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Air Pollution Modelling to Predict Maximum Ground Level Concentration for Dust from a Palm Oil Mill Stack

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Abstract

The study is to model emission from a stack to estimate ground level concentration from a palm oil mill. The case study is a mill located in Kuala Langat, Selangor. Emission source is from boilers stacks. The exercise determines the estimate the ground level concentrations for dust to the surrounding areas through the utilization of modelling software. The surround area is relatively flat, an industrial area surrounded by factories and with palm oil plantations in the outskirts. The model utilized in the study was to gauge the worst-case scenario. Ambient air concentrations were garnered calculate the increase to localized conditions.

Keywords: emission, modelling, palm oil mill, particulate, POME

1. Introduction

The palm oil industry was initially developed in Malaysia as an agricultural crop in 1917; however it was ironic that the plant was firstly used for ornamental purposes. In the 1960s, the palm oil plantation was beginning to gain popularity due to increasing demand for vegetable oil. Till today, palm oil is still vastly planted in the country and accounts for 50% the world export, with Indonesia as the second highest at 30%. Aside the profits reeked in from trade of the oils and other by-products; it also remains to be a vastly polluting one. The pollution from the palm oil processors include air pollution from the boilers, palm oil effluent mill (POME) and solid waste from the empty fruit bunches (EFB), palm fronds and shells. The focus of this study would be from air pollution from boilers. The waste generated from the process of 100 tons of full fruit bunches (FFB) is 23 tons of EFB, 16 tons of pericarp fibres and 9 tons of shell and POME. These wastes are burnt in the boiler to produce steam for the other processes. The palm fibers and shell have a heat of 12800 kJ/kg and 15400 kJ/kg.

The major pollutants in the industry remain the particulate matter and dark smoke emission from these mills (Johar *et al*., 1990). Thus, it is understandable that this industry remains the areas of focus for researches i.e. on waste management, technology improvements, crop cultivation, throughout Malaysia. It has to be noted that the palm oil industry has always been linked to the environment, either in reference to the upstream or downstream products of the industry.

The scope of this project paper is modelling emission results from an existing stack in an attempt to analyze the maximum ground level concentration from the stack. Generally, in view of compliance with the legal requirement these emission levels and the predetermined stack height should be high enough to allow for adequate dispersion to the natural atmosphere. The study also anticipates allowing for other contributing factors that may increase ground level concentrations vide a land use survey to assess contributing factors.

The singular parameter monitored is particulate matter from boiler stack emissions of a palm oil mill. The study focuses on secondary data of the emission levels from the stack; basically the main data and also focuses on the general existing land use of the palm oil mill itself. The mill is located in Selangor with daily load approximately 20 tons per day and located on flat ground.

The modelling exercise shall be carried out using pre-existing modelling tools i.e. such as formulated by the Environmental Protection Agency of the United States of America (US EPA). These models are utilized for regulatory purposes, especially when a new waste-stream is introduced in an urban area. Several models formulated by the USPEA are the screening series, Screen 3 being the latest version, (ISCST) Industrial Source Complex Short Term, the AERMOD modelling program, ISC PRIME and others.

1.1 Air Pollution

In De Nevers and Noel (2000), air pollution is defined as the presence of undesirable material in air, present in quantities large enough to produce harmful effects. The harmful effects are not restricted only to effects on human health, but also include damage to vegetation, property, aesthetics, or the global environment on the whole i.e. global warming. Air pollution occurs naturally, and humans have little control over it, however, due to urbanization and the development of human activities, i.e. mass development and manufacturing, has increase the pace of pollution and hence has created a problem that nature cannot solve automatically. Hence, the need arises where control should be exerted to reduce whatever anthropogenic activities that are major contributors towards air pollution problems these days. These activities are regulated by the government as a basic measure to develop a holistic management plan within each country.

Most industries utilize air pollution control equipment to abide with current regulatory requirements, these equipment ranges from bag filters, to scrubber systems to cyclones. The application of these equipments is mainly dependent on the type of pollutant that is predominant in the waste stream and the quantity and quality of the pollutants present in the waste stream. Pollutants that impose sever health implications will be prioritized as well. The final output, released through the stacks must fulfil regulatory requirements of the plant. These effects takes into account the amount of pollution that is released to increase the pollutant levels with the ambient air concentration, thus it ensures that the pollutants would not cause air pollution problems to the communities living downstream of the plume from dispersion stack.

1.2 Air Pollution Modeling

Dispersion modelling is the estimation or prediction of the movement of a plume (either continuous or intermittent) from a source (in this case an industrial stack) to the maximum ground level concentration (this is the point of total dispersion into the ambient air). Noonan (1999) states that dispersion modelling may be assessed a population's risk of exposure to air pollution from a local source and the main area of emphasis should be at the region closes to the source. Modelling software is categorized to several basic types, namely the Gaussian plume, puff and the Lagrangian types. The Gaussian plume dispersion models are developed mainly for regulatory purposes. Several Gaussian plume models are the SCREEN3, ISCT/AERMOD, AUSPLUME and DISPMOD.

The models are utilized as a guide to base estimates for stack height for adequate dispersion of emission. The simplest method of modelling entails the point source dispersion to a relatively short distance (estimate within 5-10 km). Complicated models would entail examination of multiple sources (point and non-point source) and considering extensive site specific data. The type and nature of pollutants being assessed would also affect the modelling process. The lesser complicate parameters such as SO_x, NO_x and particulate matter are easier to model.

1.3 Factors Affecting Dispersion of Pollutants

Dispersion models used to estimate the ambient air pollutants concentration at various downstream receptors, and in general three main factors affect the estimated time averaged concentration of pollutants, namely

1. Plume rise above the stack must be established
2. The dispersion of pollutants from source to receptor must be mathematically modeled based on atmospheric conditions.
3. Time-average concentrations at ground level should be determined (Anonymous, 1997)

Some other factors that would affect the modelling process would also require inputs such as (1) spatial scale (i.e. national, regional, or local), (2) type of pollutant (i.e., gaseous, particulate, reactive), (3) type and number of receptors, (4) emission source type (for example, stationary, mobile), (5) availability of input data (for example, (6) meteorological data, census data) and (7) an acceptable level of uncertainty in the model's results for accuracy of the modelling works.

Thus, the model utilized should be able to match the key characteristics of the site and the required evaluation, thru the functions within the model itself. The important aspect is to keep the modelling process simple and suitable to the requirements of the project, which would give a realistic estimate of magnitude of the impacts from the pollutant source to the downstream receptors. By understanding different features of individual models, this will ensure the results obtained are as per required.

In some instances, building downwash would not be an issue or the type of pollutants maybe dry deposition and not wet. At present there are many models in the market to evaluate and be utilized for various industries for point/linear and area dispersion. Some models are described in the section below.

Table 1. Key factors that affect modelling calculations (Anonymous, 1997).

Parameters	Characteristics
Topography	Flat, gently rolling terrain or complex terrain
Land use	Urban / Rural Urban has additional pollution in terms of large structures and heat
Population	SO_2 – No chemical transformation within a 5-10 km radius NO – fairly rapidly becomes NO_2 based on availability of ozone Particulates: based on particle size and travel time
Source Configuration	Height and temperature of discharge Effective plume height –physical height raises plume dispersion (as a result of buoyancy and momentum) or lowers it as due to downwash or deflection
Multiple source	All dispersion models assume that the concentration of each source is the arithmetic sum concentration of each source examined. The actually emission rates and stack parameters are not considered.
Time scale of Exposure	Most models calculated base on hourly emission rates, to obtain even annual prediction results. These models have the adequate statistical calculations incorporated within the model.

1.4 Types of Models

a. Screening Models

Screening models are simpler modelling tool that estimates conservative air concentration levels. The screening models use default assumptions and may be used to rule out the need for further analyses. The following are several screening tools utilized by the US EPA:

a. SCREEN3 is a Gaussian plume dispersion model designed to use worst-case meteorology to estimate one-hour average air concentration estimates.
b. CTSCREEN (Complex Terrain Screening model) is a Gaussian plume dispersion model designed to assess plume impaction in complex terrain.

b. Refining Models

The following samples are only a few of the air quality (dispersion) models available through EPA.

a. ISC (Industrial Source Complex Model) is a steady-state Gaussian model which can be used to assess pollutant concentrations from a wide variety of sources associated with an industrial complex to a distance of 50 kilometres.
b. (ISCST3), in addition to air concentrations, it can estimate deposition rates and is appropriate for simple and complex terrain. It is a third generation model from the ISC
c. ASPEN (Assessment System for Population Exposure Nationwide) is a Gaussian model used to estimate toxic air pollutant concentrations over a large-scale domain such as the entire continental U.S.
d. AERMOD is a steady-state plume-based model designed to estimate near-field impacts from a variety of industrial source types. This model takes into account the effect of planetary boundary layer turbulence on air dispersion. It is being considered as a replacement to the ISCST3 model.

REMSAD (Regulatory Modelling System for Aerosols and Deposition) is a three-dimensional grid-based model designed to simulate long-term (for example, annual) concentrations and deposition fluxes of atmospheric pollutants over a large geographic domain (for example, Southeast U.S.). Currently REMSAD can address toxic pollutants such as mercury, cadmium, chlorinated dibenzodioxins, polycyclic organic matter, and atrazine.

1.5 Limitations of Modelling

a. Scorer (1979) says "air pollution modeller on the other hand is not merely invited to say something that will be valid for a few decades, for that, at least, is expected to be the lifetime of the structure for whose planning the model is to be invented, he is required to do so, for otherwise he has nothing useful to say."
b. As indicated by Finkelstein (1979) in his editorial on the Control Aspects of systems and models in air and water pollution models indicate several areas whereby difficulty in obtaining accurate

modelling results due to the lack of control over some factors and parameters.

c. Generally these factors brought up by Finkelstein (1979) may be justified; however, the significance of these factors can be reduced with more through research into the past behaviour of the pre-defined contributing elements. At present, complicated models have been designed for site-specific cases; with due consideration given to meteorological elements; topographical characteristics and ambient concentration. A point to highlight here is also that the models predict based on an assumed output from the point source; therefore difference in the promised output would cause differences in the actual levels.

d. Some of the main parameters used in the past models as a factor to assess future air pollution levels include topographic characteristics in addition to the current air pollution levels. Rondie and Albert (1979) have conducted a study to assess the level of air pollution and topographic parameters in a basin utilising principle components. The conclusion obtained from the study indicates that the principle elements chosen in this study have contributed to the level of pollution on the immediate areas, and that wind profile plays little roll due to the topographic features of the site that protects it from dominant winds.

e. These opinions were recorded over 20 years ago, and these thoughts would have been contributed to the formulation of models existing these days. The models these days are designed to incorporate complex relationships between all the factors (as highlighted above) and are a better tool to estimate ground level generation.

f. However, even today, there are scientist that are of the same opinion, Beychok (1999) questions the assumptions and constraints of the Gaussian plume equation that have been utilized in many of regulatory air modelling tools. Several aspects for caution when utilizing the Gaussian Plume dispersion models are (a) accuracy in predicting plume rise, (b) accuracy of dispersion coefficients; i.e. vertical and horizontal standard deviations of emission dispersion (c) assumption of averaging time period represented is not clearly defined by the equation creator.

In the midst of all the negativity, the modelling process has gone a long way, and will continue to refine the air modelling process for greater accuracy.

1.6 Model Validation

According to Schipper (1996) the validation of a certain model is the area which corresponds between the modelling technique and an argument by which is the evidence that intentions are met. An argument can be defined as an interpretation of observations that provide evidence that an intention is met.

The observation on the other hand can be defined as an uninterrupted instances of a characteristics obtained by the applying a single instrument to a single modelling technique. It can capture either/both, quantitatively or/and qualitatively.

1.7 Regulations

DOE's regulatory framework includes the monitoring of mill emissions namely for effluent discharge, air emissions, noise and scheduled waste. The Malaysian Clean Air Regulations (1985) controls the emissions of stack in the country.

In the case of this study too, air emissions emitted from the boiler (and in some cases, incinerator) are governed through the Clean Air Regulations. The current Standard C is applicable to all new industries, where else for the industries established in the 1960s were slowly upgraded, in terms of air pollution control, in terms of providing grace periods, that the industries in questioned were upgraded to Standard B.

The general goal of this Act was to improve the emission quality to Standard C. Generally the areas governed under this act that maybe applicable are burning of waste, dark smoke emission and emission of air impurities.

The parameters being studied are dust/ particulates. The pollutant originates from the boilers unit process, where by burning fuel/biomass to generate steam for energy and internal subsequent processors.

1.8 Mill Processors

There are several unit processors involved, which are described in the Mongana Report (1955). Pollution sources from the mill are segregated to several sections, namely ecological aspects, surface water pollution and air pollution.

Table 2. Type of pollutant and the sources (Anonymous, 1999).

Type of pollution	Sources of pollutants
Gaseous emission	Boiler emissions Incinerator air emissions
Liquid effluent	Sterilization of FFB – 36% Clarification of the extracted crude palm oil – 60% of total Hydro cyclone wastewater – 4 % Others – turbine cooling water and steam condensate, boiler blow down, overflow from vacuum dryers, some floor washings, etc.
Solid waste	Boiler and incinerator ash, sludge separator residue, decanter solids

2. Methodology

Importance of modelling is identifying the right model to obtain the required results. In the earlier section, several models that are available in the market have been described along with the type of analysis that can be conducted by the model itself. In this study, the model utilize is a screening model and if required, an industrial effluent dispersion model.

The prefer model is described further in the following sections. The various stages to the entire project process are shown in Table 3.

2.1 Dispersion Air Models

The model selection was based on the type of parameter, location of the mill, type of analysis required and availability of the model at the market. Thus, three models were identified SCREEN 3, ICST 3 and AERMOD.
Air Modelling Techniques

There are two stages to modelling i) the screening stage and if required ii) the detailed modelling stage. Modelling tools have been identified for both stages as follows:
a) Stage 1: Screening Model – Screen 3
b) Stage 2 (if required) Industrial Model – ICST3 or AERMOD

All three models have been developed by the United States Environmental Protection Agency and have been widely tested models. The Screen 3 is adequate to model for single source pollutants and would allow to ground level concentrations estimates as well as identify maximum distance. The ISCT and AERMOD models are both refining models, and is the standard dispersion modelling tools for complex terrain in industrial applications. The ISCT is actually an outdated model, which was replaced by the AERMOD. However due to market availability, these two models were chosen for the study.

2.2 Data Collection

Several agencies and private companies were approached for data. Namely (1) the palm oil mill owner/operator for information on the mill processors and emission levels, (2) Meteorological Services Department for meteorological data and the Department of Statistics for the ambient air statistics for major towns.

Table 3. General methodology.

Processors	Details
Model Selection	Information pertaining to models available, studies conducted, required output, parameters to be monitored
Data collection	Emission data for identified parameters – Dust Meteorology – wind speed and direction, temperature, rainfall data, Ambient air quality data
Data input	The required information is key-in to the Software Screen 3
Data analysis	The model shall 'run' and the required output shall be obtained in the form of tables. The appropriate data is extracted for further analysis in relation to distance and ground level concentration
Data re-analyzed	If the results of Screen 3 show high levels of pollution, then the data will be remodelled in ISCT or AERMOD models for refinement.
Model Validation	The model is run through several extreme scenarios to assess the effects that can be seen and subject the model to an assessment of representation of the project.
Data Output	Data presentation in the forms of charts, tables and figures.

2.3 Data Input & Data Analysis

All appropriate data appropriate data to the model for analysis. Three scenarios were created specifically for the input, (i) the normal scenario (ii) the maximum effluent and ambient temperature scenario and (iii) the worst case scenario utilizes a very stable adiabatic class for the same emission levels as scenario (ii).

2.4 Model Validation

The model will be assessed on the accuracy of the result, through input of several extreme conditions. The input to the model and output from the model will be assessed to measure it viability to be utilized in this study.

3. Results and Discussion

3.1 Ambient Air Concentration

The following is the data obtained for ambient air concentration of particulate matter nearest to the project site.

Table 4. Ambient air concentration (Anonymous, 2003).

Year	1999	2000	2001	2002	Average
Particulate matter 10 (Klang Station)	66.83	61.40	55.00	89.23	68.11

3.2 Screen Modeling Results

Figure 1 - 6 summaries results of the modelling study in the form of tables and graphs. Meanwhile, Figure 7 and 8 are the results of the validation criteria analyzed to assess the adaptability of the model to this study.

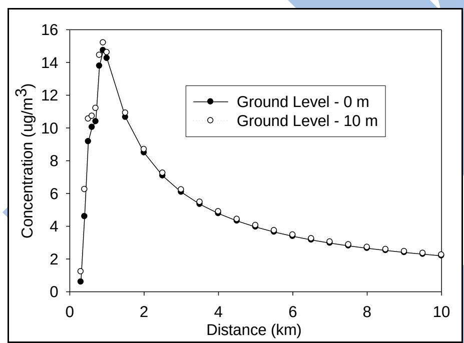

Figure 1. GLC for Case A.

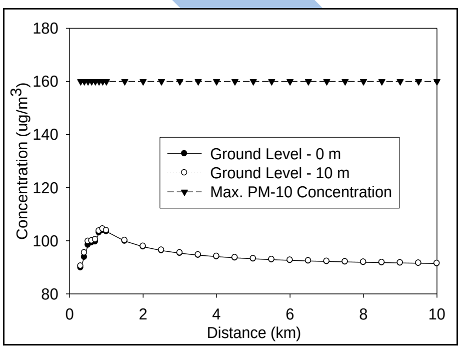

Figure 2. Ambient concentration for Case A.

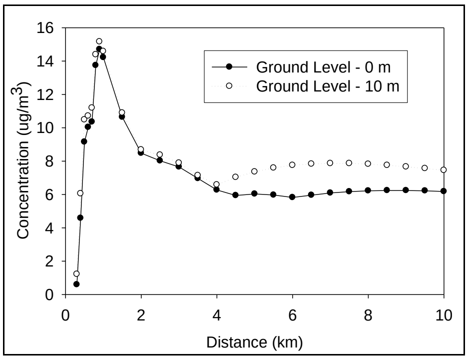

Figure 3. GLC for Case B.

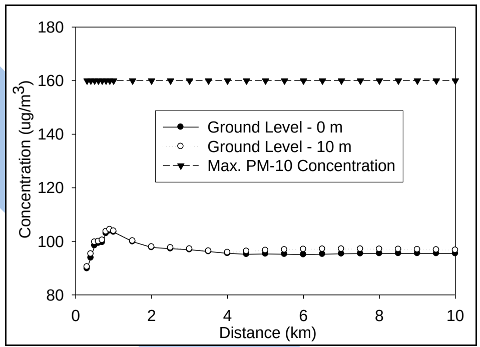

Figure 4. Ambient concentrations for Case B

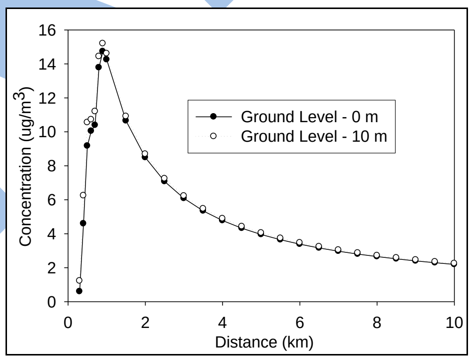

Figure 5. GLC for Case C.

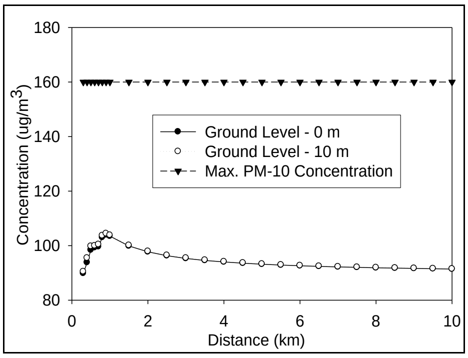

Figure 6. Ambient concentration for case C.

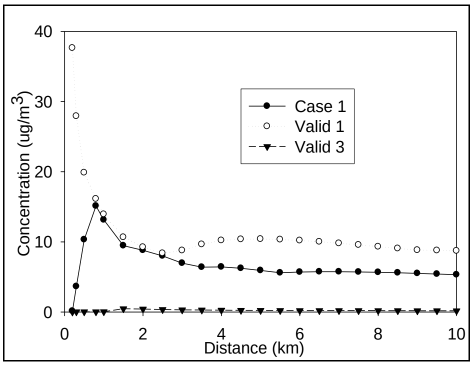

Figure 7. GLC from model on validation scenario.

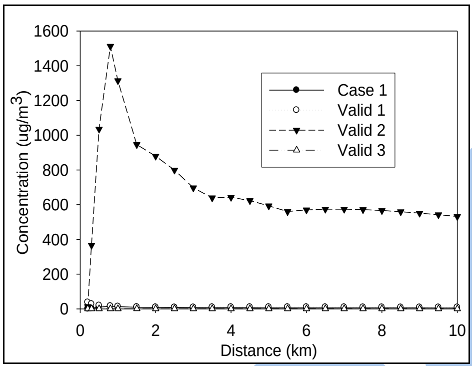

Figure 8. GLC from model on validation of 3 scenario.

3.3 Modeling Results

The study had conducted 3 main analyses, which are represented by the number of cases identified (Case A, B and C). Several factors were utilized to obtain effective results and to determine the effect of the palm oil mill in study to the surrounding areas. Amongst the factors emphasis in this study are emission levels, topology (rural or urban), and stability class. As explained in the previous sections, the modelling process utilized a tool to gauge the effects of the stack to the environment (or its dispersion rate). Thus, the first case (CASE A) is modelled based on average conditions, the parameters key-in are an averaged obtained over 3 years data, parameters that were manipulated are the emission source levels and gas exit velocity. Emission levels ranged from were 2.56 g/s and the stack exit velocity was 12.66 m/s. The results indicated very low emission levels, basically ranging from a maximum of 15.12 μg/m^3 at an estimated distance of 800 m from the stack. The trend indicates that the highest concentration of dust is dispersed relatively with 600 m to 1300 meters form the site and subsequently just decreases as the pollutant moves further away from its source. When the modelling results were combined with the ambient air levels (of Klang) the values were way below the National Ambient Air Quality Guidelines of 160 μg/m^3.

In Case B, maximum levels were incorporated into the model to assess if the model would yield high dispersion concentration. The concentration of dust was slightly higher (increase to a maximum of 5μg/m^3. The emission levels input into the model were 4.019 g/s and the stack exit velocity was given as 22.22 m/s. The dispersion trend indicated a sharp peak at 600 m to 1500 m, which affects a greater distance than Case A, and with concentrations ranging from 10.03μg/m^3 to 10.64μg/m^3. The dispersion rate declines gradually as the pollutant moves further away from the palm oil mill. The ambient concentration for Case B was also within the guidelines level (160 μg/m^3) with a maximum of 103.45 μg/m^3 at 900 meters away. Both cases were also modelled for two heights, at ground level (the height of the stack base) and 10 m above the ground level. The results indicate that there was not much change in the concentration levels between 0 to 10 m above ground level, indicating good vertical mixing.

Case 3 is predicted to be the worst case scenario, whereby the input data incorporated was based on Case B but modelled under Class A Stability co-efficient. This would model the worse case scenario under slow winds (1 -3 m/s). The results were similar, with the exception of 1-2 μg/m^3 difference. The higher concentration was dispersed at 600 m up to 1500 m with a concentration range of 10.04 μg/m^3 to 10.65μg/m^3. The highest concentration level was detected at distance 900 m at 14.73 μg/m^3. The highest ambient air levels estimated were 103.96 μg/m^3.

3.4 Validation of the Model

The validation process of the model was conducted vide agility of the model to respond to various increases in the variables. Therefore several variables were selected for analysis, which are depicted in three cases Valid 1, 2 and 3. The variable changed in Valid 1 was a decrease of 50% of the effective stack height, which yielded high results of 29070 percentage increase from the average scenario (Case 1). The pattern indicated high emission rates nearer to the mill itself. The highest values were detected within a 1 km radius of the mill. The subsequent dispersion after 3 km was also higher by 4 μg/m^3. In the second validation case, an increase of 10 percent on the emission levels were input to the model and the results indicated the highest emission levels of all validation cases. The dispersion pattern was similar to the case studies, whereby the peak were estimated at approximately 800m from the mill. The average dispersion had reached a consistent dispersion at a 545 μg/m^3 approximately a 55000 % increase in comparison to the Case 1 (normal average scenario).

The third validation process involved the increase in stack diameter by 10 percent. This modelling yielded better dispersion results by an average of 81% lesser than the normal case (Case 1). The highest value is 0.4589 μg/m^3 at 1.5 km away from the stack. The dispersion pattern indicated better results with the one km radius around the mill, whereby values were all below 0.0405 μg/m^3. It is obvious that the model in receptive to change and is a good tool for screening purposes. However, when modelling for complex scenarios, whereby the maybe other factors influencing the dispersion (hilly terrain, sea conditions, higher concentration), then a more advance model should be considered for the modelling purpose. As note in the literature review, the model is a screening tool and in cases where the scenario is not complicated, it can be utilized to give an indication of the dispersion patterns.

4. Conclusion

The study indicates that the mill does not contribute to a significant increase in ambient air quality of the area. The study indicates that the mill had been designed well in terms of air pollution control device and adequate stack height for maximum dispersion. The could be extenuating factors that could have contributed to such low results; some of which are (1) collection of stack emission data that is not fully representative, meaning that the samples collected could be at low production rates (2) the stack design is well designed to a appropriate height and width to allow for good dispersion. If a similar study to be conducted, the study focus should be extended to an area, instead of a point source emission. That would probably yield better air quality management planning for the local council or the Department of Environment for approval of new industries within the same area. This would allow for better validation process, through ambient air sampling.

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