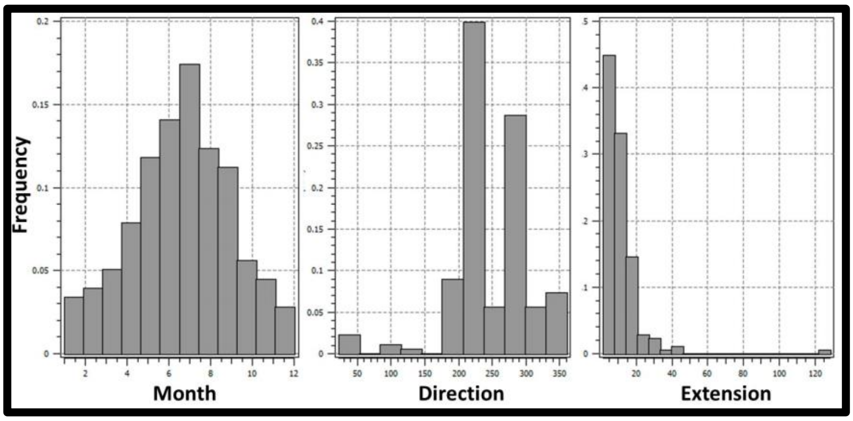

Figure 3. These figures show the frequency distribution 1. Number of images analyzed per month, 2. The direction of the plume in degrees and 3. Extension of the plume in km. Statistical analysis were performed using the software The Stanford Geostatistical Modeling Software (SGeMS) available in http://sgems.sourceforge.net/?q=node/77.

Annual evaluation of wind and plume movements - the behavior of air movements in 2011 is shown in the study of wind speed and direction, elaborated in the WRPLOT View 7.0 (Fig. 4, Gomes, 2010) with a principal transport direction of the pollutants W.

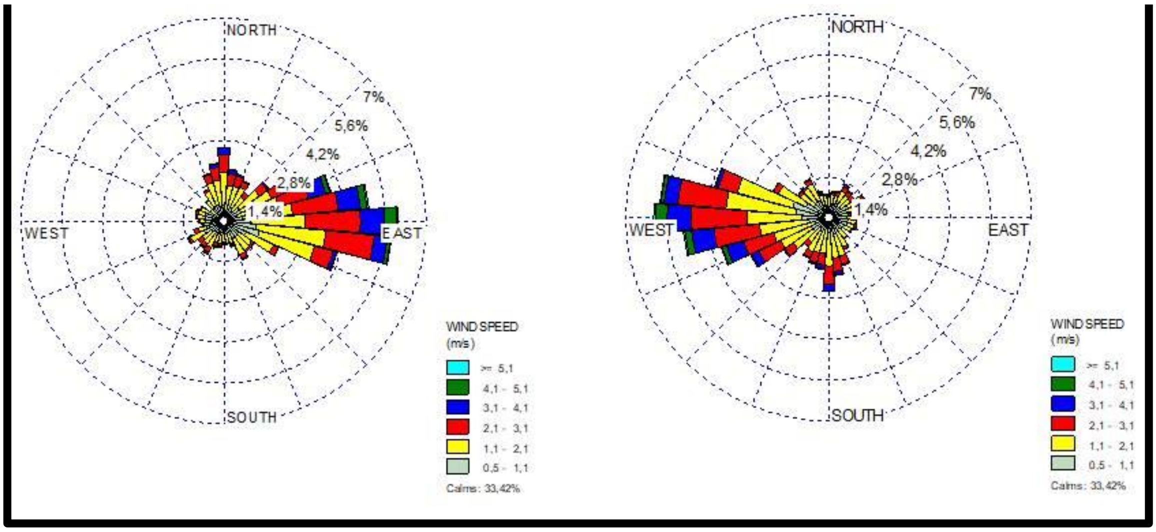

Figure 4. General wind direction and speed distribution in 2011
a. Wind direction b. Wind speed.

The annual average speed of 1.08 m/s shows that the plume existence and deposition is more common around the source also showed by the high frequency of calm winds (0,-1 < 1ms; 33.4%; Albuquerque, 2010) indicating the low potential of dispersion and transport of pollutants. It was followed by the classes between 0.5 and 1.1 (22%) and 2.1 and 3.1 (12.5%). Higher velocity frequency, between 1.1 and 2.1 m/s, occurs in 26.5% of the measurements (Fig. 5).

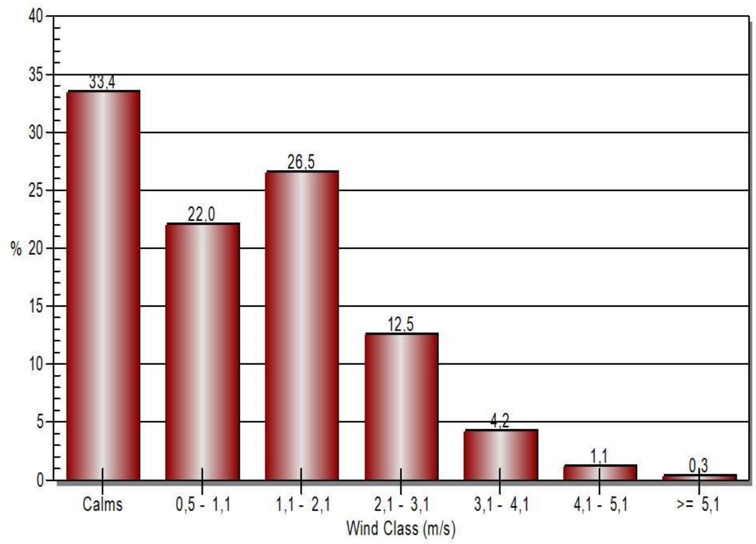

Figure 5. Wind speed distribution in 2011.

The obtained data show a clear preference of NE - wind direction during the year 2011 with a secondary distribution in other directions during the year (Fig. 5 and Fig. 6).

Between the months of November to March, direction of the wind, vary from E to N (Fig. 6) and carry the plume material in a S to SW direction. Whereas in December and January the wind originated from ~ N guiding the plume toward S, both during the rainy season. This variation of the directions explains specific deposition areas indicated by high levels of contaminants deposited.

In the period between May and October predominated wind direction is from E and, between July and October; the main orientation is West, causing a high accumulation of pollutants in the atmosphere during the dry season (Fig. 7).

In June and July, with wind from E to S occurring mainly in highest speeds (> 5, 1 m/s), causing a long distance transport in W to N (Fig. 8).

This shows that greater wind intensity allows a transport through higher distances and dispersion of pollutants changing from local to a regional-scale (50 to 500 km according to Vallero, 2008). This consequently increases the area of impact.

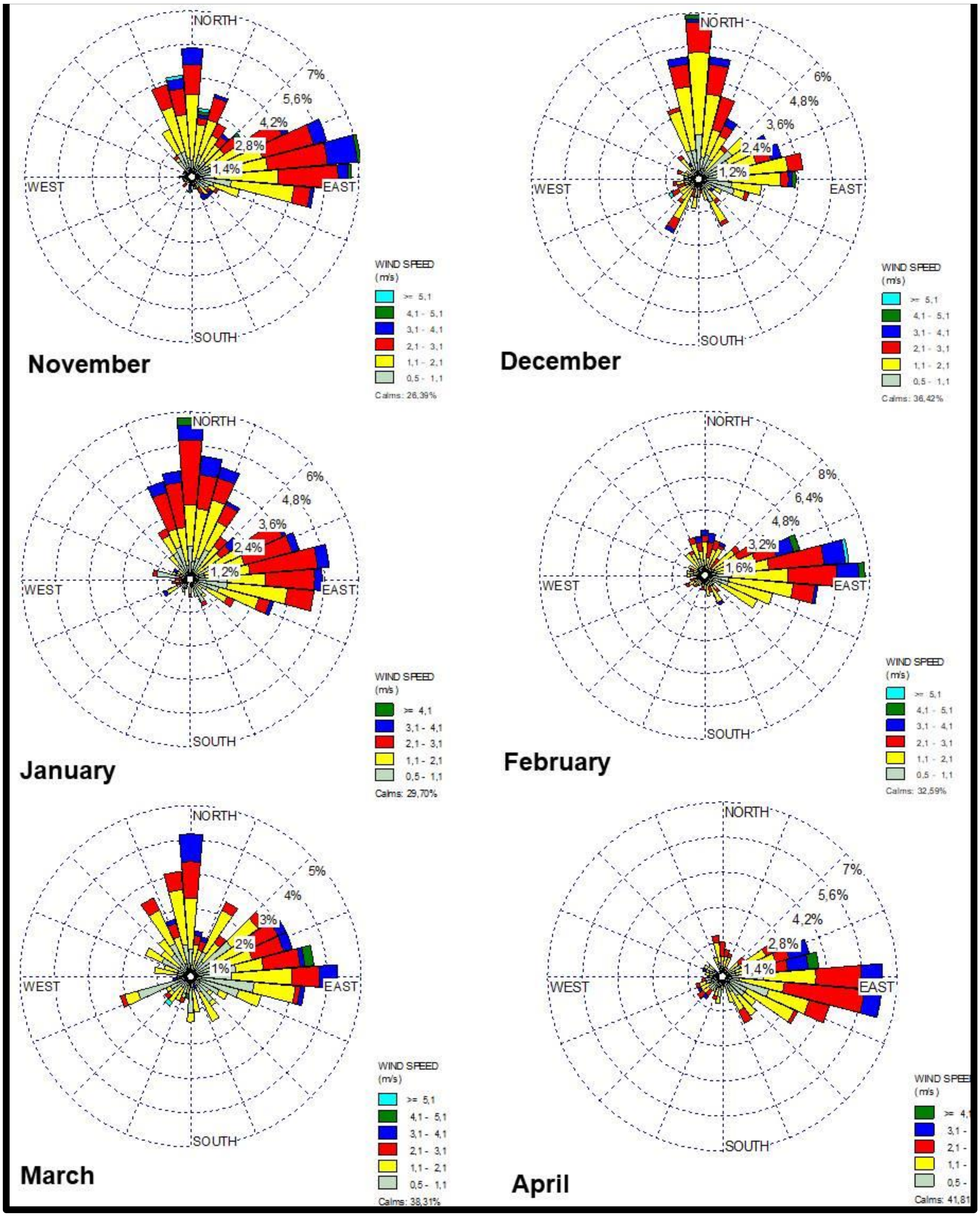

Figure 6. Evolution of wind speed and direction from November to April 2011.

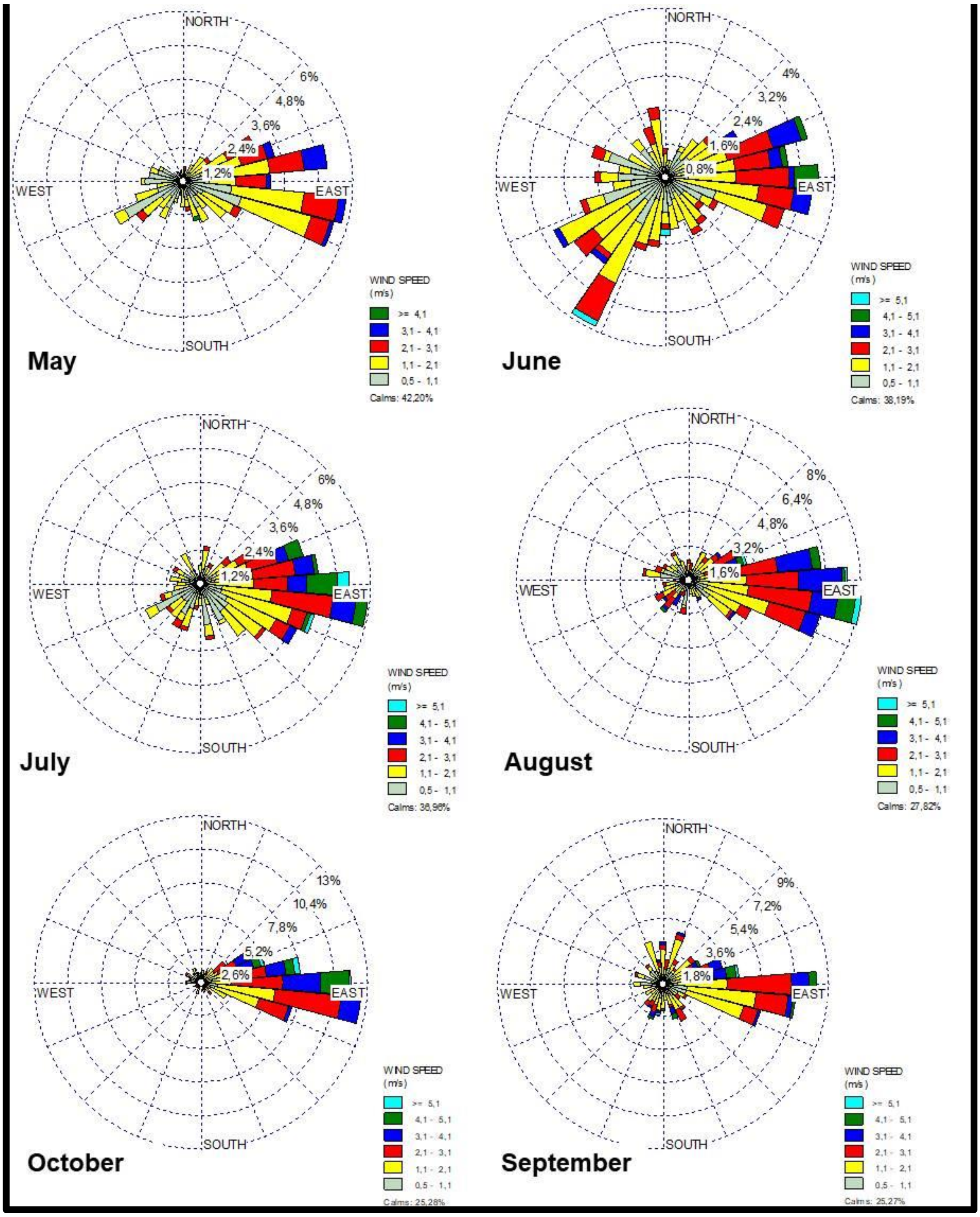

Figure 7. Wind speeds and directions for different months (between May and October 2011).

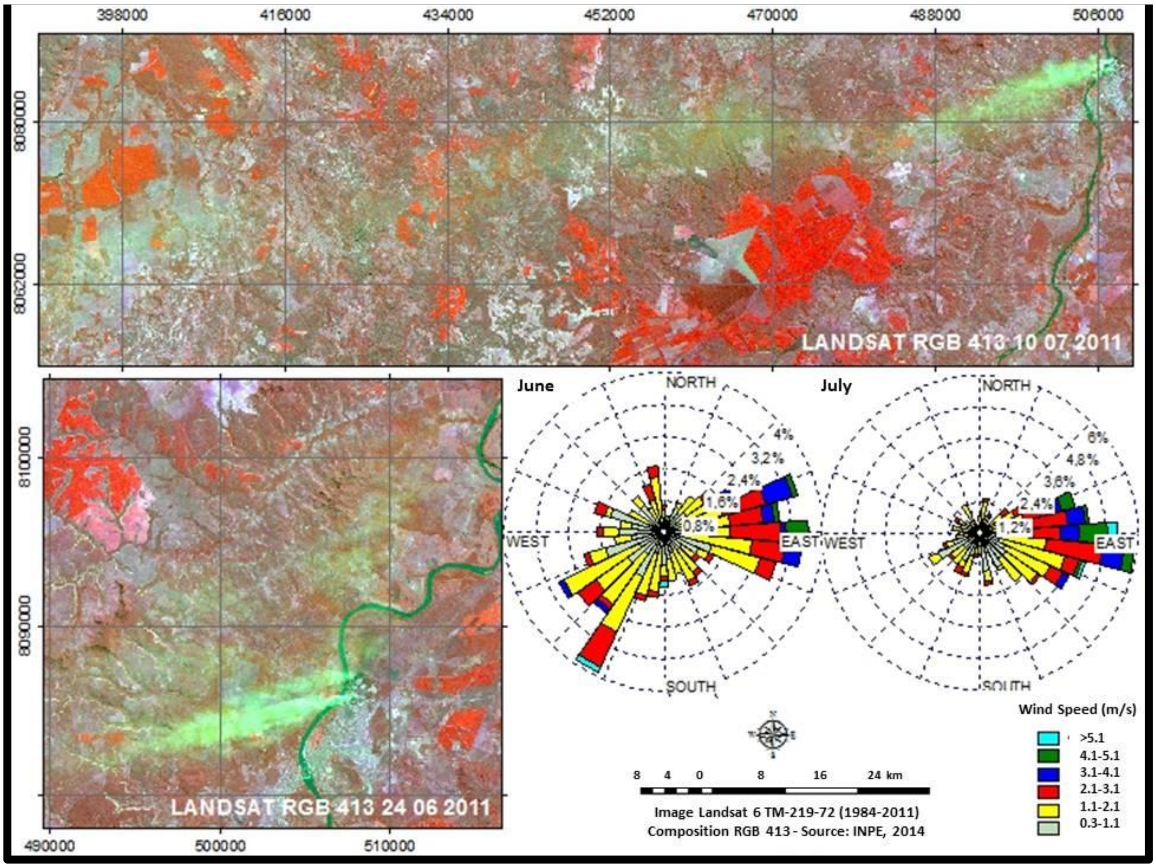

Figure 8. Wind direction and plume movement. 1. Mainly only wind from east with high speed in July (> 5.1 m/s) allowing plume transport greater than 100 km. 2. Wind form SW causing transport to SE with a secondary dispersion of the plume to the North.

The observations indicate that the main mechanism transport during the year occurs towards W, with minor and less significant variations to N-S. Consequently, the plume disperse over the water shed of the São Francisco River, the agricultural area of Buritizeiros village, SE and W, and the city of Pirapora in the SE.

Morphological control - predominant geomorphological structures in the West of the São Francisco Valley and therefore in wind and plume direction are the Highlands of Chapadão and Gerais, with altitude around 900, the Repartimento range (Morro do Trinchet) in the East up to700 m, and the Jatobá Complex (which includes the Serra do Germans; ~470 m) in the North (Fig. 9). These are the main two heights limiting and orienting the plume movement in approximately southern direction.

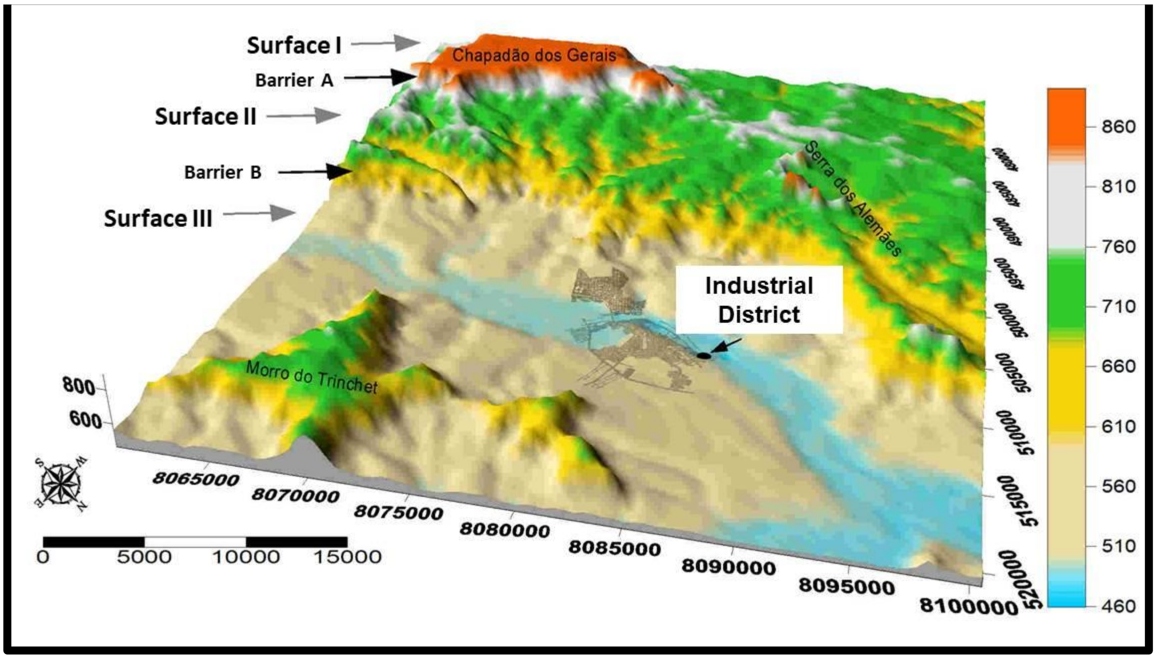

Figure 9. Digital elevation model indicating the geomorphological features and the orographic barriers (in yellow and gray). The tabular surfaces are indicated: I in orange (upper), II in green (Intermediate) and III in beige (lower). The valley of the São Francisco river is colored in blue.

The first important orographic barrier (A) is characterized by level change of about 230 m between the São Francisco depression (470 m) and an intermediate surface (700 m). The second important barrier (B) have a nearby 200 m inclination, defining the transition from the intermediate to the upper surface level (surface I) structures by erosional escarpments bordering and structuring the upper table surface (around 900 m) creating two barrier of 600 m and 800 m respectively (Fig. 10).

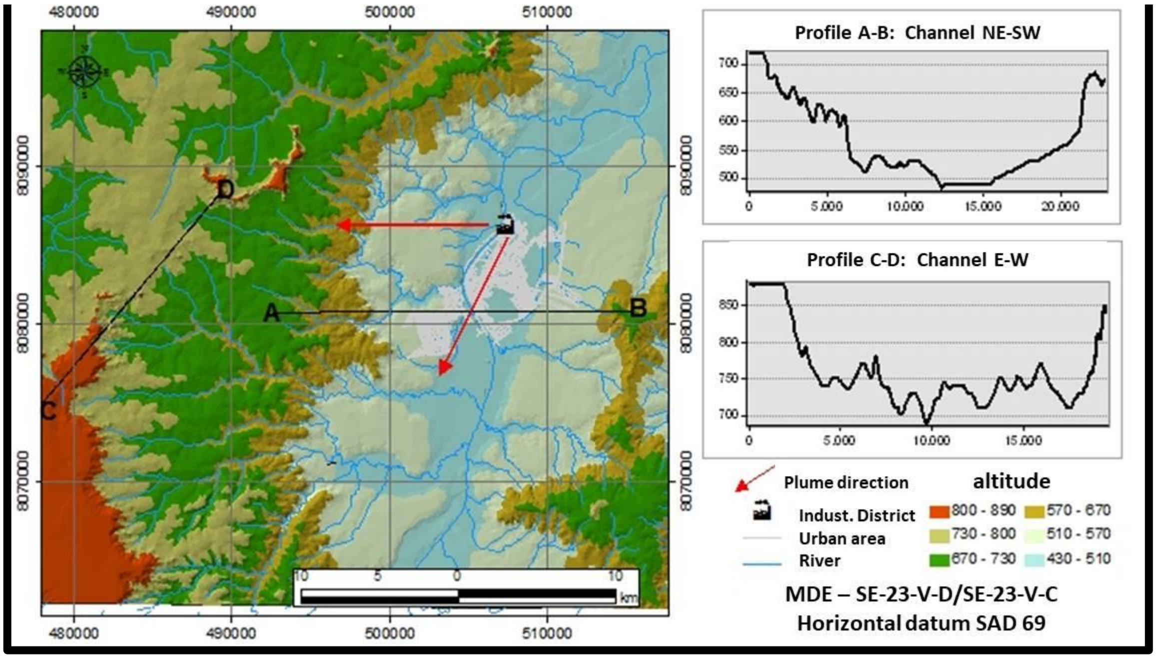

Figure 10. Topographic profiles showing the geomorphological “channels” where the plume move.

This scenario created two main geomorphological corridors (Fig. 10) where the plume can deviate certain conditions.

The first, NE-SW orientated, causes a flow deviation in 45.4% of the cases with preferential directions to SW - SSW at an average distance of 10 km smoke extension. The second, with E-W direction, which changed the the plume direction to W had lower altitudes allowing maximum transport distances (Fig. 11).

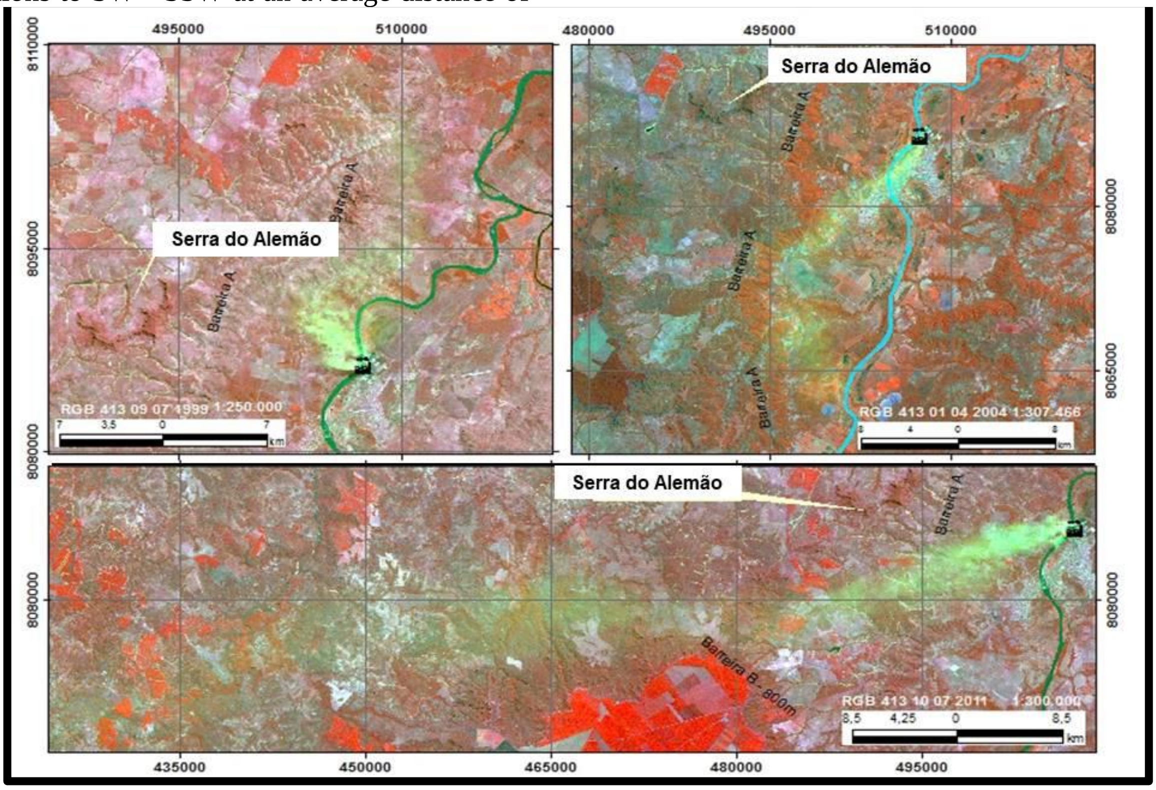

Figure 11. This figure shows satellite images in colour composition RGB413 permitting to see the distribution of the plume of particulates and the geomorphological conditioning of their transport direction.

Under low velocity conditions the plume is directed by the barriers, especially by the first, c within the main valley of the lower course of the São Francisco River and its tributaries, affecting the urban and agricultural regions partially.

Environmental risks - The environmental risks are conditioned by the wind direction, the morphological features, climatic changes, intensity and type of industrial production.

The annual variation of the plume for 2011 shows movement from SW (39.9%), the most important direction, secondly to W (28.7%), followed by N (7.3%), latter by NW-WSW (5.6%), and to S (5.1%) and finally SSW (3.9%). The rest is divided between the directions E, NE NNE and SW (3.9%).

The highest risk and quantity of pollutant transport occurs in the SW direction (80%), covering urban regions of Pirapora and Buritizeiros, and the lower in SE (2%) direction.

The plume reached a maximum extension of 128 km (SW 2011) and an average distance of 10.6 km. The highest densities of particles were observed between 20 and 45 km with the average concentration of about 24.85 km from the source.

Summary of the results

1. The movement of the plume with atmospheric particulates evaluated in satellite images and by terrestrial observation show a preferential W-WSW direction, which is influenced by:
   1.1. The orographic Barriers approximately oriented NNE-SSW;
   1.2. Principal wind direction and speed that determine the properties of the transport system and permit transport for more than 100 km.
2. The average distance achieved by the plume and its distribution allows to separate specific areas with different intensity of particle outfall, in quantity, dimensions and mineral and

chemical composition, determining delimited regions of variable environmental impact.

4. The study shows that special attention must be given to the urban areas especially the localities of Buritizeiros, andPirapora.

5. The regions of agricultural activities (fruit and vegetables)located in the E-SE are less affected by the plume outfall, due to the low frequency of winds from NW.

6. Coffee, corn and soy plantations located at more distant highland surfaces, also be under the influence of the plume (50-100 km; W). .

Conclusions

The study of the behavior of the wind, geomorphological features using satellite images and interpretation has proved an efficient tool for evaluation of the behavior and dynamics of contamination plumes.

Therefore future studies in industrial areas, with detailed use of the atmospheric conditions, evaluating emission data from industrial sources may provide important additional information about the behavior of plumes s.l. and their influence over the environment and human health.

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References

Albuquerque, F., 2010. Formação e transporte das partículas finas inorgânicas em uma atmosfera urbana: o exemplo de São Paulo. Dissertação (Doutorado em Meteorologia) – Instituto de Astronomia, Geofísica e Ciências Atmosféricas, Universidade de São Paulo, São Paulo.

Almeida-Filho, R., Shimabukuro, Y.E. 2004. Monitoring biomass burning in the Brazilian Amazônia. International Journal of Remote Sensing, 25: 5537-5542.

Alves, S.F., 2013. Utilização do modelo de dispersão ARTM associado a recursos de geoprocessamento para simulação do impacto ambiental radiológico e emissões atmosféricas de um reator de pesquisa. Dissertação (Mestrado em Ciência e Tecnologia das Radiações, Minerais e Materiais) – Centro de Desenvolvimento da Tecnologia Nuclear, Universidade Federal de Minas Gerais, Belo Horizonte.

Bouças, J.G., 2009. Aplicação de técnicas nucleares nos estudos de avaliação da poluição do ar da região metropolitana de Belo Horizonte. Dissertação (Mestrado em Ciência e Tecnologia das Radiações, Minerais e Materiais) – Centro de Desenvolvimento da Tecnologia Nuclear – Belo Horizonte.

Cheremisinoff, N.P., 2002. Handbook of Air Pollution Prevention and Control. Woburn: Butterworth-Heinemann.

Cooper, C.D., Alley, F.C., 2011. Air pollution control: a design approach. 4 ed. Long Grove: Waveland Press,

CPRM., 2001. Companhia de Pesquisa de Recursos Minerais. Análise de Consistência de dados. Belo Horizonte.

De Nevers, N., 2001. Air pollution control engineering. 2 ed. Boston: McGraw-Hill.

FEAM., 2010. Levantamento da situação ambiental e energética do setor de prospecção de ações para o desenvolvimento sustentável da atividade: relatório de requisitos legais / Gerência de Desenvolvimento e Apoio técnico às Atividades Industriais. FEAM DPED - GEDIN - RT 07/2010. Belo Horizonte: Fundação Estadual de Meio Ambiente.

Florenzano, T.G., 2002. Imagens de satélites para estudos ambientais. São Paulo: Oficina de Textos.

Gomes, J., 2010. Poluição Atmosférica: um manual universitário. 2 ed. Porto: Publindústria, Edições Técnicas.

Hoinaski, L., 2010 Avaliação de métodos de identificação de fontes emissoras de material particulado inalável (PM10). 116p. Dissertação (Mestrado em Engenharia Ambiental) - Universidade Federal de Santa Catarina, Florianópolis.

Jacobson, M.Z., 2002. Atmospheric Pollution: history, science and regulation. 399 p. Cambridge: Cambridge University Press.

Maioli, B.G., 2011. Quantificação e caracterização do Material Particulado fino (MP2,5) na região metropolitana da grande Vitória-ES. 118f. Dissertação (Mestrado em Engenharia Ambiental) - Universidade Federal do Espírito Santo, Centro Tecnológico, Vitória.

Moreira, D.M., Tirabassi, T. Moraes, M.R., 2004. Meteorologia e Poluição da Atmosfera. Ambiente & Sociedade, Vol. VII nº. 2 jul./dez. p. 1-13.

Moreira, D., Tirabassi, T., 2004. Modelo matemático de dispersão de poluentes na atmosfera: um instrumento técnico para a Gestão Ambiental. Ambiente & Sociedade, 7, 159 -172.

Moreira, D., Tirabassi, T., 2004. .Modelo matemático de dispersão de poluentes na atmosfera:um instrumento técnico para a gestão ambiental, Ambiente & Sociedade 7, 159-172.

Ribeiro, L., 2009. Procedimento de Determinação dos Coeficientes de Dispersão Atmosférica do Modelo Gaussiano através de Análise Fotográfica de Plumas de Fumaça. Rio de Janeiro: Dissertação (mestrado) - Instituto Militar de Engenharia – Rio de Janeiro, 116 f.

Stern, A.C., 1986. Air Pollution: Suplement to air pollutants, their transformation, transport, and effects. v.6. 3 ed. Orlando: Academic Press.

Tadano, Y.S., 2012. Simulação da Dispersão dos Poluentes Atmosféricos para Aplicaçãoem Análise de Impacto. Campinas: Tese de Doutorado - Universidade Estadual de Campinas.

Torsani, J.A., Viswanadham, Y., 1982. A study of atmospheric diffusion from the LANDSAT. Journal of Geophysical Research 87, 9621-9635.