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Research Article

Optimization of Protective Measures to Control PM Emissions in Areas Near the Cement Factory. Case Study: Cement Factory in Borizane, Albania

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ABSTRACT

The cement production industry is one of the most polluting activities worldwide. The Cement Factory in Borizane, Kruje, Albania, has been operating for nearly 19 years, utilizing local limestone and shale. This operator produces various types of cement. Health issues of residents and environmental problems suggest issues with protective measures. This article highlights the need to optimize protective measures to control PM10 levels around the factory, depending on dispersion due to weather, climate, geology, and topography.

According to the Source-Pathway-Receptor (SPR) concept, PM10 emissions in four stacks, climate conditions, and terrain were analyzed. The AIRMOD program assessed their dispersion. The study concluded two dispersion scenarios. The first scenario, good dispersion of PM10 concentrations within the norm during months with cool temperatures, wind speeds ≥ 3 m/s. The second scenario, low dispersion of PM10 levels exceed the European norm (40 μg/m³) during high-temperature months with winds ≤ 2 m/s, southwest direction toward populated areas.

Long-term exposure may link to increased bronchial, cardiac, and cancer risks. Minimizing PM10 levels with cost-effective protective measures is essential, especially in months with winds ≤ 2 m/s.

Keywords: Air Pollution, Cement Factory, Environmental Impact, Human Health Impact.

INTRODUCTION

The Boka e Kuqe Area, Borizane, Kruje-Albania, is known for its potential for limestone exploitation and cement production. It is located 50 km away from Tirana, the capital of Albania. The village of Borizane has about 5500 residents and covers an area of about 13,000 km². Small settlements and private properties are spread throughout the region. The land is primarily used for agriculture. Besides the Cement Factory in the Fushe-Kruje - Kruje area, there is another cement factory as well as quarries exploiting limestone. Since 2006, the Cement Factory has been operating in this area. Despite the fact that these activities represent an important pillar of economic sustainability, they are accompanied by significant impacts that affect the land surface, water and other natural resources, not to mention the possible negative effects on human health.

Figure 1. Area of Study (source: Google Earth)

Figure 2. Cement Factory (source: Google Earth)

Studies indicate that high levels of pollutants increase the morbidity and mortality rates [1],[2]. Long-term exposure to $PM_{2.5}$ and PM_{10} particles increases the risk of acute and chronic respiratory infections, lung cancer, atherosclerosis, and cardiovascular disease [3][4][5]. The study originates from complaints by residents in the area surrounding the factory, noting that dust levels are continuously high in the air and on various surfaces, there is also a decline in agricultural production and vineyards. According to statistics [6] from the Kruje Health Center and Kruje Public Health Directorate, from 2014 to 2018 and onwards, the highest number of people affected by chronic pulmonary diseases, mainly bronchial asthma and chronic bronchitis, has been in the Borizane area.

Figure 3. (Photos Bratko B, 2023)

Figure 4. (Photos Bratko B, 2023)

PM emissions are discharged into the atmosphere through four stacks at the cement factory, from the stack of the raw material mill (limestone and clays, extracted from quarries near the factory), from the kiln stack where clinker is prepared, which in addition to PMs also emits SO_x, CO^2, and NO_x, from the coal mill stack which is burned in the clinker kiln and from the stack of the cement mill. Dust is also generated during the drilling-blasting process, excavation, loading, and transport of material. Accidental dust emissions occur every 2-3 months, lasting 20-30 minutes and are caused by the failure of filters that are present in every stack. To assess the impacts of these pollution sources on the environment of the area, air pollution modeling is conducted using resource data, meteorological data, and geographic data (topography, land use type). One of the most important air pollution dispersion models is the American Meteorological Society and U.S. Environmental Protection Agency Regulatory Model (AERMOD). AERMOD is used to determine the concentration of various pollutants in urban and rural areas [7];[8]. AERMOD is a steady–state Gaussian plume dispersion model aimed at short–range (<50 km) air pollution dispersion from point, line, area, and volume sources [9]. AERMOD's concentration algorithm considers the effects of vertical variations of wind, temperature, and turbulence profiles. AERMOD is aimed at the short-range dispersion of air pollution emissions from stationary industrial sources and is not equipped to account for the chemical reactivity of emissions [10]. The AERMOD program was used to estimate particulate matter PM levels in residential areas. It indicated that wind speed and the stack height impact pollutants dispersion [11]. The impact of PM emissions from the cement factory, as well as other activities related to the exploitation of limestone and another cement factory in the area around them, requires further studies, but our study seeks to highlight the need for optimization of protective measures, according to meteorological conditions. Implementing the AERMOD program will help us assess the dispersion of PMs from stacks of different heights, different emissions, at different wind speeds, and undertake specific protective measures based on these factors.

MATERIALS AND METHODS

As suggested by the Source-Pathway-Receptor (SPR) concept [12], the environmental receptor impacts from anthropogenic activities depend on the polluting sources, their potential to cause harm, the conditions of transport and transformation of pollutants, and the sensitivity of the receptors. Following this, all necessary information has been gathered according to the SPR model.

Data for the area where the Cement Factory operates

Geographical position of the factory: it is located at these coordinates: 41°32'56.93"N, 19°43'30.86"E. As mentioned earlier, the nearest populated area to the Cement Factory is Borizane. The land is primarily used for agriculture. Borizane is characterized by ecological diversity but its habitat is not unique. It falls into the category of areas with low vegetation (out of 4 zones) which in Albania are called "sclerophyllous forests and shrubs with permanent greenery" (or 'typical Mediterranean vegetation with permanent greenery'). Several plants, reptiles, and amphibians found in or near the factory area are protected and listed in the Red List of Albania [13]. Two species of flora included in the Red List in Albania, named Oak (Quercus) and Salvia officinalis (sage), are featured in the rehabilitation process of quarries. The Kruje - Borizane - Droje - Picrage region is part of the Dajti - Kruje - Lac to Renc-Kakarriq mountain range. Its geological structure is mainly composed of carbonate and flysch formations of the Kruje Zone, with an anticlinal form and a tendency to slope from the east. The study region consists of carbonate rocks, mainly massive and slab limestone of the Upper Cretaceous (Cr2) and partially of the Eocene (Pg2), Oligocene flysch, as well as terrigenous deposits, represented by claystone, siltstone, and marlstone of the Tortonian. (Albanian Geological Service)

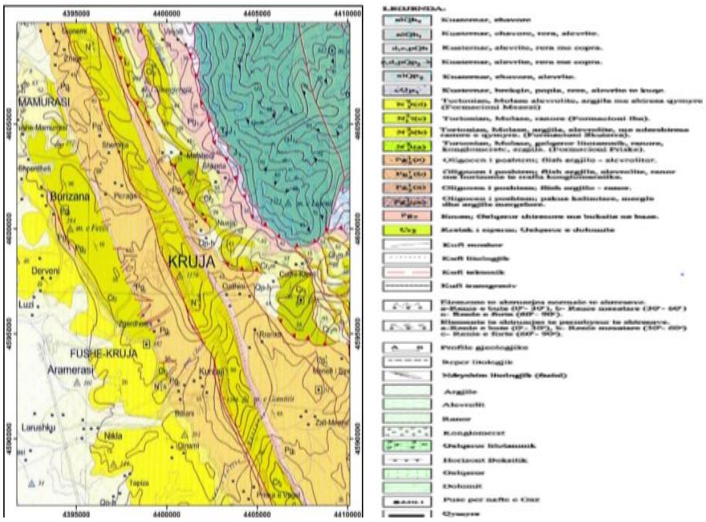

Figure 5. Geological map of the study region, [Source: Geological Map of Albania at scale 1:200,000, Year 2002, (Authors Group)]]

Meteorological Data

The climate conditions of the area are typically Mediterranean, characterized by hot and dry summers and mild, wet winters. The meteorological data are the long-term averages from the Kruje meteorological station from 2010 to 2023 [14]. The average annual rainfall in Borizane is high, about 550 mm, primarily during winter.

Table 1. Average monthly temperatures and winds, long-term averages from the Kruje meteorological station.

Month	Temp ^oC	Winds (m/s)
January	9.3	4.1
February	12.3	4.4
March	15.1	4.1
April	18.5	3.8
May	23.4	2.8
June	26.6	1.9
July	34.2	1.9
August	33.7	2.3
September	32.3	2.4
October	26.8	3.1
November	17.2	4.1
December	8.8	4.3

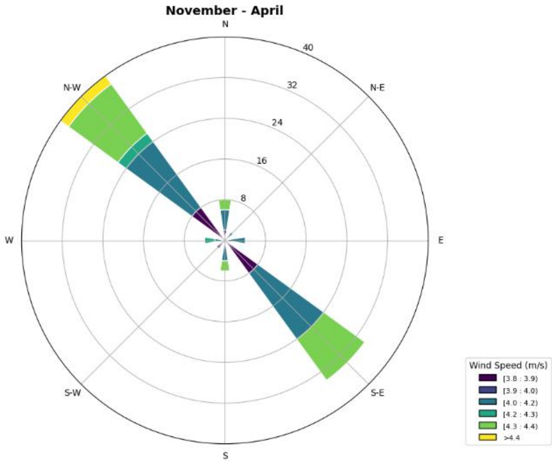

Figure 6. Wind rose for the period November-January, constructed with long-term monthly averages

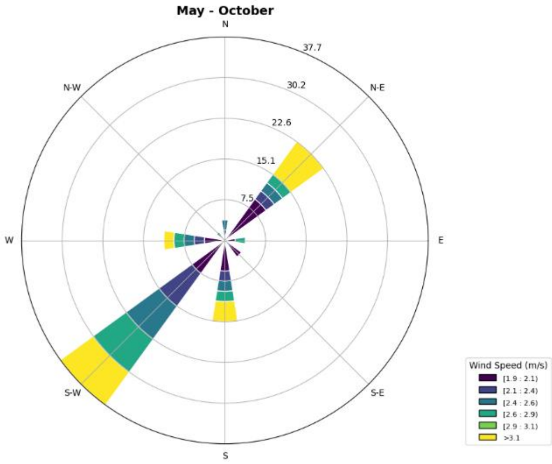

Figure 7. Wind rose for the period May-October, constructed with long-term monthly averages

The data from these years clearly demonstrate that the prevailing wind blows from the northwest and carries also the largest amounts of rainfall. The distribution of wind direction occurrences based on seasonal data shows a well-defined annual pattern. Throughout the year in the Kruje region, the southeast and northwest directions are predominant. This direction distinctly dominates over others, especially during the winter season with an occurrence of 20%. In contrast, during the summer, the southwest direction prevails with an occurrence of 20.5% and high temperatures. Winds with very low occurrences blow in other directions during spring and autumn, as seen in the wind rose, coinciding with cooler air temperatures.

Figure 8. Cement Factory

Phases of the Cement Production Process

The factory produces cement from raw materials extracted from quarries nearby. These raw materials are heated and then processed at very high temperatures, causing thermal reactions that produce cement clinker. According to market demands, three other types of Portland cement are also produced, which contain 95% clinker and 5% additional components. Limestone cement, with a clinker content of 70%-80% and other additives (primarily gypsum), varies from 20%-30%. The annual clinker production is 1.4 million tons per year, and the daily amount is 3400 tons per day.

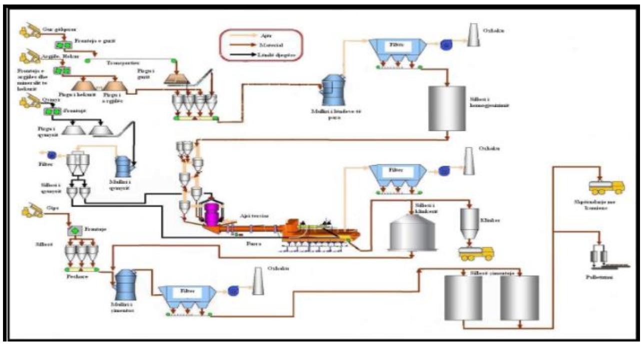

Figure 9. Schematic representation of the work processes in the cement factory

Extraction of Raw Materials

The primary raw materials are: I. Limestone as a source of CaO. II. Clay as a source of SiO_2, Al_2O_3, Fe_2O_3. III. Iron ore as an additional source of Fe_2O_3. IV. Bauxite as an additional source of Al_2O_3. The quantity of heavy metals remaining in the baked clinker does not pose a significant ecological problem for the use of these cements in construction; the exception is the slightly high content of hexavalent chromium (Cr VI), which exceeds the European Committee requirements of 1-13 ppm. Analyses/surveys conducted on the raw and auxiliary materials for chromium content show that the main amount comes from the clay. However, a significant pollutant for chromium is the iron ore, which contains from 300-3000 ppm Cr. Other operations include: Preparation of the Raw Material—grinding it in the raw material mill, the stack of which is 30 meters high. Preparation of Solid Fuel in the form of coal in the coal mill, also with a stack 30 meters high. Heating of the Raw Material, the production of clinker, the kiln of which has a stack 140 meters high. Clinker is a semi-finished product obtained by baking the mixture of raw materials, limestone, and clay in proportions: 76-78% limestone and 22-24% clay. The main oxides included in the clinker composition are the same ones introduced with the raw materials. The content of the main oxides in the Portland cement clinker typically falls within these ranges: CaO 64-67%, Al_2O_3 4-8%, SiO_2 21-25%, Fe_2O_3 2-5%. Other operations also include grinding of the Cement, this mill has a 30 m high stack, storage and packaging in bags, and distribution of cement [15]. The table below contains data reported by the operator itself, about PM emissions, stack heights, their diameters, exit speeds, and temperatures for the recent years.

Table 2: Data on significant sources of PM_{10}

Source	Location inside the factory	PM_{10} Emission rate (g/s)	Height (m)	Exit Speed (m/s)	Diameter (m)	Exit Temp (K)
Raw material mill stack	South-West	11.54	30	13.6	1.5	323
Kiln stack	South-East	8.5	140	15.6	1.5	389
Coal mill stack	North-East	10.5	30	11.6	1.5	332
Cement mill stack	Northwest	11.8	30	13.2	1.5	343

RESULTS AND DISCUSSION

The Gaussian plume model is the fundamental air dispersion model used to estimate air pollution impacts in both urban and rural areas. Most regulatory air dispersion models, such as SCREEN3 and AERMOD, are based on the principles of Gaussian plume dispersion. This model allows for the calculation of potential concentrations of pollutants downwind of a source by defining several parameters: the atmospheric stability class, plume rise, and dispersion parameters σy and σz. Subsequently, effective protection measures can be implemented to control and reduce high concentrations of PM_{10}. Following this, WKC's 5-step online tool is utilized to calculate the potential downwind concentration from a point emission source, such as the factory stacks. This approach adheres to the principles of the USEPA Screen 3 [16]. Implementation of the AERMOD model has been carried out for two scenarios: Scenario 1, the calculation of PM concentrations emitted from the four aforementioned stacks, in the nearest inhabited area, for wind speeds w.s ≥ 3.0 m/s and the second scenario, the calculation of PM_{10} concentrations in the inhabited area for wind speeds w.s ≤ 2 m/s, directed towards the inhabited area, making this the worst-case scenario. The results for PM_{10} concentration for wind speed (W.S) ≤ 2 m/s and for wind speed (w.s) ≥3.0 m/s, near the inhabited area are shown in the table below

Table 3: Parameters calculated by the AERMOD model

Source	**Stack Height**	**Emmision Rate g/s**	**Distance from residential area**	**Plume height from village**	**PM_{10} Concentration (µg/m³ /w.s≤2m/s)**	**PM_{10} Concentration (µg/m³ /w.s) ≥3,0 m/s**	**EU Norm PM_{10}**	**Exit Speed (m/s)**	**Exit Temp (K)**
Raw material mill stack	30	11.54	640	36.7	54.68	20.38	40	13.6	323
Kiln stack	140	8.5	680	148	20.63	7.75	40	15.6	389
Coal mill stack	30	10.5	650	37	44.96	16.84	40	11.6	332
Cement mill stack	30	11.8	690	37	57.23	21.47	40	13.2	343

It turns out that PM_{10} concentrations exceed the allowed European norm [17] for the period when wind speeds are low. This type of wind occurs 20% of the time and is southwest-facing, causing the dispersion of PM_{10}, despite high protection standards, to be above the allowed norm [17] during this period, which coincides with the vegetation flowering period, potentially causing not only harm to the health of the residents but also to the overall growth of vegetation in the area. The implementation of AERMOD clearly shows that the height of the stack is an important parameter in the dispersion of emissions; both calculated PM_{10} concentration values for (W.S) ≤ 2 m/s and for (w.s) ≥3.0 m/s are within the European norm.

Below is also a graphical representation of the dispersion of PMs from all four stacks of the factory for both scenarios: (W.S) ≤ 2 m/s and for (w.s) ≥3.0 m/s, according to the wind direction and orientation. According to [18], the concentration curve is fitted with the line of an exponential function: $y = y_0 + a \exp(-bx)$. In this equation, the concentration decreases to a relatively constant value of y_0, which represents the concentration of the pollutant far from the factory. In fact, this value reflects the background concentration. The parameter a indicates the increase in pollutant concentrations due to the factory, and parameter b is the decay rate, which can be used for comparing the gradient decay rate of concentrations under different conditions.

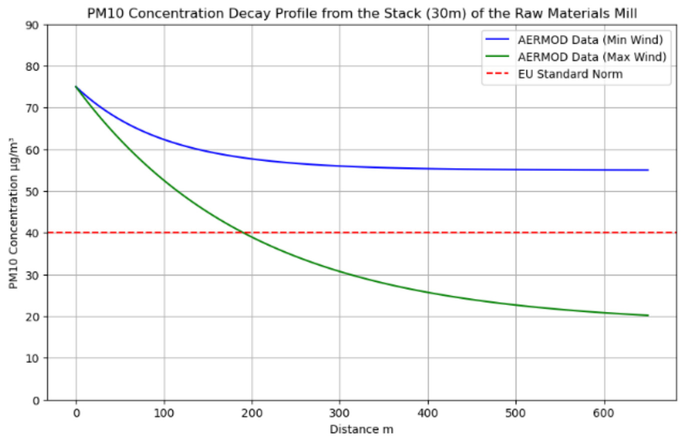

Figure 10. PM_{10} Concentration Decay Profile from the stack of the Raw Materials Mill

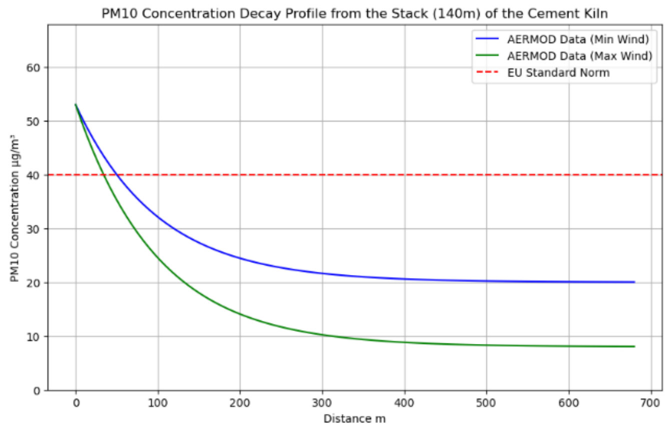

Figure 11. PM_{10} Concentration Decay Profile from the stack of the Cement Kiln

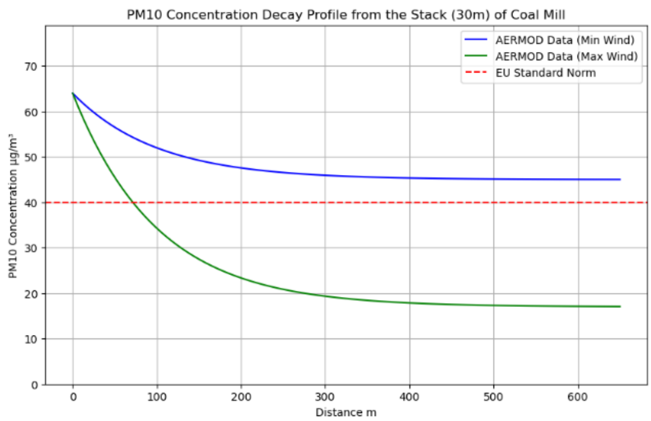

Figure 12. PM_{10} Concentration Decay Profile from the stack of the Coal Mill

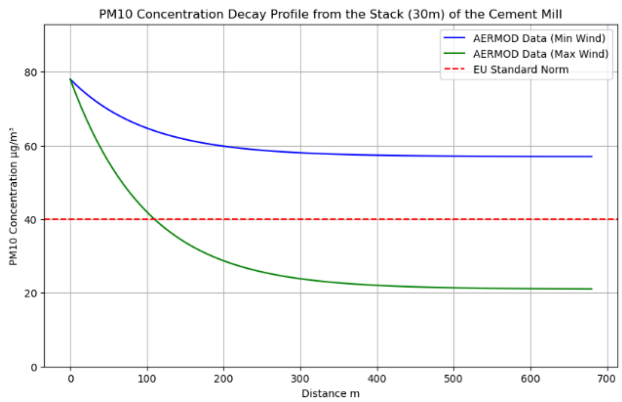

Figure 13. PM_{10} Concentration Decay Profile from the stack of the Cement Mill

CONCLUSION

From the application of the AERMOD program, it results that there are periods of the year where PM_{10} concentrations in the area around the factory exceed the allowed European norm. Different wind speeds cause PM_{10} to disperse differently during the summer months compared to other months, while the same measures are taken at the factory, the same filters are used and changed with the same frequency. Periods with low wind speeds, with climate changes, are expected to become even longer, which will lead to an extension of periods with PM concentrations above the allowed European norm [17]. Nearly periodic and long-term exposure to dust, sometimes with concentrations below the norm and sometimes above, is likely to be associated with high incidences of bronchial, cardiac, and carcinogenic diseases among residents of the area and other environmental problems, such as a decline in agricultural production, fruit growing, and viticulture. These facts demonstrate the insufficiency of the same protective measures throughout the year and the need for their optimization to control especially the concentrations above the allowed norm of PM, with the lowest possible economic cost. For this, it is necessary to take additional measures for the period when wind speed ≤2 m/s, which hinder the dispersion of PMs. An improvement in the quality of filters and their replacement at the beginning of the summer would be a quick and suitable measure. The inhabited area of Borizane and other areas, such as Thumane, Fushe-Kruja, and Kruja, are also under pressure from other limestone exploitation activities. Addressing these problems and effective and efficient protective measures requires monitoring of air quality, which is lacking in these areas, monitoring of health and environmental problems, and further studies.

REFERENCES

[1] Andersen, Z.J., Mendez, M.A., Garcia-Aymerich, J., Hertel, O., Tjønneland, A., Overvad, K., Raaschou-Nielsen, O. and Nieuwenhuijsen, M.J., 2015. A study of the combined effects of physical activity and air pollution on mortality in elderly urban residents: the danish diet, cancer, and health cohort. Environmental Health Perspectives (Online), 123(6), p.557

[2] Beelen, R., Hoek, G., Raaschou-Nielsen, O., Stafoggia, M., Andersen, Z.J., Weinmayr, G., Hoffmann, B., Wolf, K., Samoli, E., Fischer, P.H. and Nieuwenhuijsen, M.J., 2015. Naturalcause mortality and long-term exposure to particle components: an analysis of 19 European cohorts within the multi-center ESCAPE Project. Environmental health perspectives, 123(6), p.525.

[3] Pope III, C.A., Burnett, R.T., Thun, M.J., Calle, E.E., Krewski, D., Ito, K. and Thurston, G.D., 2002. Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution. Jama, 287(9), pp.1132-1141.

[4] Brook, R.D., Rajagopalan, S., Pope, C.A., Brook, J.R., Bhatnagar, A., Diez-Roux, A.V., Holguin, F., Hong, Y., Luepker, R.V., Mittleman, M.A. and Peters, A., 2010. Particulate matter air pollution and cardiovascular disease an update to the scientific statement from the American Heart Association.Circulation, 121(21), pp.2331-2378.

[5] Karakatsani, A., Analitis, A., Perifanou, D., Ayres, J.G., Harrison, R.M., Kotronarou, A., Kavouras, I.G., Pekkanen, J., Hämeri, K., Kos, G.P. and de Hartog, J.J., 2012. Particulate matter air pollution and respiratory symptoms in individuals having either asthma or chronic obstructive pulmonary disease: a European multicentre panel study. Environ Health, 11(1), p.75.

[6] Kruje Health Center and Kruje Public Health Directorate

[7] US Environmental Protection Agency (EPA), 2005. Revision to the Guideline on Air Quality Models, Adoption of a Preferred General Propose (Flat and Complex Terrain) Dispersion Model and Other Revisions, Final Rule (Federal Register), 70 (215).

[8] US Environmental Protection Agency (EPA), 2009. AERMOD Implementation Guide. Latest Revision, US, 2009.

[9] Caputo, M., Giménez, M. and Schlamp, M., 2003. Intercomparison of atmospheric dispersion models. Atmospheric Environment, 37(18), pp.2435-2449.

[10] Stevens, R.G., Pierce, J.R., Brock, C.A., Reed, M.K., Crawford, J.H., Holloway, J.S., Ryerson, T.B., Huey, L.G., Nowak, J.B., 2012. Nucleation and growth of sulfate aerosol in coal-fired 11 power plant plumes: sensitivity to background aerosol and meteorology. Atmospheric Chemistry and Physics, 12, 189-206

[11] Heckel, P.F. and LeMasters, G.K., 2011. The use of AERMOD air pollution dispersion models to estimate residential ambient concentrations of elemental mercury. Water, Air, & Soil Pollution, 219(1-4), pp.377-388.

[12] Holdgate, M. W. 1979: A perspective of environmental pollution. Cambridge: Cambridge University

[13] Ministry of Environment, Order No. 1280, dated 20.11.2013 “On the approval of the red list of wild flora and fauna”

[14] Climatological bulletin of IGEO Institute Albania

[15] Dissertation defended at the University of Tirana, Albania: Evaluation and adaptation of raw materials for the production of clinker at the Antea Cement Sh. a factory, Borizane –D. Prifti, 2015.

[16] US Environmental Protection Agency, Air dispersion modeling -screening model (EPA SCREEN3

[17] Decision of the Council of Ministers of Albania No. 352, dated 29.4.2015 On the assessment of environmental air quality and requirements for some related pollutants

[18] Mohammad Nayeb Yazdi, Mohammad Arhami, Mehdi Ketabchy, Maryam Delavarrafeei, 2016. Modeling of Cement Factory Air Pollution Dispersion by AERMOD, 13 (p 5)