USING GEOGRAPHICAL INFORMATION SYSTEM (GIS) TO STUDY THE IMPACT OF CHEMICAL POLLUTANTS EMERGING FROM INDUSTRIES

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by

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CERTIFICATION OF APPROVAL

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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ABSTRACT

The purpose of this project is to analyze the impact of air pollution concentration unto the surrounding area of the industrial site. The analysis will be focused on the subject of air pollution modelling, simulation and computational methods using Geographical Information System (GIS) software. By using GIS, analysis of the impact in the scale of a digital map could be done in a much precise manner. Using the raw data input of the industrial site that being processed into air pollution modelling software called Point Source Dispersion (PSD), the output from PSD analysis could be used further as input for analysis in GIS. The results of GIS analysis will be appeared in multiple ring buffers that being characterized by the concentration of air pollution in proportional to the affected areas around the industrial site. By having these results, a risk and safety assessment of the industrial site could be done efficiently and in cost-saving manner.

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CHAPTER 1

INTRODUCTION

1.0 Problem Statement

Industrial site has always being attributed to the problem of pollution. One of the most significant environmental problems in our life today arises from chemical-related Industry. The pollutants from those sites can vary from solid, liquid to gaseous form. Scientists have determined many of the harmful local effects of air pollution. We know, for instance, that air pollution can negatively impact human health and cause coughs, burning eyes, breathing problems, and even death. We know that atmospheric haze or smog reduces visibility and that acid rain from chemical emissions damages property, pollutes water resources, and can harm forests, wildlife, and agriculture. This project will be focusing on recording the impact of gaseous chemical pollutants such as CO_X, NO_X, SO_X or particulate matter that emerges from the plant using environmental assessment software called Geographical Information System (GIS).

1.1 Objectives

The objectives of this project are:

(1) To collect relevant data about the pollutants emerge from the plant area,

(2) To analyze the possible consequences of pollutants to the surrounding area, and

(3) To assess the air pollution impact to the vicinity areas from a nearby industries using Geographical Information System (GIS).

1.2 Scope of study

The project would be utilizing a software called geographic information system (GIS) in order to analyze the effect of pollutants to the surrounding industrial area, the map and the emission data of pollutants from the industrial site must be obtained from relevant authority. The raw input data from the industrial site will be used as the input in an air pollution modeling software called Point Source Dispersion (PSD). By utilizing the PSD software, estimation of the pollutant concentrations emerging from industrial stacks could be calculated in efficient and precise manner. The output from PSD will be used as the input for ArcGIS. Then ArcGIS software will be used to display these concentrations to the surrounding industrial area. From the result analysis, a propose solution for the problems will be given at the end of the assessment.

CHAPTER 2

LITERATURE REVIEW

2.0 History of Air Pollution

Many might think the Industrial Revolution opens the pandora box for air pollution problem. The truth is, air pollution problem has begun earlier than that. Even during the Roman Imperium era in (about AD 61) the sighting of air pollution has been reordered by their historian (Boubel *et al*, 1973). Even during the Medieval Age in Europe, the problem of air pollution resultant from coal and wood burning had become prevalent in the society. Due to this, the government during that time had to construct edicts to control the source of air pollution around the city area. Despite edicts and royal proclamation from the monarchs, coal continued to be burned in the public. For example, in 1661, the pollution of London had become bad enough to prompt John Evelyn to submit a brochure "Fumifugium, or the Inconvenience of the Aer, and Smoake of London Dissipated (together with some remedies humbly proposed)" to King Charles II and Parliament (Boubel *et al*, 1973).

Things got worsen in Industrial Revolution era in the late 18^{th} and early 19^{th} centuries. The creation of steam engine and the rapid advancement of factories had caused severe air pollution in industrial European country. The predominant air pollution problem of the 18^{th} century was smoke and ash from the burning of coal, or oil in the boiler furnaces of stationary power plants, locomotives, and marine vessels, and in home heating fireplaces and furnaces (Boubel *et al*, 1973).

The continuation of economic and scientific advancement from those era till our time has made the air pollution problem as a subject that must be addressed seriously by the intellectuals. With the popularity and advocacy from the environmentalist and scientific community who constantly highlight the danger of global warming in today's time, air pollution must be viewed as an utmost urgent agenda of engineers to treat the problem at its sources particularly in industrial site.

2.1 Current state of air pollution

According to World Health Organization (WHO) states that 2.4 million people die each year from causes directly attributable to air pollution, with 1.5 million of these deaths attributable to indoor air pollution.

Since the end of 16^{th} century, the problems of poor urban air quality has been well documented. Hundreds of years later, in 1952, a five-day temperature inversion in London trapped fog laden with pollutants created by burning coal. More than 4000 deaths were attributed to this deadly "black fog." Similar incidents claimed 1000 lives in 1956 and 700 lives in 1962 (Boubel *et al.*, 1994). However, during the 1980s the number of motor vehicles in urban areas steadily increased and air quality problems associated with motor vehicles became more prevalent.

The most common disaster of air pollution accrued is due to the release of hydrogen sulphide at Poza Rica, Mexico in 1950 (McCabe and Clayton, 1952) and the other example is toxic release at Bhopal, India in 1984. Table 2-1 summarizes the air pollution disasters between years 1930 and 1997.

	Mortality and morbidity	Age groups affected	Weather	Geographical setting	Sources	Pollutants
Meuse Valley, Belgium 1930	60 death , 6000 ill	elderly	anticyclonic inversion and fog	river valley	steel and zinc manufacture	SO_2 , smoke
Donora, Pennsylvania, 1948	15 death , 5900 ill	elderly	anticyclonic inversion and fog	river valley	steel and zinc manufacture	SO_2 , smoke
Poza Rica, Mexico, 1950	22 death	all ages	nocturnal inversion low winds	coastal	sulphur recovery (accident)	H_2S
London, UK 1952	4000 death, >20,000	elderly at first	anticyclonic inversion and fog	river plain	domestic coal burning	SO_2 , smoke
Bhopal, India 1984	2500 death, 10,000 ill	-	nocturnal low winds	-	fracturing of tank (accident)	Methyl-isocyanide
London, UK 1991	160 death	patients with respiratory illness	anticyclonic inversion and fog	river valley	vehicles	NO_2 , particles
Indonesia Sep. 1997-Nov.1997	527 death, 356,220 ill	all ages		-	haze	CO, CO_2, SO_2 , NO_2

Table 2-1: Air pollution disasters (Amagai *et al.*, 2002).

2.1.1 Sources of Air Pollution

Air pollutant sources can be categorized according to the type of source, their number and spatial distribution, and the type of emissions. Categorization by type includes natural and anthropogenic sources (Liu and Lipták, 2000).

Natural air pollutant sources include:

- Dust from natural sources,
- Methane, emitted by the digestion of food by animals,
- Radon gas from radioactive decay within the Earth's crust,
- Smoke and carbon monoxide from wildfires and volcanic activity, which produce sulfur, chlorine, and ash particulates.

Anthropogenic sources include:

- Stationary sources, such as smoke stacks of power plants, manufacturing facilities, municipal waste incinerators,
- Mobile sources, such as motor vehicles, aircraft,
- Marine vessels, such as container ships or cruise ships, and related port air pollution,
- Burning wood, fireplaces, stoves, furnaces and incinerators,
- Oil refining, and industrial activity,
- Chemicals, dust and controlled burn practices in agriculture and forestry management,
- Fumes from paint, hair spray, varnish, aerosol sprays and other solvents,
- Waste deposition in landfills, which generate methane.
- Military, such as nuclear weapons, toxic gases, germ warfare and rocketry.

Compound	Natural sources	Anthropogenic sources
Carbon-containing compounds		
Carbon dioxide (CO_2)	Respiration; oxidation of natural CO; destruction of forests	Combustion of oil, gas, coal and wood; limestone burning
Methane (CH4)	Enteric fermentation in wild animals; emissions from swamps, bogs etc., natural wet land areas; oceans	Enteric fermentation in domesticated ruminants; emissions from paddy fields; natural gas leakage; sewerage gas; colliery gas; combustion sources
Carbon monoxide (CO)	Forest fires; atmospheric oxidation of natural hydrocarbons and methane	Incomplete combustion of fossil fuels and wood, in particular motor vehicles, oxidation of hydrocarbons; industrial processes; blast furnaces
Light paraffins, C_2–C_6	Aerobic biological source	Natural gas leakage; motor vehicle evaporative emissions; refinery emissions
Olefins, C_2–C_6	Photochemical degradation of dissolved oceanic organic material	Motor vehicle exhaust; diesel engine exhaust
Aromatic hydrocarbons	Insignificant	Motor vehicle exhaust; evaporative emissions; paints, gasoline, solvents
Terpenes ($C_{10}H_{16}$)	Trees (broadleaf and coniferous); plants	
CFCs & HFCs	None	Refrigerants; blowing agents; propellants
Nitrogen-containing trace gases		
Nitric oxide (NO)	Forest fires; anaerobic processes in soil; electric storms	Combustion of oil, gas, and coal
Nitrogen dioxide (NO_2)	Forest fires; electric storms	Combustion of oil, gas, and coal; atmospheric transformation of NO
Nitrous oxide (N_2O)	Emissions from denitrifying bacteria in soil; oceans	Combustion of oil and coal

Ammonia (NH_3)	Aerobic biological source in soil Breakdown of amino acids in organic waste material	Coal and fuel oil combustion; waste treatment
Sulfur-containing trace gases		
Dimethyl sulfide (DMS)	Phytoplankton	Landfill gas
Sulfur dioxide (SO_2)	Oxidation of H_2S; volcanic activity	Combustion of oil and coal; roasting sulfide ores
Other minor trace gases		
Hydrogen	Oceans, soils; methane oxidation, isoprene and terpenes via HCHO	Motor vehicle exhaust; oxidation of methane via formaldehyde (HCHO)
Ozone	In the stratosphere; natural NO–NO_2 conversion	Man-made NO–NO_2 conversion; supersonic aircraft
Water (H_2O)	Evaporation from oceans	Insignificant

Table 2-2: Natural and anthropogenic sources of a selection of trace gases (Cox and Derwent 1981).

China, India, United States, Russia, Mexico, and Japan are the world leaders in air pollution emissions. Table 2-3 shows the most polluted world cities.

Particulate matter, µg/m³	**City**
169	Cairo, Egypt
150	Delhi, India
128	Kolkata, India (Calcutta)
83	Ahmadabad, India
125	Tianjin, China
123	Chongqing, China
109	Kanpur, India
109	Lucknow, India
104	Jakarta, Indonesia
101	Shenyang, China

Table 2-3: Most Polluted World Cities (World Bank, 2004).

2.2 Primary and Secondary Pollutants

Pollutants are usually classified as primary pollutants and secondary pollutants. A primary pollutant is one that is emitted into the atmosphere directly from the source of the pollutant. The main, primary gaseous pollutants are the following (Builtjes, 2003):

- Carbon compounds, e.g. CO_2, CO, CH_4, the VOC's (volatile organic compounds)
- Nitrogen compounds, e.g. N_2O, NO, NH_3
- Sulfur compounds, e..g. SO_2, H_2S

- Halogen compounds, e.g. chlorides, fluorides, bromides

The main, primary particle pollutants are the following (Builtjes, 2003):

- Particle smaller than 2.5 μm in diameter. Included are the Aitken nuclei, particles smaller than 0.1 μm in diameter, which grow rather fast by coagulation to larger particles. The chemical composition of these primary particles is, to a large extent, carbon but also heavy metals as iron, zinc, copper, etc will also be contained in these particles.
- Particles with a diameter from 2.5 to 10 μm. These larger particles are often composed of sea salt and dust.

A secondary pollutant is not directly emitted as such, but forms when other pollutants (primary pollutants) react in the atmosphere. Examples of a secondary pollutant are:

- Ozone created from organic vapours given off at a gasoline station. The organic vapours react with sunlight in the atmosphere to produce the ozone, the primary component of smog.
- Nitrogen dioxide NO_2
- Sulfuric acid H_2SO_4

There are many other air pollutants that may be important in particular situations. At least 3000 different chemicals have been identified in air samples. Examples of these pollutants are (Colls, 2002):

- Fluorine is produced as gaseous HF by chemical processes such as fertilizer production and steel manufacture.
- Heavy metals such as arsenic, cadmium, chromium, manganese, mercury, nickel and vanadium.
- Formaldehyde is an irritant chemical released from, for example, urea formaldehyde cavity wall insulation.

- Polychlorinated dibenzo furans (PCDF) and Polychlorinated dibenzo dioxins (PCDD) are complex molecules produced by high-temperature combustion processes such as municipal waste incineration.
- Polychlorinated biphenyls (PCB) are released during the production and disposal of PCBs used for transformer insulation in the electrical industry.
- Asbestos covers a range of mineral fibres released from building thermal insulation and brake linings.
- Secondary cigarette smoke is probably responsible for several hundred deaths per year in the UK.

The Environmental Protection Agency (EPA) has set National Ambient Air Quality Standards for six principal pollutants, which are presented in Table 2-4.

Pollutant	Standard Value		Standard Type
Carbon Monoxide (CO)			
8-hour Average	9 ppm	(10 mg/m^3)	Primary
1-hour Average	35 ppm	(40 mg/m^3)	Primary
Nitrogen Dioxide (NO_2)			
Annual Arithmetic Mean	0.053 ppm	(100 $\mu g/m^3$)	Primary & Secondary
Ozone (O_3)			
1-hour Average	0.12 ppm	(235 $\mu g/m^3$)	Primary & Secondary
8-hour Average	0.08 ppm	(157 $\mu g/m^3$)	Primary & Secondary
Lead (Pb)			
Quarterly Average	1.5 $\mu g/m^3$		Primary & Secondary
Particulate (PM 10)	*Particles with diameters of 10 micrometers or less*		
Annual Arithmetic Mean	50 $\mu g/m^3$		Primary & Secondary
24-hour Average	150 $\mu g/m^3$		Primary & Secondary
Particulate (PM 2.5)	*Particles with diameters of 2.5 micrometers or less*		

Pollutant	Standard Value		Standard Type
Annual Arithmetic Mean	15 µg/m^3		Primary & Secondary
24-hour Average	65 µg/m^3		Primary & Secondary
Sulfur Dioxide (SO_2)			
Annual Arithmetic Mean	0.030 ppm	(80 µg/m^3)	Primary
24-hour Average	0.14 ppm	(365 µg/m^3)	Primary
3-hour Average	0.50 ppm	(1300 µg/m^3)	Secondary

Table 2-4: National ambient air quality standards (EPA, 2007)

2.3 Air Pollution modelling and simulation.

There are four factors that affect the transport, dilution, and dispersion of air pollutants:

- emission or source characteristics
- the nature of the pollutant material
- meteorological characteristics
- the effects of terrain and anthropogenic structures.

Source characteristics

Most industrial pollution is discharged vertically from a stack or duct into the open air. As the contaminated gas stream is emitted, the plume (body of polluted air) expands and plume means the body of polluted air, wind that is horizontal air movement will bend the plume in the downwind direction. At some distance from the source, the plume will level off. While the plume is rising, bending, and starting to move with the wind in the downwind direction, the flue gas is being mixed and diluted by the ambient air. As the gas is being diluted by increasing volumes of air, the contaminant will eventually reach the ground.

The initial rise of the plume is due to the upward inertia of the gas stream exiting the stack, and by its buoyancy. The vertical inertia is related to the exit velocity and mass of the gas. The buoyancy is related to the density relative to the surrounding air, primarily determined by temperature. Increasing exit velocity, and increasing exit temperature will increase the plume rise.

The plume rise, together with the physical stack height, is called the *effective stack height*

For a given set of stack and discharge conditions, the ground level concentration is proportional to the mass flux, i.e., the amount emitted per unit time. Increasing emission rates will therefore lead to a proportional increase in ambient concentrations.

Downwind distance

The greater the distance from the discharge point, the greater the volume of air available for dilution. However, since the plume starts above the ground and needs some time to reach the ground (by bending and spreading), there is no concentration observable in the immediate vicinity of the stack, then we can observe an increase for some distance as the plume approaches the ground. After this, the ground-level concentration will decrease with increasing distance from the emission source.

Wind speed and direction

The wind direction will determine the direction in which the plume will move across local terrain. Wind speed affects the plume rise (fast wind will bend the plume faster), and will increase the rate of dilution.

Thus, the effects of wind speed work in two opposite directions:

- increasing wind speed will decrease plume rise, thus increase ground level concentrations;
- Increasing wind speed will increase mixing, thus decreasing ground level concentrations.

Depending on the specific conditions, one or the other of these phenomena will prevail. These effects also determine the distance from the source where the maximum concentration will occur.

Atmospheric stability

The tendency of the atmosphere to resist or enhance vertical motion and thus turbulence is termed stability. Stability is related to both the change of temperature with height (the lapse rate) and wind speed.

A neutral atmosphere neither enhances nor inhibits mechanical turbulence. An unstable atmosphere enhances turbulence, whereas a stable atmosphere inhibits mechanical turbulence.

The turbulence of the atmosphere is by far the most important parameter affecting dilution of a pollutant. The more unstable the atmosphere, the greater the dilution.

Stability classes are defined for different meteorological situations, characterised by wind speed and solar radiation (during the day) and cloud cover during the night. The so called Pasquill-Turner stability classes (based on D. Bruce Turners *Workbook of Atmospheric Dispersion Estimates* include six stability classes:

1	A	very unstable
2	B	unstable
3	C	slightly unstable

4	D	neutral
5	E	stable
6	F	very stable

Mixing height

Inversions result from the vertical temperature profile of the air: while temperature normally decreases with altitude (on average, at a rate of one degree Centigrade per 100 meters), an inversion describes an increase of temperature with increasing height. This results in a stable temperature profile (the colder air is stable under the upper warmer layer), restricting vertical mixing, and exacerbating pollution episodes through restricted mixing volumes.

2.4 Air pollution model

A model is a simplified picture of reality. It doesn't contain all the features of the real system but contains the features of interest for the management issue or scientific problem we wish to solve by its use. Models are widely used in science to make predictions and/or to solve problems, and are often used to identify the best solutions for the management of specific environmental problems.

Models may be:

• physical – a scaled-down representation of reality

• mathematical – a description of the system using mathematical relationships and equations.

Contaminants discharged into the air are transported over long distances by large-scale air-flows and dispersed by small-scale air-flows or turbulence, which mix contaminants with clean air. This dispersion by the wind is a very complex process due to the presence of different-sized eddies in atmospheric flow. Even under ideal conditions in a laboratory the dynamics of turbulence and turbulent diffusion are some of the most difficult in fluid mechanics to model. There is no complete theory that describes the relationship between ambient concentrations of air pollutants and the causative meteorological factors and processes.

An atmospheric dispersion model is a:

- Mathematical simulation of the physics and chemistry governing the transport, dispersion and transformation of pollutants in the atmosphere
- Means of estimating downwind air pollution concentrations given information about the pollutant emissions and nature of the atmosphere.

Dispersion models can take many forms. The simplest are provided in the form of graphs, tables or formulae on paper. Today dispersion models more commonly take the form of computer programs, with user-friendly interfaces and online help facilities. Most modern air pollution models are computer programs that calculate the pollutant concentration downwind of a source using information on the:

- contaminant emission rate
- characteristics of the emission source
- local topography
- meteorology of the area

• ambient or background concentrations of pollutant.

A generic overview of how this information is used in a computer-based air pollution model is shown in Figure 2.1.

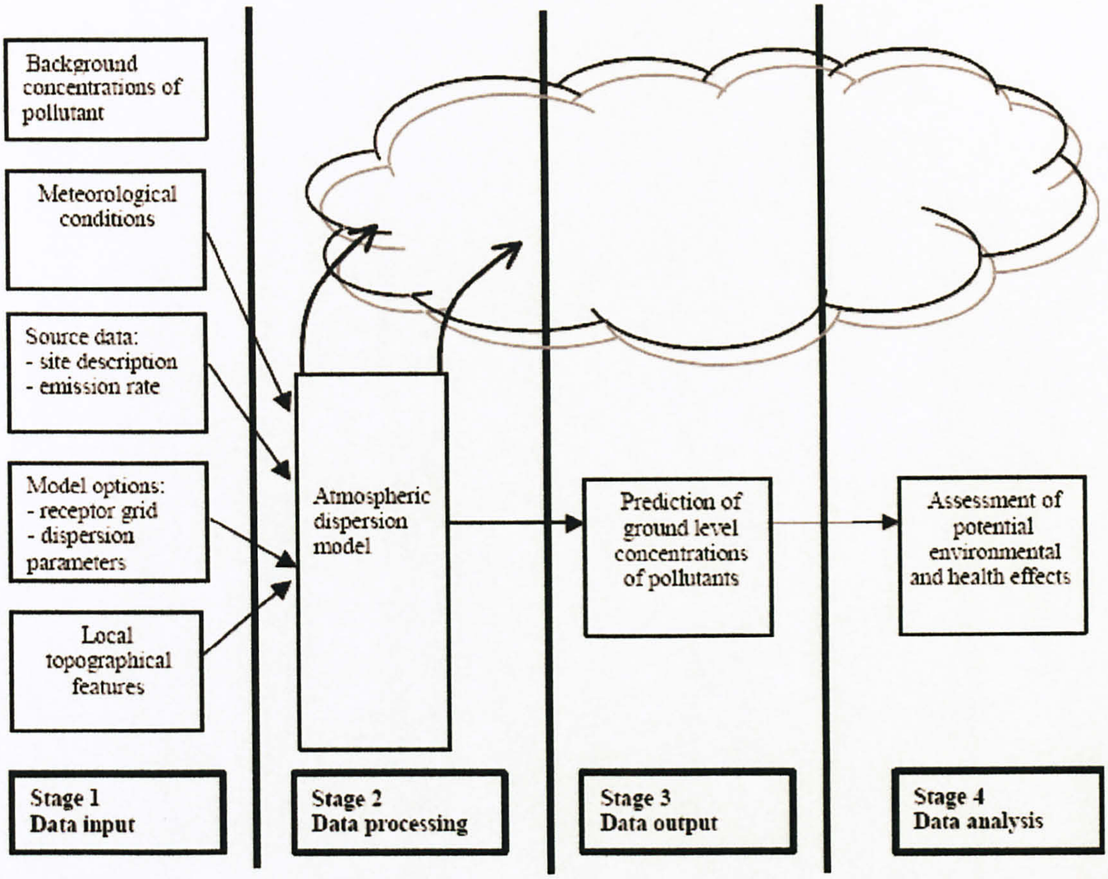

Figure 2.1: Overview of the air pollution modelling procedure (MFE, 2004)

The process of air pollution modeling contains four stages (data input, dispersion calculations, deriving concentrations, and analysis). The accuracy and uncertainty of each stage must be known and evaluated to ensure a reliable assessment of the significance of any potential adverse effects.

Currently, the most commonly used dispersion models are steady-state Gaussian-plume models. These are based on mathematical approximation of plume behaviour and are the easiest models to use. They incorporate a simplistic description of the dispersion process, and some fundamental assumptions are made that may not accurately reflect reality. However, even with these limitations, this type of model can provide reasonable results when used appropriately.

More recently, better ways of describing the spatially varying turbulence and diffusion characteristics within the atmosphere have been developed. The *new generation* dispersion models adopt a more sophisticated approach to describing diffusion and dispersion using the fundamental properties of the atmosphere rather than relying on general mathematical approximation. This enables better treatment of difficult situations such as complex terrain and long-distance transport.

2.4.1 Type of Air pollution model

Gaussian model: The Gaussian model is perhaps the oldest (circa 1936) and perhaps the most accepted computational approach to calculating the concentration of a pollutant at a certain point. The origin of the Gaussian model is found in work by Sutton (1932), Pasquill (1962, 1974), and Gifford (1961, 1968). Gaussian models are most often used for predicting the dispersion of continuous, buoyant air pollution plumes originating from ground-level or elevated sources. Gaussian models may also be used for predicting the dispersion of non-continuous air pollution plumes (called puff models). A Gaussian model also assumes that one of the seven stability categories, together with wind speed, can be used to represent any atmospheric condition when it comes to calculating dispersion.

There are several versions of the Gaussian plume model. A classic equation is the Pasquill-Gifford model. Pasquill (1961) suggested that to estimate dispersion one should measure the horizontal and vertical fluctuation of the wind. Pasquill categorized the atmospheric turbulence into six stability classes named A, B, C, D, E and F with class A being the most unstable or most turbulent class, and class F the most stable or least turbulent class.

Lagrangian model: a Lagrangian dispersion model mathematically follows pollution plume parcels (also called particles) as the parcels move in the atmosphere and they model the motion of the parcels as a random walk process. Lagrangian modelling well described by number of studies by Rohde (1972, 1974), Fisher (1975), Eliassen (1978), Hanna, (1981), Eliassen *et al.*, (1982) and Robert *et al.*, (1985). Langrangian modelling is often used to cover longer time periods, up to years (Builtjes, 2001).

Box model: The simplest approach to estimating pollutant concentrations over a given domain is to implement a single box model (Lettau, 1970). As the name implies, the principle is to identify an area of the ground, usually rectangular, as the lower face of a cuboid which extends upward into the atmosphere (Colls, 2002). Box models are used to analyse observations of selected chemical species, and study troposheric chemistry under specific conditions (Brasseur *el al.*, 2003). Box models which assume uniform mixing throughout the volume of a three dimensional box are useful for estimating concentrations, especially for first approximations (Boubel *et al.*, 1994). The box modelling approach is well discusses by; Lettau, (1970), Derwent *et al.*, (1995) and Middleton (1995, 1998).

2.4.2 The Gaussian steady-state dispersion model

Gaussian-plume models are widely used, well understood, easy to apply, and until more recently have received international approval. Even today, from a regulatory point of view ease of application and consistency between applications is important. Also, the assumptions, errors and uncertainties of these models are generally well understood, although they still suffer from misuse.

Gaussian-plume models play a major role in the regulatory arena. However, they may not always be the best models to use and it was noted at the 15th International Clean Air Conference 2000 – Modelling Workshop, that particular models are not always chosen on an objective scientific basis (Ross, 2001).

The Gaussian-plume formula is derived assuming 'steady-state' conditions. That is, the Gaussian-plume dispersion formulae do not depend on time, although they do represent an ensemble time average. The meteorological conditions are assumed to remain constant during the dispersion from source to receptor, which is effectively instantaneous. Emissions and meteorological conditions can vary from hour to hour but the model calculations in each hour are independent of those in other hours. Due to this mathematical derivation, it is common to refer to Gaussian-plume models as steady-state dispersion models. In practice, however, the plume characteristics do change over time, because they depend on changing emissions and meteorological conditions. One consequence of the plume formulation is that each hour the plume extends instantaneously out to infinity. Concentrations may then be found at points too distant for emitted pollutants to have reached them in an hour.

Steady-state models calculate concentrations for each hour from an emission rate and meteorological conditions that are uniform across the modelling domain. Thus they simulate hourly-average concentrations. Both Gaussian-plume and advanced modelling are time-varying, changing from hour to hour. The term 'steady-state' should not be taken to mean that conditions are steady from hour to hour. The plume formula has the uniform wind speed in the denominator and hence breaks down in calm conditions. It is usual to specify a minimum allowable wind speed for the model.

The Gaussian-plume formula provides a better representation of reality if conditions do not change rapidly within the hour being modelled (i.e. conditions are reasonably steady and do not deviate significantly from the average values for the hour being modelled). The Gaussian-plume representation of dispersion described above is simplistic and, as such, should only be applied under certain conditions.

However, it is impossible to prescribe in advance the exact conditions under which a Gaussian-plume model is applicable. The modeler should initially be guided by the recommendations in this Guide and later by experience. A careful examination of model results should be carried out to determine how realistic the output concentrations are at critical times, given the known geography and meteorology. In this sense, the assessment of model results may be more important than the initial choice of model.

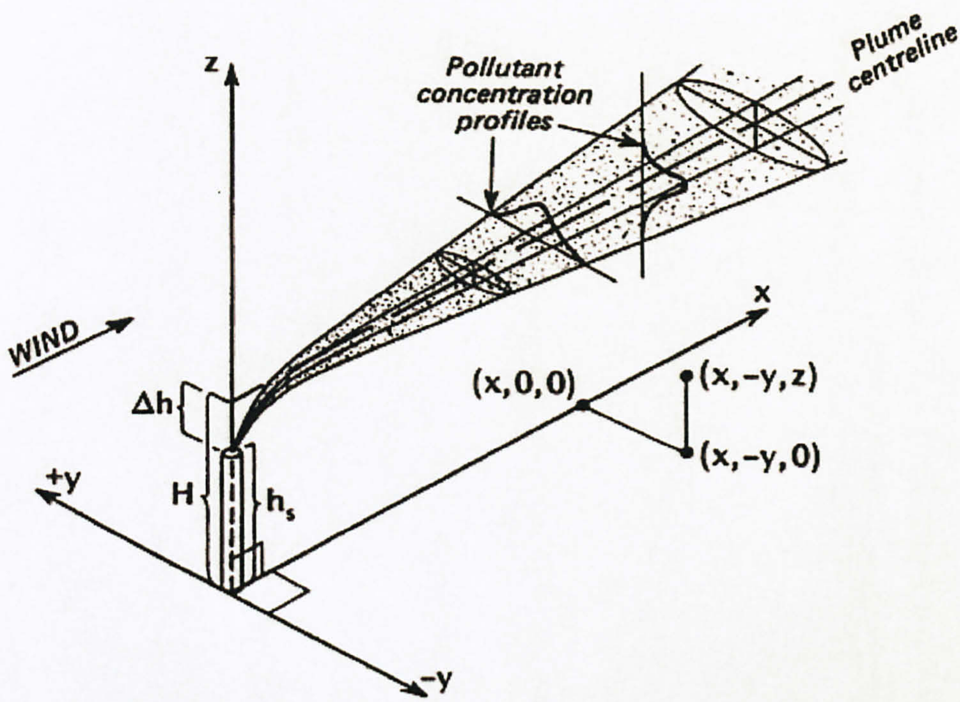

Figure 2.2: A typical plume from an elevated point source (MFE, 2004)

The most commonly used model for regulatory purposes is the Gaussian steady-state model. It provides a steady-state solution to the transport and diffusion equations (transport plus diffusion = dispersion). Steady-state implies that the basic assumption is a constant emission and constant meteorological conditions:

The basic Gaussian diffusion equations assume:

- that atmospheric stability and all other meteorological parameters are uniform and constant throughout the layer into which the pollutants is discharged, and in particular that wind speed and direction are uniform and constant in the domain;
- that turbulent diffusion is a random activity and therefore the dilution of the pollutant can be described in both horizontal and vertical directions by the Gaussian or normal distribution;
- that the pollutant is released at a height above the ground that is given by the physical stack height and the rise of the plume due to its momentum and buoyancy (together forming the effective stack height);
- that the degree of dilution is inversely proportional to the wind speed;
- that pollutant material reaching the ground level is reflected back into the atmosphere;
- that the pollutant is conservative, i.e., not undergoing any chemical reactions, transformation or decay.

2.5 History of GIS

Humankind existence has given birth to a long tradition of map making. As they know the world better through exploration, map making has become more complicated and meaningful in organizing geographical data. With the advent of computer technology, Global Information System (GIS) has become a standard tool in manipulating ever-increasing information in a map.

A landscape architect by the name Ian McHarg, who advocated "transparent-overlay maps" in the 1960s, a rational approach to site planning which he termed physiographic determinism, as a way for planners to see more clearly the aspects of nature, forests, wildlife, and marshes that new roads and buildings would obliterate (McHarg, 1992)

McHarg's method looks remarkably like the output of contemporary GIS; coloured thematic maps were generated that aided in planning even though the process was cumbersome and the amount of data limited.

Important geographic work was also being done at universities throughout the 1950s and 1960s. The Harvard Laboratory for Computer Graphics and Spatial Analysis laid its foundation with the development of general purpose mapping software in the mid-1960s by Howard Fisher. A GIS-type course was taught in 1966 as a "collaborative regional-scale studio and used SYMAP in a landscape-planning study of the peninsula. SYMAP was invented in Chicago and then Fisher moved to Harvard where SYMAP and GIS evolved into many other things. The educational and research programme grew through the 60s, 70s and the 80s with GIS approach and automated mapping systems with development of databases. Apart from the SYMAP, other Harvard packages, which were equally important in the developing field of GIS and spatial data analysis, were CALFORM (late 1960s), SYMVU (late 1960s), GRID (late 1960s), Polyvrt (early 1970s) and ODYSSEY (mid 1970s). These early GIS packages were often written for specific applications and required the mainframe computing systems found usually in government or university settings.

Those physical overlay maps inspired a generation of environmentalists, notably Jack Dangermond, who studied landscape architecture at Harvard University. The idea of creating maps from layers of data became the heart of GIS, and it's the secret of its power. Using software like Dangermond's, people could combine census information, satellite photos, and many other types of data to reveal relationships that were never obvious before. Jack and Laura Dangermond founded Environmental Systems Research Institute (ESRI) in 1969 as a privately held consulting group. The business began with $1100 from their personal savings and operated out of an historic home located in Redlands, California.

ESRI's early research and development in cartographic data structure, specialised GIS software tools and creative applications set the stage for today's revolution in digital mapping. In 1981, ESRI released Arc/Info, a standard package which ran on mainframe computers (ESRI, 1992). GIS became a viable technology for state and municipal planning as the hardware prices and computing power increased in 1980s (Harris and Elmes,1993). A major improvement in usability over Arc/Info's command-line interface signaled the new era of desktop mapping system with a graphical user interface (GUI) called ArcView being was being released in 1992 (ESRI, 1992).

The adoption of GIS as a planning or research tool for community organization and underfunded group was made possible in the late 1990s after the development of ArcView for Microsoft Windows and ArcIMS being done by ESRI. It enables the distribution of mapping and spatial analysis over the Internet and eliminates many of the hardware and licensing expenses of a full software package, that benefit greatly to the marginalized and underfunded groups. (Harris and Elmes, 1993).

Today ESRI continues to set standards in the GIS industry. Its software is installed at more than 100,000 client sites worldwide, of which about 13000 are in Asia and the Pacific regions. Worldwide, ESRI has over 91 distributors, 16 of which are located in Asia.

However ther is another version of history of GIS. According to John Cloud a geographer with the National Oceanic and Atmospheric Administration in Washington DC. It is a misleading history of GIS which gives university-based scientists more credit for GIS than they deserve. The *real* roots of digital mapping, he says, reach back to the Cold War and to the U.S. Defense Department's secret campaign to assemble accurate maps of nuclear targets in the Soviet Union.

Before taking his current job as a historian for the National Oceanic and Atmospheric Administration, Cloud spent more than a decade assembling an alternative genealogy of GIS, showing military planners, not idealistic landscape architects, to be its fathers. In the 1950s, the Defense Department recruited scientists to determine the exact distances between the earth's continents -- essential for aiming intercontinental ballistic missiles. Later, Pentagon officials sent the first remote-sensing satellites aloft to photograph "denied territories" inside the Soviet Union. In the 1960s, the Pentagon converted those images into digital data, and in the 1980s, the U.S. Air Force launched the Global Positioning System, the essential tool for today's mapmakers.

These military projects were the pillars on which geographic information systems were built, Cloud says. In scale and sophistication, they dwarfed anything accomplished in the civilian world at that time. And the world imagined in these maps was not one of environmental sustainability but one of nuclear war.

As for Ian McHarg's transparent-overlay maps, intended to help preserve nature and facilitate more-livable cities – according to Cloud, that, too, is a cover story. There were other forerunners of layered digital maps, he says, including some that were used for less uplifting purposes than McHarg's.

All in all, the history of GIS is pretty colourful and significant for humankind development in understanding the world especially throughout the 20th century as well in upcoming future where numerous problems and challenges will be relating to organizing the information in large-scale system.

2.6 Definition of GIS

A geographic information system (GIS) may be defined as .a computer-based information system that enables capture, modelling, manipulation, retrieval, analysis and

presentation of geographically referenced data. (Worboys 1995). A broadly accepted definition of GIS is the one provided by the National Centre of Geographic Information and Analysis:

> GIS is a system of hardware, software and procedures to facilitate the management, manipulation, analysis, modelling, representation and display of georeferenced data to solve complex problems regarding planning and management of resources (NCGIA, 1990)

In fact, it's more than mapmaking. It's a way of organizing information about anything that happens at a particular geographic location. That includes real-estate development, military operations, logging, farming, oil drilling -- the list goes on and on. GIS lets companies use mailing addresses to build maps of their customer bases, environmentalists study the effects of climate change on vegetation and glacier movement, and medical researchers investigate links between contaminated drinking water and cancer incidence. Some of the fields that have been using GIS extensively are: Geography, Cartography, Photogrammetry, Remote Sensing, Geology, Geodesy, Surveying, Statistics, Computer Science, Mathematics, Chemical Engineering and Civil Engineering.

2.6.1 Type of GIS software

- *Autodesk* – Products include Map 3D, Topobase, MapGuide and other products that interface with its flagship AutoCAD software package.
- *Bentley Systems* – Products include Bentley Map, Bentley PowerMap and other products that interface with its flagship MicroStation software package.
- *Intergraph* – Products include GeoMedia, GeoMedia Professional, GeoMedia WebMap, and add-on products for industry sectors, as well as photogrammetry.
- *ERDAS* – Products encompassing GIS, Photogrammetry, and Remote Sensing.
- *ESRI* – Products include ArcView 3.x, ArcGIS, ArcSDE, ArcIMS, and ArcWeb services.
- *ENVI by ITT* – Utilized for image analysis, exploitation, and hyperspectral analysis.
- *MapInfo by Pitney Bowes* – Products include MapInfo Professional and MapXtreme. integrates GIS software, data and services.
- *Manifold System* – GIS software package.
- *Smallworld* – developed in Cambridge, England (Smallworld, Inc.) and purchased by General Electric and used primarily by public utilities.

2.6.2 GIS Application

- *mapping locations*: GIS can be used to map locations. GIS allows the creation of maps through automated mapping, data capture, and surveying analysis tools.

- *mapping quantities*: People map quantities, like where the most and least are, to find places that meet their criteria and take action, or to see the relationships between places. This gives an additional level of information beyond simply mapping the locations of features.

- *mapping densities*: While you can see concentrations by simply mapping the locations of features, in areas with many features it may be difficult to see which areas have a higher concentration than others. A density map lets you measure the number of features using a uniform areal unit, such as acres or square miles, so you can clearly see the distribution.

- *finding distances*: GIS can be used to find out what's occurring within a set distance of a feature.

- *mapping and monitoring change*: GIS can be used to map the change in an area to anticipate future conditions, decide on a course of action, or to evaluate the results of an action or policy.

2.7 Environmental Application of GIS.

GIS give a wide framework where different discipline and topic can be accommodating into one database. The specific application play an important role in adapting different type of GIS tool and in many instance provide the basis for unification of these system. GIS can act like central information hub.

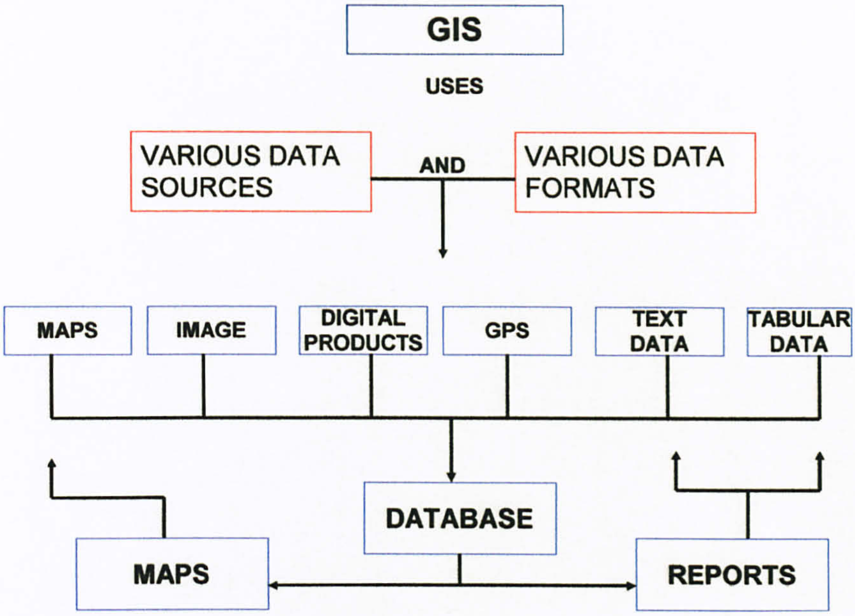

Figure 2.3: GIS acted like central information hub.

GIS can be broken down to 5 major activities. In its simples function, GIS can present data in a map form to communicate information.

Second, GIS can organize geographic data in the map, chart or table form to visualize spatial pattern in order o stimulate visual thinking. Third, GIS can query geographic point of interest and associates attributes to answer the question, "what and where?" fourth, it can provide new information by building geographic theme from older layers. Finally, GIS can also track pattern in space and time to aid in the function of analysis, decision making and workflow.

2.7.1 GIS Application in air pollution

Various capabilities of GIS may be utilized for air modelling, which may include locating monitoring stations, developing air quality models and development of spatial decision support system. By doing air quality modelling under GIS environment, the output of the pollutant records can be obtained in the form of spatial records. GIS techniques are capable of supporting the development of geospatial air quality models (Agrawa *et al.*, 2003). For more complex models that go beyond the classical Gaussian plume models, topographic relief, surface roughness, and surface temperatures are important input parameters.

Sources of pollution are spatially distributed, and may be point sources such as large industrial stacks or power plants, line sources such as highways, and area sources, such as urban areas (Fedra, 1994). The prediction of the magnitude of impacts is often undertaken by the application of simulation models (Fedra, 1993). The obtained result will most often be a map of the value of a given environmental descriptor (e.g., concentration of an air pollutant) at any location within the study area. The extension of environmental impacts can therefore be estimated from the spatial distribution of environmental quality values predicted for each alternative.

Sharma *et al.*, (2003) summarised in their article in regards to various GIS applications used in air pollution modelling. Their article cited several works authors who have been involved in the area of air pollution using GIS applications. For instant, Medina *et al.*, (1994) presented the framework for air quality analysis model that integrated CADD, GIS, transportation and air quality models linking traffic information within GIS framework for use in vehicle emission and air pollution dispersion models. Hallmark and O'Neil, (1996) described the development of a model that combined the micro scale air quality model applicable for intersection (CAL3QHC) with GIS.

Anderson *et al.* (1996) described the use of GIS as a tool to illustrate the spatial patterns of emission and to visualize the impact that congestion has on emissions. The model consisted of an integrated urban model that interfaced with the emission rate model (MOBILE 5C). The integrated model allowed the impact of transportation and land use policy changes to be simulated in terms of their air quality impact. Briggs *et al.*, (1997) described the GIS application as a tool when combined with least square regression analysis for mapping traffic related air pollution to generate predictive models of pollution surfaces, based on monitored pollution data and exogenous information. In case of large scale air quality modelling, more detailed spatial data are needed to include the impact of buildings and other manmade barriers on the distribution of air pollutants, (Janour, 1999; Civis, 2001; Matejicek, 2005). Pummakarnchana *et al.*, (2005) applied a suitable gas sensing device coupled to a personal digital assistant to monitor urban air pollution and disseminate the information in real time through wireless GIS.

CHAPTER 3

GENERAL THEORETICAL METHODOLOGY

3.1 Air pollution assessment using GIS

Before we start to use GIS, there is a great need to understand the work flow of the process as being outlined by the Figure 3.1 above. The main input of GIS would be from the air pollution simulation which makes use software that being developed by UTP final year student in determining the concentration over distance of particular gaseous pollutant called Point Source Dispersion Software (PSD).

Before the simulation can be performed, certain important data must be gathered. There is a need to understand the case study condition of the industrial plant such as the stack height, velocity of gas at the exit of the stack as well the emission rate of the gaseous pollutant. Besides that, data from meteorological department must also be obtained particularly the wind speed, pressure and temperature of that affect the industrial site.

The data that we have obtained from those two major divisions will be acting as the input for the air pollution simulation. The results from the simulation process, which is the concentrations over distance of the gaseous pollutant, will be used as the main input for the GIS. The pollutant concentrations can be generated graphically as a buffer zones on the map of the industrial site to determine the possible effect of the emission that comes out from the industrial site upon the surrounding area, notably the residential area.

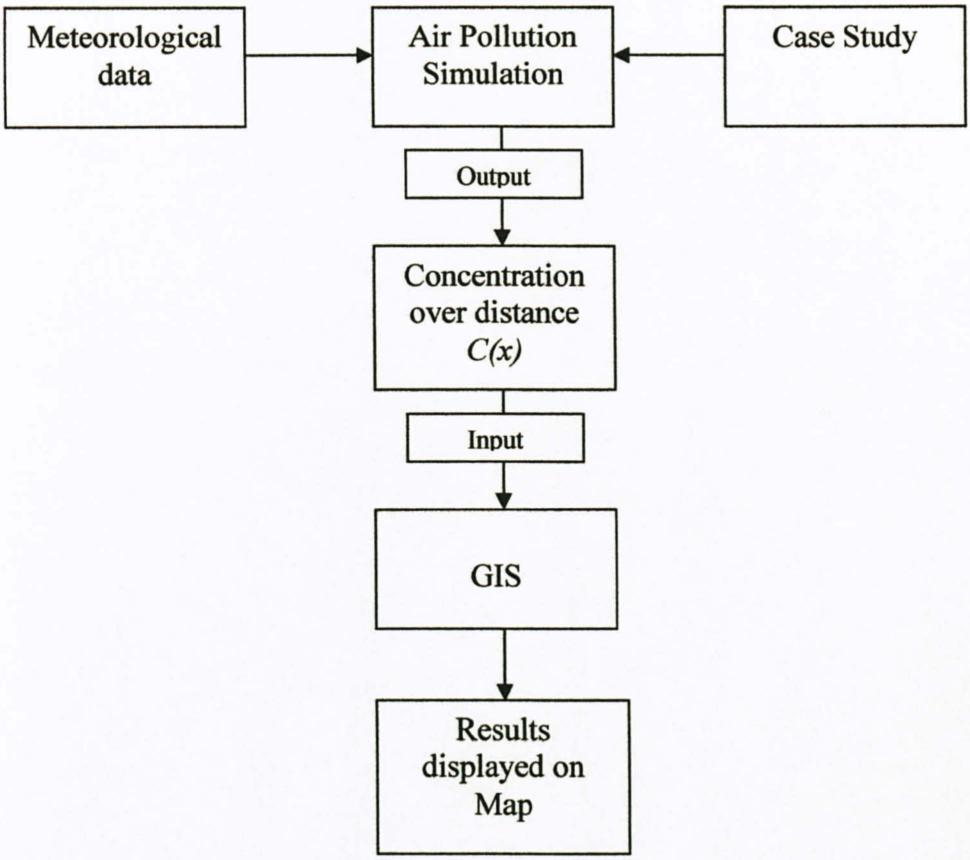

Figure 3.1 Work flow of project methodology

3.2 The model equations – Gaussian model.

The spatial dynamics of pollution dispersion is described by the following type of equation in a Gaussian model:

(1)

$$C(x,y,z,t) = \frac{Q}{2\pi.u.\sigma y.\sigma z}.\exp\left(-\frac{y^2}{2\sigma_y^2}\right)\left[\exp\left(-\frac{(z-H_{eff})^2}{2\sigma_z^2}\right)\right] + \exp\left(-\frac{(z-H_{eff})^2}{2\sigma_z^2}\right)$$

Equation 3.2: Gaussian model mathematical equation

Where

- C(x, y, z) : pollutant concentration at point (x, y, z);
- U : wind speed (in the x "downwind" direction, m/s)
- σ represents the standard deviation of the concentration in the x and y direction, i.e., in the wind direction and cross-wind, in meters;
- Q is the emission strength (g/s)
- H_{eff} is the effective stack height.

From the above equation one can deduce, in steady state, the concentration in any point (x, y, z) in the model domain, from a constant emission rate.

3.3 Point Source Dispersion Software (PSD) Interface

The point source dispersion interface consists of four sections in order to allow users to view the results of the simulation and to evaluate the concentration of emission gas from the stack as shown in Figure 3.3. Gas Information is the first section of the software which the users have to key in name of the pollutant gas and the molecular weight. Second section is for Atmospheric Conditions. For this section, users have to key in the wind speed and select the atmospheric stability class form the atmospheric stability class's combo. The third section is the Stack Parameters. In this section the users have to enter the stack height, stack diameter, gas exit temperature, ambient temperature, atmospheric pressure, gas emission rate as well as the gas exit velocity. In the fourth section, the users have to choose the distance either less than 1 km or more than 1 km as well as the concern distance.

After the users filled up all the input sections, then they can click the Calculate command button to view the predicted concentration results as shown in Figure 3.3. PSD software is also can estimate human fatality (the percentage of people affected). In order to calculate the percentage of people effected, user need to key in the variables in fatality section, (i.e., constant of A, B, n, and time exposure).

PSD Software is designed to perform Pasquill modified by Gifford calculation methods for point source dispersion. The results of simulation are presented in Predicted Concentration section as shown in Figure 3.3. Figure 3.3 illustrates the calculation of gas pollutant that released from a stack (Farhana, 2009).

Figure 3.3: PSD Graphical User Interface (GUI) (Farhana, 2009)

CHAPTER 4

COMPUTATIONAL SIMULATION METHODOLOGY

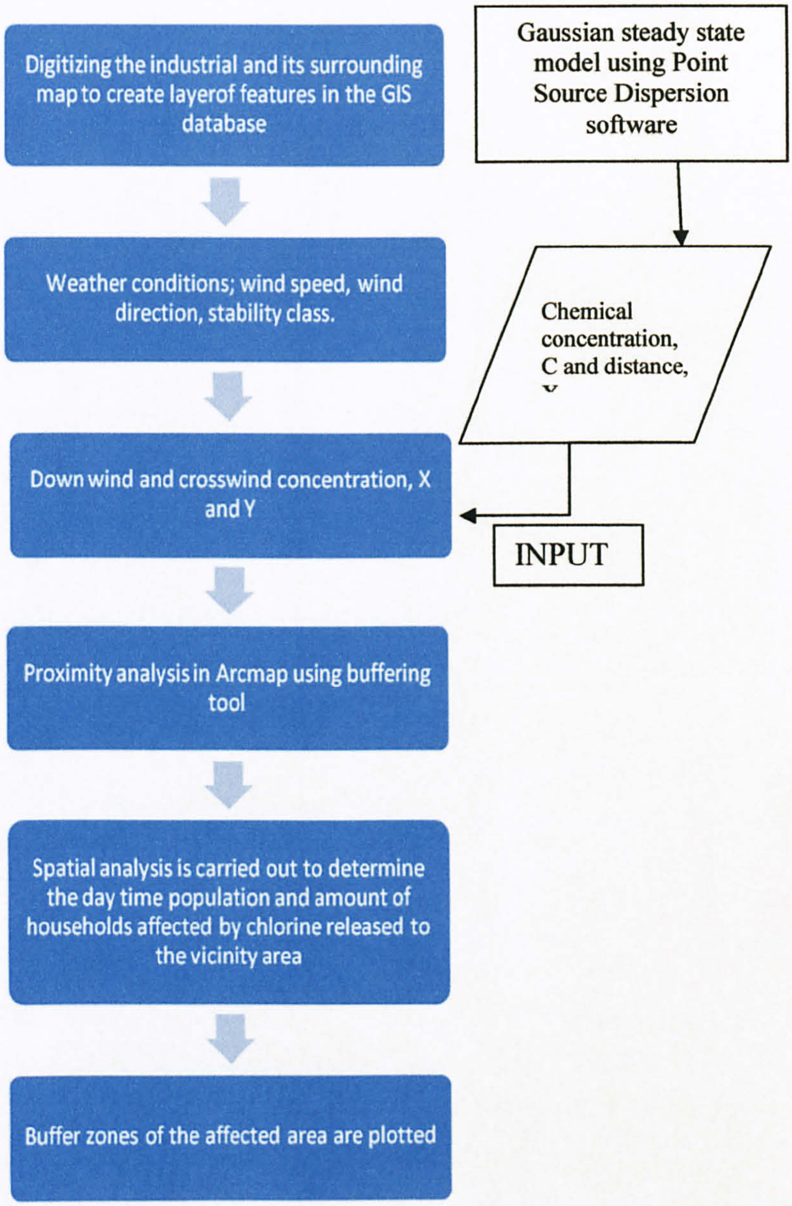

Figure 4.0: Computational Simulation Methodology

Step 1: Digitizing the industrial and its surrounding map to create layer of features in the GIS database

Before using Arcmap, we need to provide a geographical image as its input. For this purpose, Arcmap supports digitized or geo-referenced map from Google Earth application software that can be easily accessed from the net.

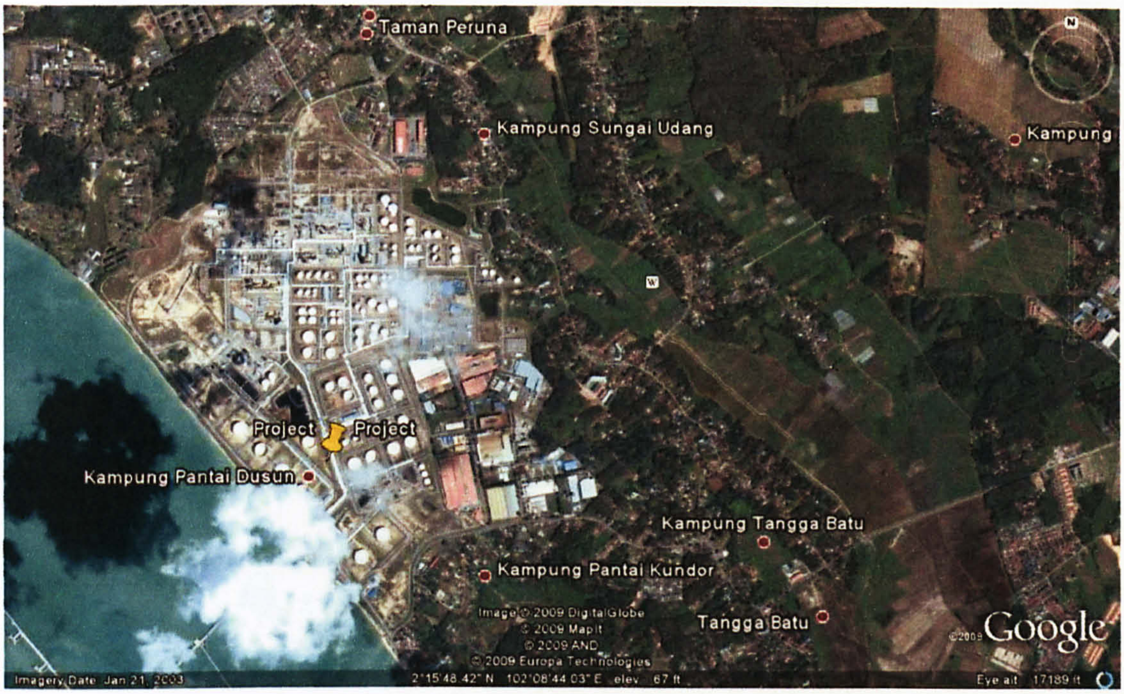

Figure 4.1: Map of industrial site taken from Google Earth.

Step 2: Collecting relevant geographical, climate and pollutants data.
Geographical data such as distance of point source of pollution to surrounding areas and climate data such as weather conditions, wind speed, wind direction as well the stability class are being obtained from relevant authorities (local meteorological department).

Pollutant data such as type of pollutants that being emitted as well the value of its concentration from the point source which being considered as classified information are obtained from the industrial personnel.

Step 3: Mathematical calculation using Point Source Dispersion software

For this purpose, we made use of air pollution analysis software named Point Source Dispersion (PSD) Software (developed by Farhana, 2009) is specifically used to analyze emission of pollutant gases released from industrial stacks. Pasquill equation and modified by Gifford as well Gaussian steady state model are used behind the software interface.

The model consider the atmospheric conditions, stack parameters and distance as the input of the simulation program. Producing the calculations is complex and that is the reason why the computer simulation is necessary in order to derive the reliable results. The results of PSD Software will show the concentration of respective pollutant gases over the distance as well as the percentage of people affected as a result from the exposure to the pollutant at certain concentration.

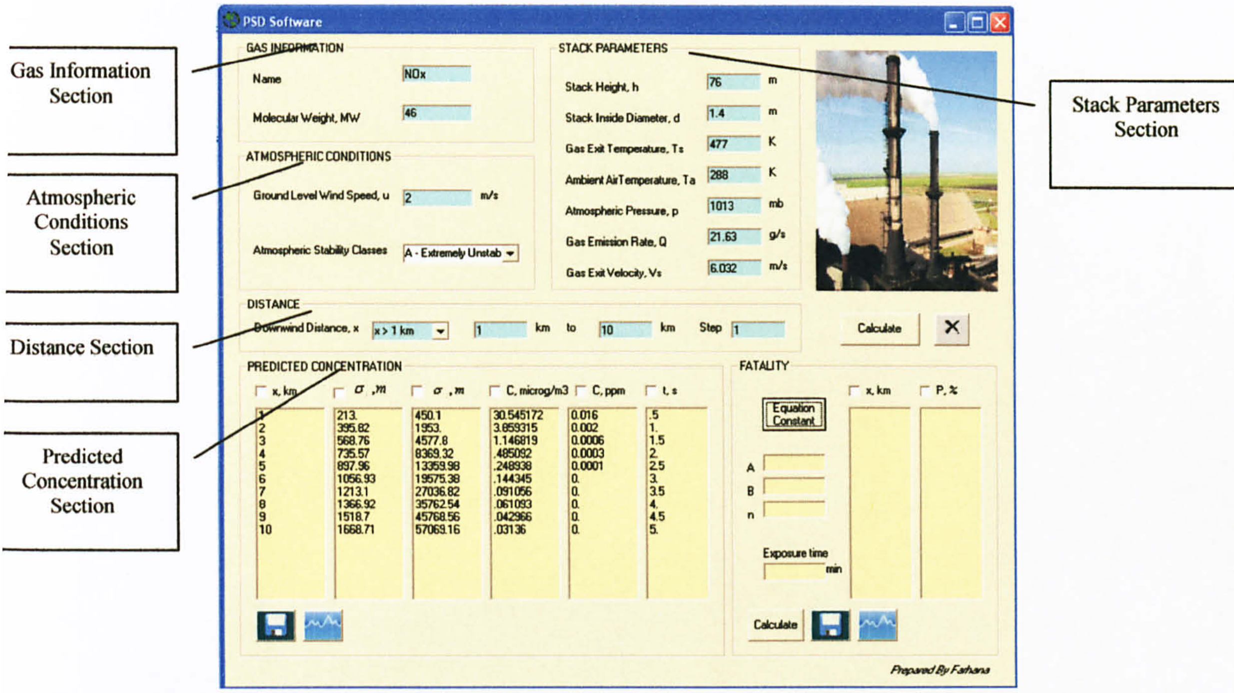

Figure 4.2: PSD Graphical User Interface (GUI) source: (Farhana, 2009)

The results obtained have been validated with data from case study and actual data as well as other established air pollution software to identify for any error occur. This software is to estimate for all type of pollutants concentration after the gas is released from the industrial stacks. This software is also used to estimate the percentage of people affected as a result from the exposure to at certain concentration. The final results from this calculation will be used as the input functions in proximity analysis in Arcmap software.

Step 4: Proximity analysis (buffering) using Arcmap

The output of Point Dispersion Software is being used as the input of Arcmap in its proximity analysis. Our main goal of using Arcmap is to create buffer plots on the map to determine the dispersion effect of the pollutants in graphical manner.

In GIS, there are two types of buffer: single ring or multiple ring buffer. A single ring buffer creates buffer polygons to a specified distance around the input Features. A multiple ring buffer creates a new feature class of buffer features using a set of buffer distances.

Since this project involved various level of air pollution concentration, the best type of buffer to be used in this analysis is multiple ring buffer. The concentration of fuel gas, which is the selected sample of air pollutant will be measured in proportional to the distance of its emission beginning from the stack till it covers the farthest distance of its dispersion pattern.

The formation of multiple ring buffer will be elaborated further in Chapter 5, Results and Discussion section.

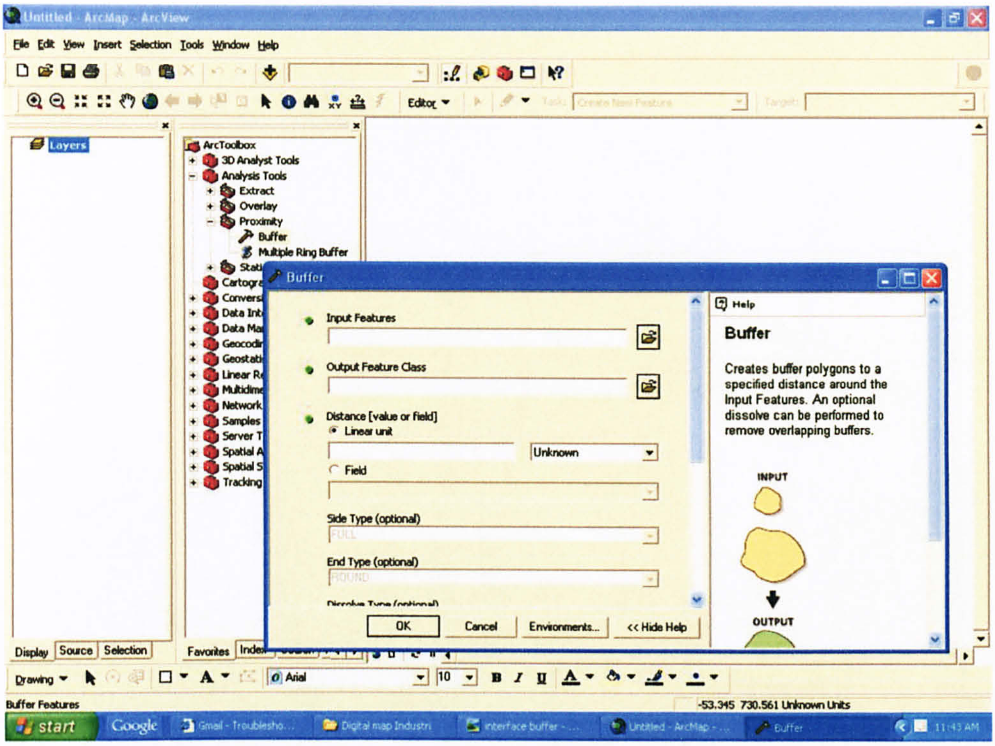

Figure 4.3: Proximity analysis using buffer

CHAPTER 5

RESULTS AND DISCUSSION

In this section, buffering process will be explained in details to show the final result that we intended to see regarding the effect of air pollution concentration in proportional to the distance of its emission on the map itself.

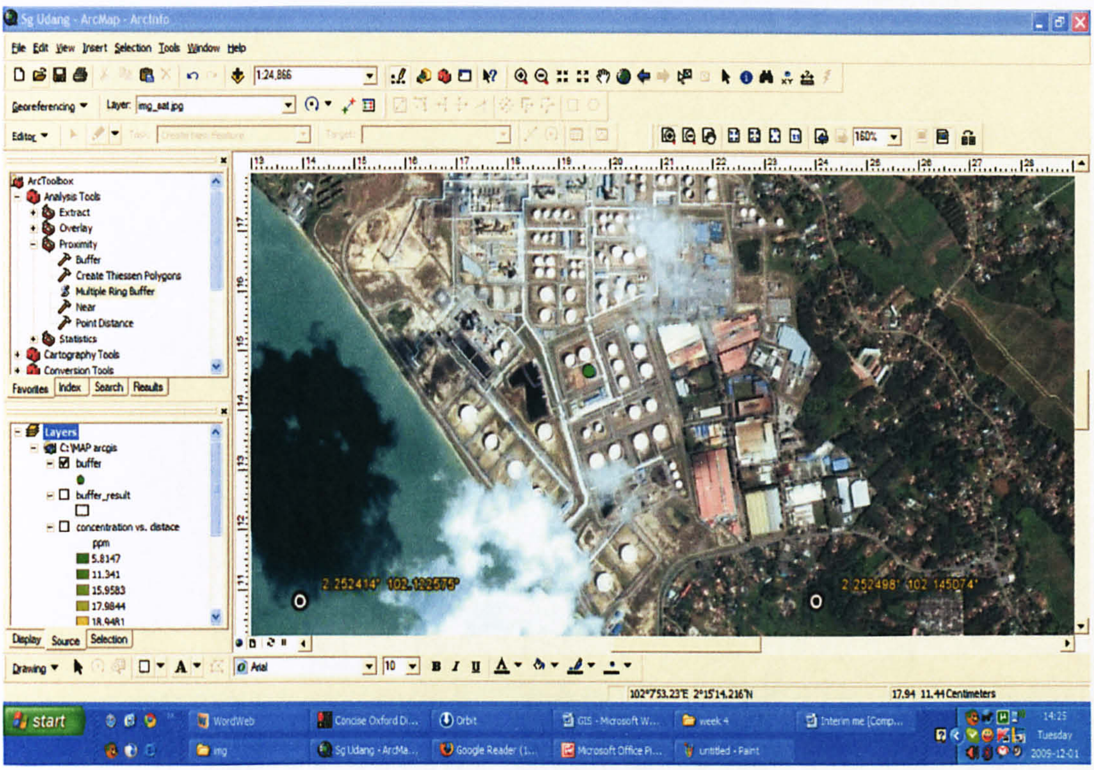

Figure 5.1: Define reference point for layer.

The first step that we need to do is to create a layer that will act as a starting point for the multiple ring buffer. By adding a dataset to Arcmap, a layer is created. Each map layer is used to display and work with a specific GIS dataset. A layer represents geographic data in Arcmap, such as a particular theme of data. Example map layers include streams and lakes, terrain, roads, political boundaries, parcels, building footprints, utility lines, and orthophoto imagery.

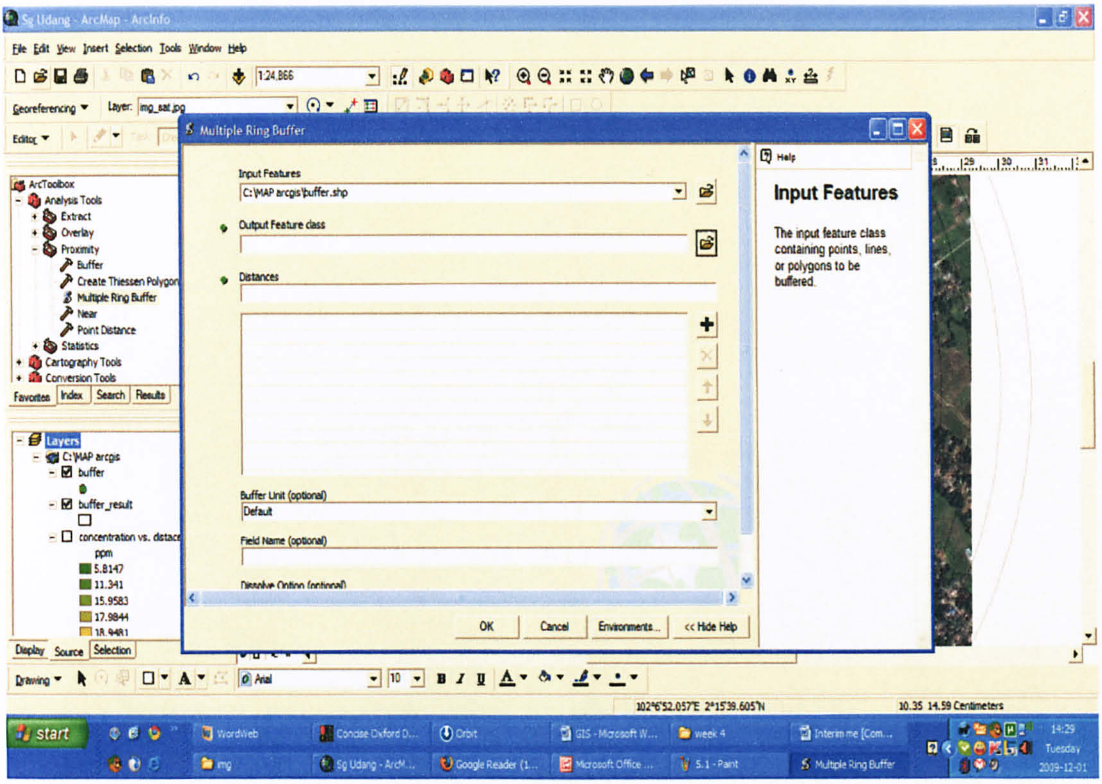

Figure 5.2: Creating multiple ring buffer

Once the reference layer has been laid on the map, we can start using the multiple ring buffer tools that being grouped under the Proximity section of Analysis tools command.

Input features for the multiple ring buffer will be referring to the reference layer that we have created earlier. Next we can key in the marginal distance of the multiple ring buffer which in this case is 0.2 km.

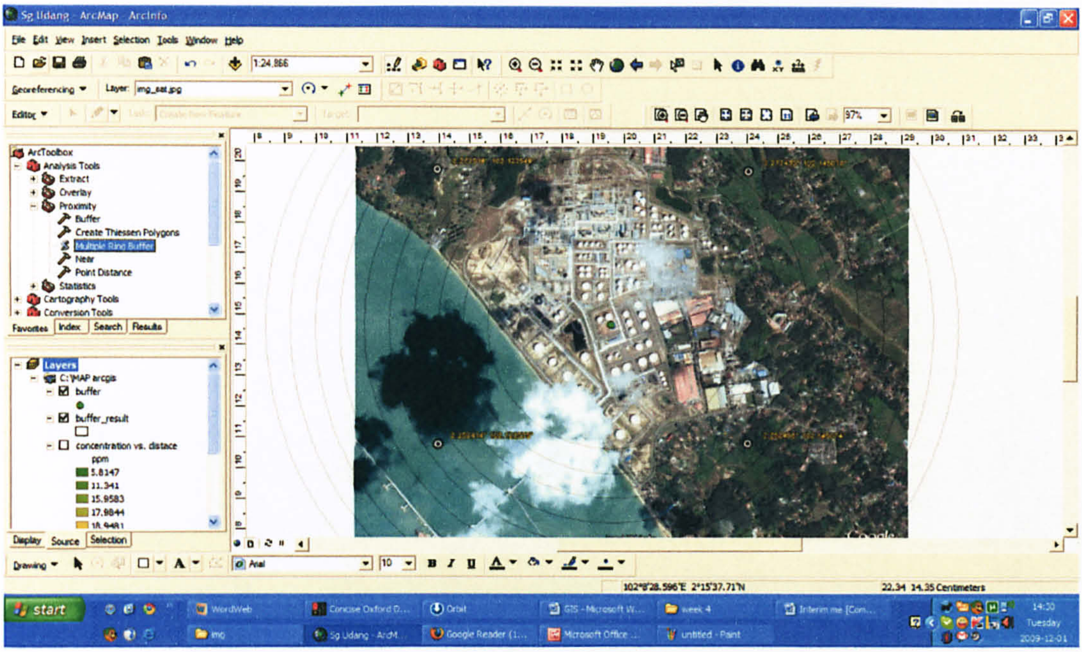

Figure 5.3: Multiple ring buffer being formed on the map

As we have set up the input features as well the output features of the multiple ring buffer, the result of the input will be projecting a multiple layers of perfect circle on the map as being depicted in the Figure 5.3 above.

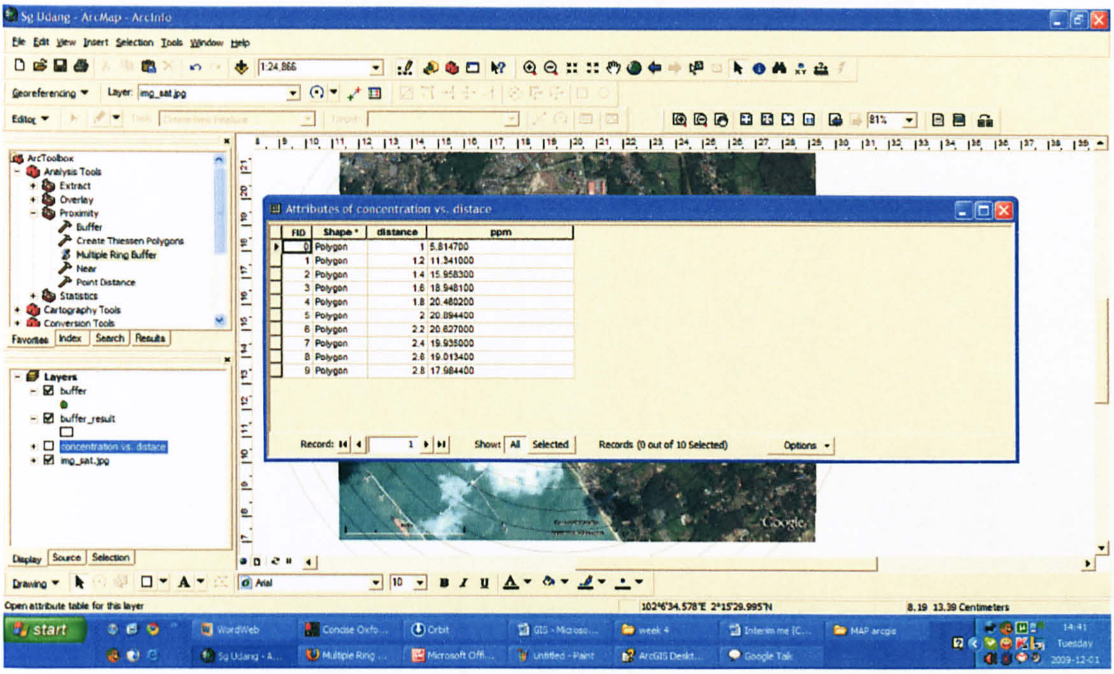

Figure 5.4: Attributes table of concentration vs. distance

Once the multiple ring buffer being formed, we can start to insert the concentration vs. distance data that we have generated earlier using Point Source Dispersion software.

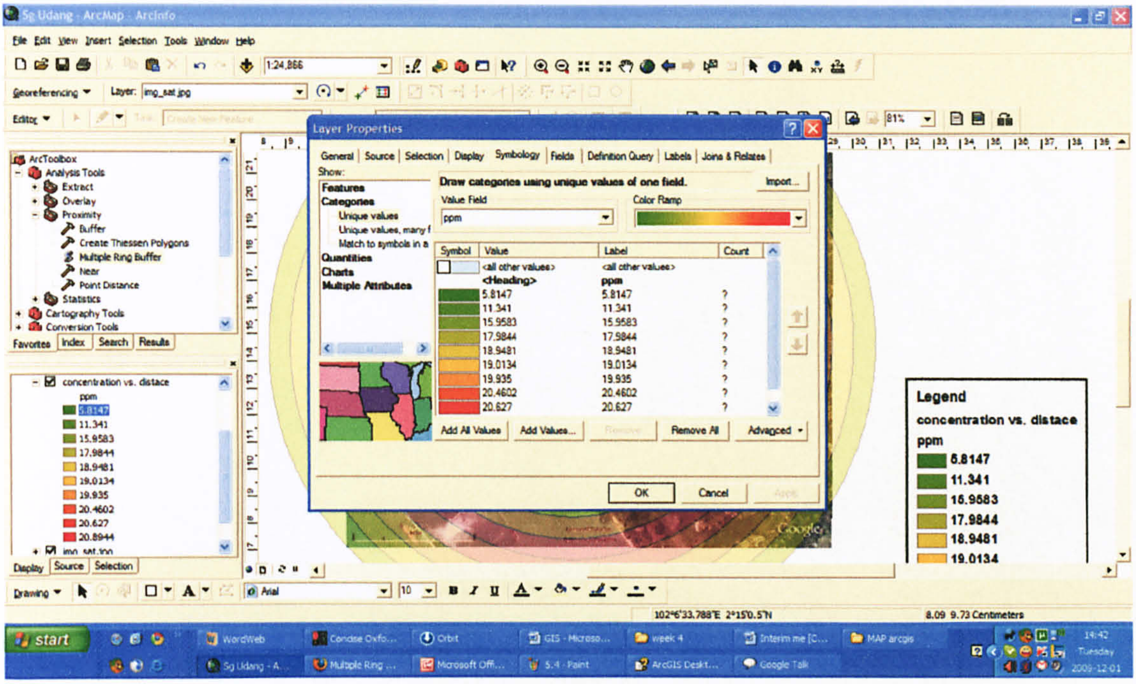

Figure 5.5: Customization of Layer Properties

The different values that being represented by each layers can be analyzed better by using customization tool of layer properties in the Arcmap itself. This tool could generate different colours of the layers according to the degree of assigned values on each of the multiple ring buffers. In Figure 5.5 above, the most concentrated value of air pollutant on the buffer layer will be represented by the fiery red colour. A lesser value of air pollutant concentration will be represented by a lesser degree of red colour until it become dark green which is the lowest value being represented by the buffer layer.

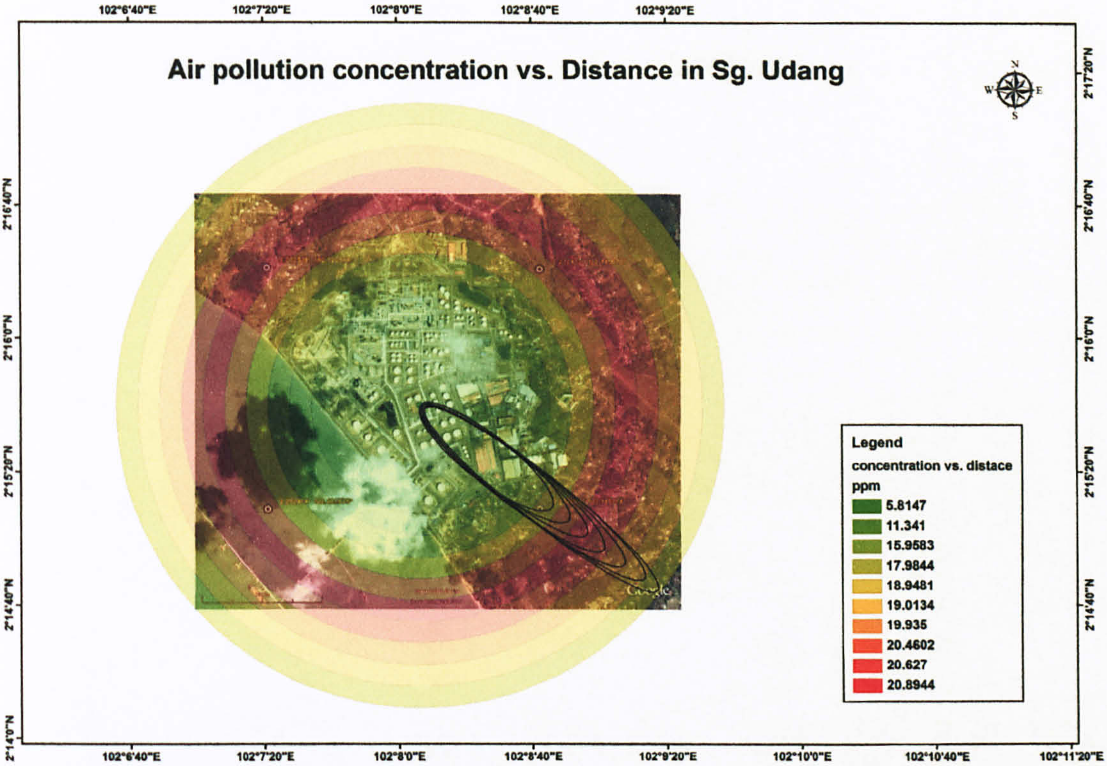

Figure 5.6: Buffer zones of the pollutants in relation to surrounding areas.

It can be clearly seen that on the map itself, there is a formation of layers of different colours according to the degree of air pollutant concentration that being emitted from the point source and dispersed throughout the surrounding of the industrial site.
Due to the effect of geographical factors such as air stability, wind, and temperature, normally the emission of air pollutant will be in a shape of ellipse rather than circular.

We can see clearly the most hazardous layer or section of the air pollutant dispersion will be in the middle of the multiple ring buffers as being represented by the red layers of buffer.

This result could be explained using the inversion theory of the inversion. An inversion occurs when air temperature increases with altitude. Plumes emitted into air layers that are experiencing an inversion (inverted layer) do not disperse very much as they are transported with the wind.

Plumes that are emitted above or below an inverted layer do not penetrate that layer, rather these plumes are trapped either above or below that inverted layer.
High concentrations of air pollutants are often associated with inversions since they inhibit plume dispersion.

Pollutants that cannot be dispersed upward may be dispersed horizontally by surface winds. The combination of vertical air movement and horizontal air flow influences the behaviour of plumes from point sources (stacks).

The looping plume occurs in highly unstable conditions and results from turbulence caused by the rapid overturning of air. While unstable conditions are generally favorable for pollutant dispersion, momentarily high ground-level concentrations can occur if the plume loops downward to the surface.

If the plume is released just under an inversion layer, a serious air pollution situation could develop. As the ground warms in the morning, air below an inversion layer becomes unstable. When the instability reaches the level of the plume that is still trapped below the inversion layer, the pollutants can be rapidly transported down toward the ground. This is known as fumigation. Ground-level pollutant concentrations can be very high when fumigation occurs. It is not strange phenomena as the industrial site itself is being built very near to the coastal area which normally produces sea-breeze and land-breeze effect into the industrial site thus affecting the dispersion factor of the air pollutants as being shown in the analysis in the Arcmap.

CHAPTER 6

CONCLUSION

GIS is very effective tool to analyze and evaluate a situation. The ArcGIS software has a lot capability to manipulate input data. This capability is very useful in analyzing the environmental impact of the air pollution. All of this depends on the accuracy of the data input and how it being manipulates. The data that will retrieve from PSD has high accuracy and this can ensure the good data input for analysis.

From the results and discussion, it is noted that the middle part of the multiple ring buffer exhibits the most hazardous section of air pollution dispersion which covers certain residential areas. This could give a fatal indicator in the long run if the problem is not being addressed carefully by management of the industrial site.

One of the simplest ways to tackle this problem is by increasing the height of the stack in order to alter the air pollution dispersion pattern that affected the residential areas.

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