ARTIFICIAL NEURAL NETWORKS PREDICTION OF PM_{10} CASE STUDY : BANGKOK AREA

WANLOP VISITHAMAKUN

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Thesis
Entitled

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ARTIFICIAL NEURAL NETWORKS PREDICTION OF PM_{10} CASE STUDY : BANGKOK AREA

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ABSTRACT

The objective of this study was to develop a model for predicting the PM_{10} concentration 1-day in advance by using an Artificial Neural Network (ANN). The data used in this study were collected from five air quality monitoring stations of the Pollution Control Department and from Department of Meteorology. These data were splitted into two parts, i.e. training and testing sets. A multiple stepwise regression analysis was used to investigate the relationship between the $PM_{10}(t+1)$ and other input parameters such as $PM_{10}(t)$,pollutant concentrations, metrological data, etc. in each air quality monitoring station. Then, those input parameters that had a statistically significant relationship with $PM_{10}(t+1)$ at each air quality monitoring station used as input variables in developing the model for each station.

The Multilayer Feedforward Neural Networks (MLFF) with Backpropagation (BP) learning process of Artificial Neural Networks was selected for this study. In addition, three activation functions, i.e. Sigmoid, Hyperbolic Tangent, and Linear Function were also employed. In the model testing process, the Mean Absolute Percentage Error (MAPE), Standard Deviation (SD) and the Pearson correlation (r) were used as the indicator of the model performance.

As a result, the ranges of MAPE, SD, and r obtained from those five air quality monitoring stations were 13.48-20.80, 13.48-21.53,and 0.773-0.900, respectively. The highest Pearson correlation (r) obtained from the Chok-Chai police station in this study was a little less than 0.94 obtained from the study of Cecchettic and others in the Milan area, Italy. However, the Pearson correlation (r) obtained from the other four stations were all less than that obtained from Milan. Therefore, it appeared that the model performance in this study was not as good as that obtained from the Milan area.

KEY WORDS : PM_{10} / ARTIFICIAL NEURAL NETWORK / MULTILAYER FEEDFORWARD / BACKPROPAGATION

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การพยากรณ์ฝุ่นละอองขนาดเล็กกว่า 10 ไมครอน โดยใช้โครงข่ายใยประสาทเทียม พื้นที่ศึกษา : บริเวณกรุงเทพมหานคร (ARTIFICIAL NEURAL NETWORKS PREDICTION OF PM_{10} CASE STUDY : BANGKOK AREA)

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บทคัดย่อ

การศึกษาครั้งนี้มีวัตถุประสงค์เพื่อพัฒนาแบบจำลองสำหรับพยากรณ์ปริมาณฝุ่นละอองขนาดเล็กกว่า 10 ไมครอนล่วงหน้า 1 วัน โดยการประยุกต์ใช้แบบจำลองโครงข่ายใยประสาทเทียม ซึ่งการศึกษาครั้งนี้จะใช้ข้อมูลจากสถานีตรวจวัดคุณภาพอากาศ 5 สถานีของกรมควบคุมมลพิษและข้อมูลอุตุนิยมวิทยาจากกรมอุตุนิยมวิทยา โดยหลังจากที่ได้ทำการเก็บรวบรวมข้อมูลจะทำการแบ่งข้อมูลออกเป็น 2 ส่วนสำหรับกระบวนการเรียนรู้และกระบวนการทดสอบแบบจำลอง โดยใช้ Multiple Stepwise Regression Analysis ในการวิเคราะห์ปัจจัยนำเข้า เช่น ความเข้มข้นของสารมลพิษ ข้อมูลอุตุนิยมวิทยา เป็นต้น ที่มีความสัมพันธ์กับ $PM_{10}(t+1)$ และจะใช้ปัจจัยต่างๆ เหล่านี้สำหรับเป็นตัวแปรนำเข้าของแบบจำลองในแต่ละสถานี

ในการศึกษาครั้งนี้ใช้โครงข่าย Multilayer Feedforward Neural Networks (MLFF) ร่วมกับกระบวนการเรียนรู้แบบแพร่กลับ (BP) สำหรับการพัฒนาแบบจำลองรวมทั้งทำการทดลองใช้ Activation Function 3 functions ได้แก่ Sigmoid, Hyperbolic Tangent, and Linear Function ในกระบวนการทดสอบแบบจำลองโดยใช้ Mean Absolute Percentage Error (MAPE), Standard Deviation (SD) และ the Pearson correlation (r) สำหรับเป็นดัชนีชี้วัดประสิทธิภาพของแบบจำลองที่ได้พัฒนาขึ้นมา

ผลการศึกษาพบว่าค่าของ MAPE, SD และ r ที่ได้จากสถานีตรวจวัดคุณภาพอากาศ 5 สถานี อยู่ในช่วง 13.48-20.80, 13.48-21.53 และ 0.773-0.900 ตามลำดับ โดยสถานีตรวจวัดคุณภาพอากาศสถานีตำรวจโชคชัยพบค่าสูงสุดของ Pearson correlation (r) ซึ่งมีค่าน้อยกว่าผลการศึกษาของ Cecchettic (Pearson correlation (r) = 0.94) ที่เมืองมิลาน ประเทศอิตาลี เพียงเล็กน้อย อย่างไรก็ตามที่จุดศึกษาอีก 4 สถานีพบค่า Pearson correlation (r) น้อยกว่าผลการศึกษาของ Cecchettic ทั้งหมด ทำให้สรุปได้ว่าประสิทธิภาพของแบบจำลองในการศึกษาครั้งนี้ให้ผลไม่ดีเท่ากับผลการศึกษาของ Cecchettic เมืองมิลาน

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CONTENTS

	Page
ACKNOWLEDGEMENTS	**iii**
ABSTRACT (ENGLISH)	**iv**
ABSTRACT (THAI)	**v**
LIST OF TABLES	**viii**
LIST OF FIGURES	**xii**
CHAPTER I INTRODUCTION	**1**
1.1 State of the problems and the importance of the research	1
1.2 Objectives	3
1.3 Conceptual Framework	3
1.4 Scope of the research	4
1.5 Research Expectations	7
CHAPTER II LITERATURE REVIEWS	**8**
2.1 Study Area	8
2.2 Air pollution	9
2.3 Particular Matter - 10	12
2.4 Artificial Neural Networks	17
2.5 The Statistic Analysis	25
2.6 Related Researches	26
CHAPTER III MATERIALS AND METHODS	**29**
3.1 Materials	29
3.2 Research Methodology	29

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CONTENTS (Cont.)

Page

CHAPTER IV RESULTS AND DISCUSSIONS **35**

4.1 Selection of the study sites 35

4.2 Data Collection 37

4.3 The analysis of relationship between parameters and PM_{10} 42

4.4 The data preparation and model design 57

4.5 The model development and testing 59

CHAPTER V CONCLUSION AND RECOMMENDATION **68**

5.1 Conclusion 68

5.2 Recommendations for further study 69

REFERENCES **70**

APPENDIX **72**

A Relationship between real and predicted values 73

B The weight and bias values of model 76

BIOGRAPHY **86**

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LIST OF TABLES

		Page
Table 2-1	The estimation of expenditure for diseases caused by the PM_{10} in 2000	14
Table 2-2	Relation between neural and artificial neural source	18
Table 2-3	BP activation function	24
Table 3-1	Data and source of data	32
Table 4-1	Comparing number and percentage of days that PM_{10} exceeding the ambient air standard in each air quality monitoring station	36
Table 4-2	The statistical values of the PM_{10} concentration for weekdays and weekends at Chok-Chai Police Station's Air Quality Monitoring Station.	43
Table 4-3	The statistical results of the hypothesis test at Chok-Chai Police Station's Air Quality Monitoring Station.	43
Table 4-4	The statistical values of the PM_{10} concentration for weekdays and weekends at Din-Daeng Housing Community's Air Quality Monitoring Station.	44
Table 4-5	The statistical results of the hypothesis test at Din-Daeng Housing Community's Air Quality Monitoring Station.	44
Table 4-6	The statistical values of the PM_{10} concentration for weekdays and weekends at Klong-Jun Housing Community's Air Quality Monitoring Station.	45
Table 4-7	The statistical results of the hypothesis test at Klong-Jun Housing Community's Air Quality Monitoring Station.	45

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LIST OF TABLES (Cont.)

Page

Table 4-8 The statistical values of the PM_{10} concentration for weekdays and weekends at Nonsi Withaya School's Air Quality Monitoring Station. 46

Table 4-9 The statistical results of the hypothesis test at Nonsi Withaya School's Air Quality Monitoring Station. 46

Table 4-10 The statistical values of the PM_{10} concentration for weekdays and weekends at Singharach Vitayacom School's Air Quality Monitoring Station. 47

Table 4-11 The statistical results of the hypothesis test at Singharach Vitayacom School's Air Quality Monitoring Station. 47

Table 4-12 The statistical values of the parameters significantly related to PM_{10}(t+l) at Chok-Chai Police Station's Air Quality Monitoring Station. 49

Table 4-13 The statistical values of the parameters significantly related to PM_{10}(t+l) at Din-Daeng Housing Community's Air Quality Monitoring Station 50

Table 4-14 The statistical values of the parameters significantly related to PM_{10}(t+l) at Klong-Jun Housing Community's Air Quality Monitoring Station. 51

Table 4-15 The statistical values of the parameters significantly related to PM_{10}(t+l) at Klong-Jun Housing Community's Air Quality Monitoring Station after removal of the SO_2 parameter. 52

Table 4-16 The statistical values of the parameters significantly related to PM_{10}(t+l) at Nonsi Withaya School's Air Quality Monitoring Station 52

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LIST OF TABLES (Cont.)

Page

Table 4-17 The statistical values of the parameters significantly related to PM_{10}(t+l) at Nonsi Withaya School's Air Quality Monitoring Station. 53

Table 4-18 Summary of the parameters significantly related to PM_{10}(t+1) in each Air Quality Monitoring Station 56

Table 4-19 Data preparation 57

Table 4-20 ANN Design 58

Table 4-21 The results of the model development and testing at ANN 1 59

Table 4-22 The results of the model development and testing at ANN 2 60

Table 4-23 The results of the model development and testing at ANN 3 61

Table 4-24 The results of the model development and testing at ANN 4 62

Table 4-25 The results of the model development and testing at ANN 5 63

Table B – 1 Weight values in hidden layer of ANN1 76

Table B – 2 Weight values in output layer of ANN1 76

Table B – 3 Bias values in hidden layer and output layer of ANN1 77

Table B – 4 Weight values in hidden layer of ANN2 77

Table B – 5 Weight values in output layer of ANN2 79

Table B – 6 Bias values in hidden layer and output layer of ANN2 80

Table B – 7 Weight values in hidden layer of ANN3 82

Table B – 8 Weight values in output layer of ANN3 83

Table B – 9 Bias values in hidden layer and output layer of ANN3 83

Table B – 10 Weight values in hidden layer of ANN4 84

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LIST OF TABLES (Cont.)

Page

Table B – 11Weight values in output layer of ANN4 84

Table B – 12 Bias values in hidden layer and output layer of ANN4 84

Table B – 13 Weight values in hidden layer of ANN5 85

Table B – 14 Weight values in output layer of ANN5 85

Table B – 15 Bias values in hidden layer and output layer of ANN5 85

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LIST OF FIGURES

		Page
Figure 1-1	Conceptual framework diagram	4
Figure 1-2	The study areas at five air quality monitoring stations, Pollution Control Department	5
Figure 2-1	Air pollution system	10
Figure 2-2	The origin of air pollution	11
Figure 2-3	The relationship between the PM_{10} and the respiration disease's patient	14
Figure 2-4	The AIRVIRO SYSTEM in Thailand	17
Figure 2-5	The principle of the basic ANN and activation function	18
Figure 2-6	The pattern of the learning process	19
Figure 2-7	The architecture of ANN	20
Figure 2-8	Multilayer Feedforward Network with Backpropagation learning	21
Figure 3-1	Research methodology	30
Figure 4-1	Land use of surrounding buildings at Chok-Chai Police Station	38
Figure 4-2	Land use of surrounding buildings at Din-Daeng Housing Community Station	39
Figure 4-3	Land use of surrounding buildings at Klong-Jun Housing Community Station	40
Figure 4-4	Land use of surrounding buildings at Nonsi Withaya School Station	41
Figure 4-5	Land use of surrounding buildings at Singharach Vitayacom School Station	42

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LIST OF FIGURES (Cont.)

Page

Figure A-1 The Relationship between real and predicted values of ANN1 73

Figure A-2 The Relationship between real and predicted values of ANN2 74

Figure A-3 The Relationship between real and predicted values of ANN3 74

Figure A-4 The Relationship between real and predicted values of ANN4 75

Figure A-5 The Relationship between real and predicted values of ANN5 75

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CHAPTER I
INTRODUCTION

1.1 State of the problems and the importance of the research

Air pollution is a major problem in all metropolitan areas and communities. It harmfully affects people's sanitation and health, especially causing skin problems and respiration diseases. Moreover, air pollution has an adverse effect on people's immunity, which later on results in eye, nose, and skin irritations, as well as a symptom towards allergy. Furthermore, air pollution also accelerates environmental degradation, such as, a reduction of the ozone layer in the stratosphere, a stimulator of global warming problem, etc.

Particular matter-10 (PM_{10}), in particular, is a very small particle (particle size $< 10\,\mu m$) that can easily enter into human's respiration system and has a toxic effect on human's health. In fact, traffic congestion and skyscraper construction are principal sources of these small dust particles. As a consequence, dealing with the problem arisen from these PM_{10}, management strategies regarding solution to the problem and prevention of the problem to happen in the future must be seriously consideration. On one hand, to solve the problem of these PM_{10} is to find out the way to reduce their amount in the air in the future. However, at this moment, there is no way to eliminate these PM_{10} from the air. Therefore, on the other hand, prevention strategy will be our first priority to be considered. In addition, developing dust forecasting system that provides detailed information and data for those areas where dust problem is serious and provides the communities ways to get rid off this dust problem, and introducing and encouraging people to wear dust-prevention equipment, are examples of dust prevention strategies.

Thailand's capital city or Bangkok is renowned as one of the biggest city in the world where there is very high density in population. As it is a big city, Bangkok has been pushed towards industrial development and indirectly resulted in a substantial expansion in population in Bangkok. In response to a higher demand of living in

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Bangkok, these, in turn, brought about an emergence of several projects that facilitate convenient lifestyle and increase living standard of Bangkok people, including malls building, road and mass transport construction, and so forth, all of which are major source of air pollution. All of these land developments directly contribute to the generation of air pollution. In fact, it can be apparently seen that air pollution is currently a serious problem as its effects has been substantial. According to the data provided by Pollution Control Department, Bangkok Thailand, in 2004, it can be found that the PM_{10} concentration in Bangkok has significantly increased comparing to the result found in 2003. In 2004, The highest figure was 215.9 $\mu g / m^3$ and the 24-hour average figure was 21.5-215.9 $\mu g / m^3$ at RamaVI Road. The second highest figure of 203.8 $\mu g / m^3$ at Santiparb Road. On the other hand, air pollution problem in the following areas, including Paholyotin, RamaIV, Din-Daeng, Ladprao, and Intarapitak has come out to be diminished (1). In fact, major sources of air pollution problem in Bangkok are from automobile in the form of carbon monoxide and smoke, from all matters that dropped or diffused or blew in the streets in the form of dust during transportation, i.e. soil and construction materials , and from all other activities that generate air pollution such as building construction and constructing public utility.

Artificial Neural Network (ANN) was replicated from the Black Box Model. The model simulation has given rise to the reduction in designing complexity of ANN. By applying the model, it allows users to recognize the relationship between input data and target data through the acknowledgement of the previous data and to apply to the new model. ANN was initiated to work similarly to human's brain. Nowadays, ANN is well renowned for effective solving non-linear problems.

As a consequence, the development of ANN by using Multilayer Feed-forward Neural Network (MLFF Network) and Back-propagation (BP) Learning with studying together with factors affecting PM_{10} , would ease future management of PM_{10}. This is because it allows the users to be able to forecast the PM_{10} concentration in the ambient air. Moreover, the model also effectively provides data that supports air pollution warning system as well as indirectly suggests ways to reduce the risk of being unhealthy and having respiration disease.

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1.2 Objectives

1.2.1 To analyze parameters related to $PM_{10}(t+1)$ in each Air Quality Monitoring Station, Pollution Control Department, Bangkok, Thailand.

1.2.2 To develop a model for predicting the PM_{10} concentration 1-day in advance in each Air Quality Monitoring Station, Pollution Control Department, Bangkok, Thailand.

1.3 Conceptual Framework

This research focuses on the development of mathematical model for predicting the 24-hour average of PM_{10} concentration 1-day in advance at five Air Quality Monitoring Stations, including Nonsi Withaya School, Singharach Vitayacom School, Chok-Chai Police Station, Din-Daeng Housing Community, and Klong-Jun Housing Community. The study is based on meteorological data, data of PM_{10} concentration (24-hour average), data related to climate seasons, data concerned pollution matters, and data related to characteristics of each day of the week. A Multiple Stepwise Regression method was used in the analysis of studying the relationship between relating parameters and PM_{10} concentration. The 0.05 significant level was set in order to correspond with designing and developing the mathematical model. This mathematical model was constructed in compliance with the idea from ANN by means of MLFF Network with BP Learning. In adjusting for appropriate weight value, Levenberg-Marquardt back propagation algorithm (LMBP) method was utilized. Furthermore, three activation functions, including, Linear Function, Sigmoid Function and Hyperbolic Tangent function, were tested against the trial adjustment number of the hidden layer, as shown in Figure 1-1.

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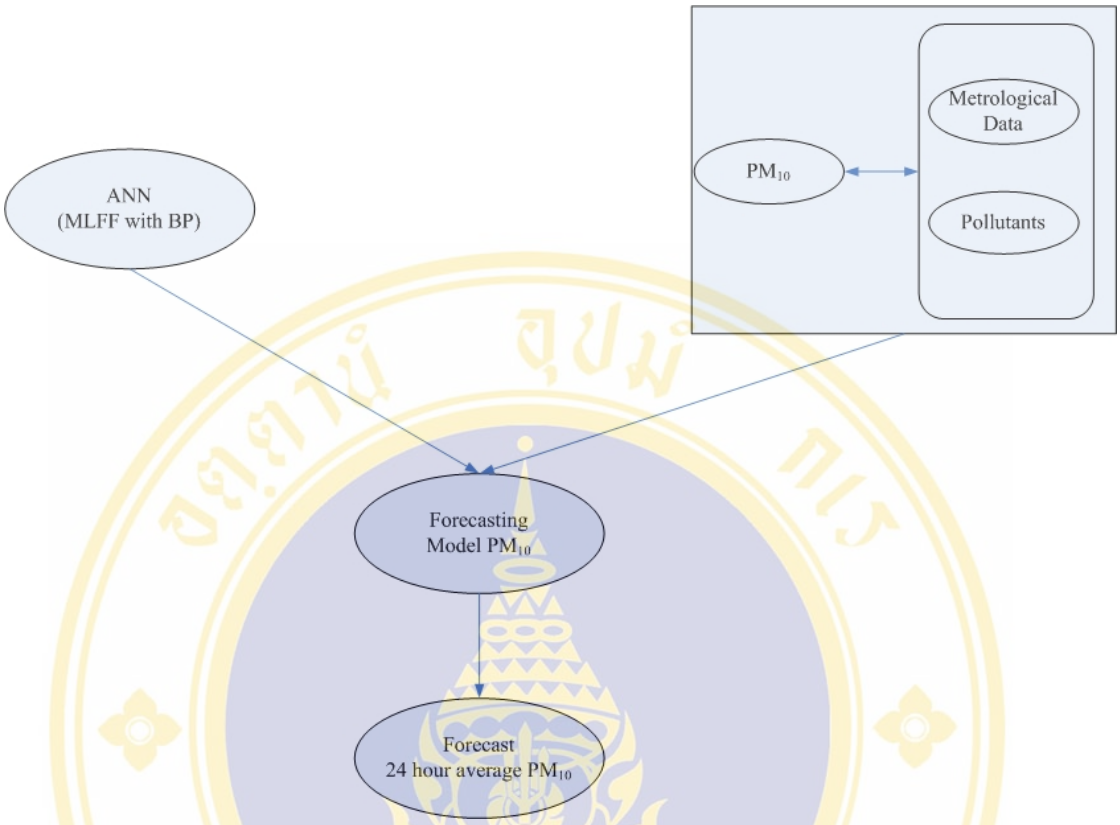

Figure 1-1 Conceptual framework diagram

1.4 Scope of the research

The model for predicting the PM_{10} concentration 1-day in advance in Bangkok area is constructed by using MLFF network with BP Learning.

1.4.1 Study Area

The scope of the research locations is the study areas in Bangkok located at the five Air Quality Monitoring Stations, Pollution Control Department, as follows. Please refer to Figure 1-2.

- Nonsi Withaya School
- Singharach Vitayacom School
- Chok-Chai Police Station
- Din-Daeng Housing Community
- Klong-Jun Housing Community

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Figure 1-2 The study areas at five air quality monitoring stations, Pollution Control Department

1.4.2 Scope of the data

Data used in developing and testing the model was gathered during January 1st, 2000 and April 30th, 2005. The followings are necessary determinants used in developing the model.

- Meteorological data entails: -
  - Temperature at 2 m.
  - Wind Speed at 10 m.
  - Wind Direction at 10 m.
  - Relative Humidity at 10 m.
  - Solar Radiation
  - Pressure.
  - Days, which can be classified into two groups - weekdays and weekends:
    - Weekdays - Monday to Friday
    - Weekends - Saturday, Sunday, and other public holidays

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- Seasons, which can be categorized into three seasons:
  - Rainy Season - between May 16th – October 15th
  - Winter - between October 16th- February 14th
  - Summer - between February 15th - May 15th
- Net Solar Radiation.
- Rain.
- Minimum Mixing Height.
- Maximum Mixing Height.

- Data necessary in measuring air pollution is a data that is actually used by all Air Quality Monitoring Stations, Pollution Control Department, Bangkok, Thailand, which includes: -
  - PM_{10} concentration.
  - Carbon monoxide (CO).
  - Nitric Oxide (NO).
  - Oxides of Nitrogen (NO_x).
  - Nitrogen Dioxide (NO_2).
  - Sulfur Dioxide ($S0_2$).
  - Ozone (0_3).
  - Total Hydrocarbons (THC).
  - Methane (CH_4).
  - Non Methane Hydrocarbons (NMHC).

To examine the relationship between several relevant factors and PM_{10}, in each studying unit, each relevant parameter is considered unequally depending on results found by each Air Quality Monitoring Station and both Minimum Mixing Height and Maximum Mixing Height data. That is, the data from the Department of Meteorology and the data found in the study areas are employed.

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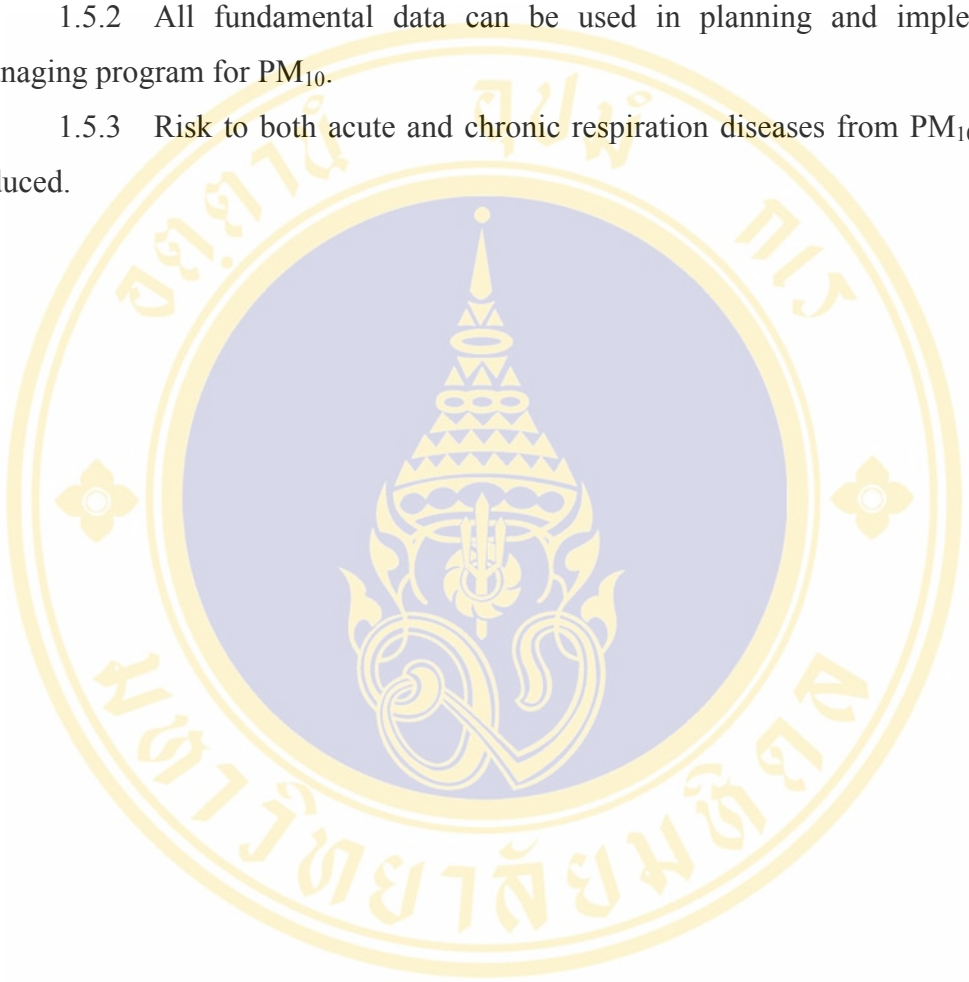
1.5 Research Expectations

1.5.1 The data can be used to refrain from or prevent dangerous impacts from PM_{10}.

1.5.2 All fundamental data can be used in planning and implementing managing program for PM_{10}.

1.5.3 Risk to both acute and chronic respiration diseases from PM_{10} can be reduced.



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CHAPTER II
LITERATURE REVIEWS

2.1 Study Area

2.1.1 Locations and Geological Characteristics

Bangkok city is located at the latitude 13-degree and 45-minute north and the longitude 100-degree and 28-minute east. It is geographically categorized as a bottom land and situated only 2.31 meters above the average sea level, however, areas around Chao Praya River is situated at a level less than 1.5 meters above the average sea level (2).

2.1.2 Climate and Temperature

Bangkok is situated in a hot zone and is naturally affected by both northeast and southwest monsoons and generally has high humidity throughout the year at average of 60-80%. It has three seasons as follows: -

Rainy Season - between May 16th and October 15th

Winter - between October 16th and February 14th

Summer - between February 15th and May 15th

Average temperature is between 33 – 38 ^{0}C, with 25-32 ^{0}C in the rainy season, 20-25 ^{0}C in winter, and 40-42 ^{0}C in summer, consecutively (2).

2.1.3 Population

According to the census of December 2004, there are totally 5,634,132 people in Bangkok, which composes of 2,698,051 males and 2,936,081 females (2).

2.1.4 Boundary of Bangkok

Since 2001, Bangkok has been divided into 3 parts consisting of 50 districts accordingly, as follows (2).

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Inner Bangkok composes of 21 districts, i.e. Pra-Nakorn, Pomprab Satrupai, Sampantawong, Pathumwan, Bangrak, Yannawa, Sathorn, Bang Korlam, Dusit, Bang Suu, Payatai, Ratch Tevee, Huay Kwang, Klong Toey, Chatuchak, Thonhuri, Klong San, Bangkok Noi, Bangkok Yai, Din-Deang, and Wattana.

Middle Bangkok consists of 18 districts, i.e. Pra Kanong, Prawate, Bang Kane, Bangkapi, Lad Prao, Buing Kluim, Bangplad, Pasicharoen, Jomtong, Ratch Burana. Suan Luang, Bangna, Tuing Kru, Bang Kae, Wang Tonglang, Kannayao, Sapan Soong, and Sai Mai.

Outer Bangkok comprises of 11 districts, i.e. Min Buri, Don Muang, Nongjok, Ladkrabang, Talingchan, Nongkam, Bang Koon Tean, Laksi, Klong Samwa, Bang Bon, and Taweewattana.

2.2 Air Pollution

2.2.1 The definition of air pollution

Scientists defined the word of "Air pollution" in various meanings such as :

Yupin defined that air pollution is the air that contaminated with particles or gasses by natural interaction or human activities. And the concentrations of these contaminants are high enough to annoy or harm living things and environment by direct and indirect way, which these contaminants are called "Pollutant". In other word, "Air pollution" means air which is contaminated with pollutants in the level that exceed the standards and can harm life and environment (3).

Howard E. Hesketh defined that air pollution is the finding of gas or particles or the mixing of gas and particles in the air that harm the environment and the human’s health. This definition includes the adverse effect on plants or animals and other natural resources (4).

Environmental Impact Assessment Division defined that air pollution is the substance in the air which can harm living thing, material, human health or cause an annoyance (5).

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Wongpan defined that air pollutant is any substances in the air has an adverse effect on human health or other living things and to conceive a dislike or undesirable of internal or external human body, or the substance that causes an adverse effect on human life by direct or indirect way (6).

These indicate that "Air Pollution" has various meanings. It can be concluded that "Air Pollution" is the air that contaminated with pollutants which has the concentration and exposed time enough to harm human, animal, plant, climate, materials and ecological system by direct or indirect way.

2.2.2 Air Pollution System

Air Pollution System consists of three parts which related with each other. This includes source of pollutants, air or atmosphere and target or receptor (7), as shown in Figure 2-1.

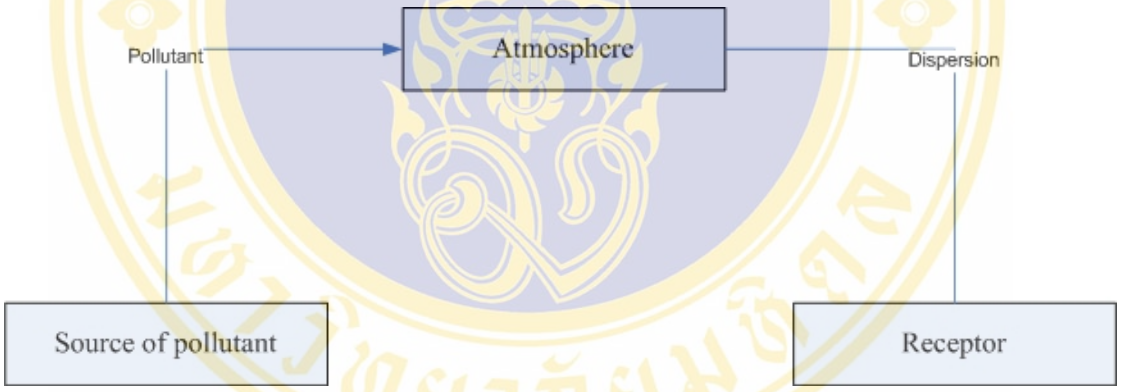

Figure 2-1 Air pollution system

From Figure 2-1, source of pollutants is the part that originates air pollution which the type of pollutants depend on any kinds of source. Pollutants will drift and distribute to the atmosphere which the form of pollutants distribution depends on meteorological conditions. Pollutants will distribute to target such as human, plant and animal or nonliving things including building, etc. The damage depends on the type of pollutants, concentration and contact time.

From the Air Pollution System figure, it shows that any area, amount and type of pollutants from an origin source, meteorological conditions and geography are the factors that define type and concentration of pollutants which contaminate the

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air at faraway. And air quality is the indicator of characteristic and severity of an adverse effect (7) that showed the relation in Figure 2-2.

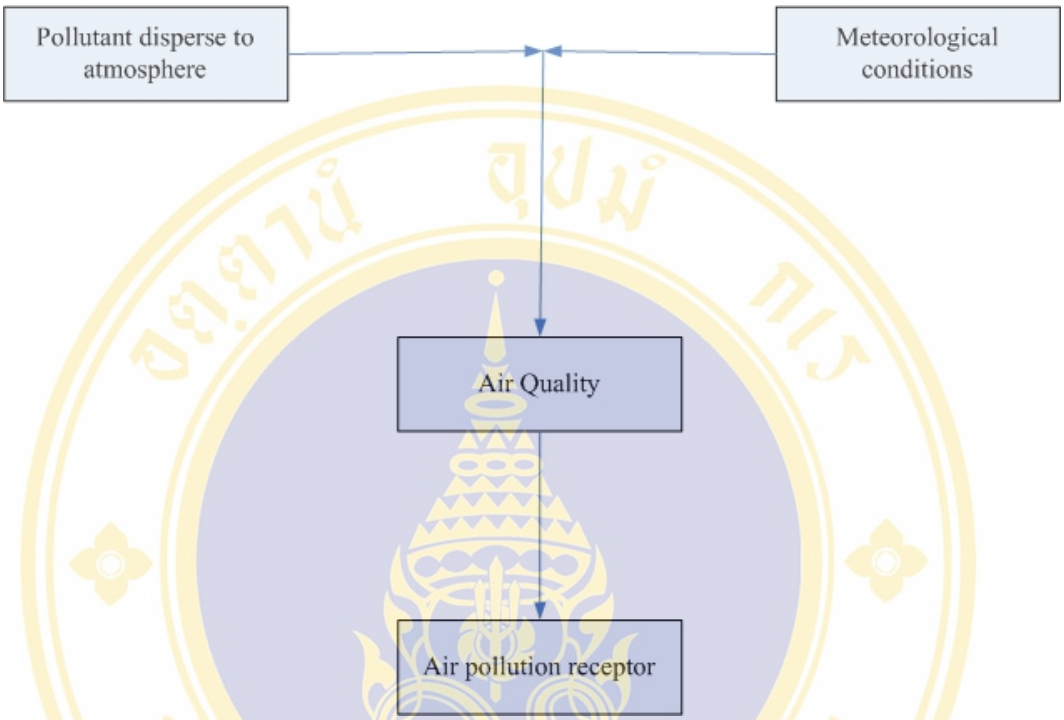

Figure 2-2 The origin of air pollution

2.2.3 Type of Origin Source

Pollutants, no matter what dust, vapor, gas or particle of heavy metal that distributes to atmosphere, come from an important source that is natural source and human's activities as follows (3):

2.2.3.1 **Natural sources**

Almost all of pollutants from natural source always change slowly. They are not harsh or not high in concentration or suddenly occurs like the pollutants from human activities, except natural risk such as exploding of volcano and wildfire, etc.

2.2.3.2 **Anthropogenic sources**

This is the source that human or human's activities is the cause of pollutant origin, and pollutants are ventilated into the air. This source can be divided in to two types;

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- Mobile sources such as automobile, motorboat, airplane, train, etc.
- Stationary sources such as power plant, oil refinery, cement factory, etc.

2.2.4 Type of Pollutants

Air pollutants can be divide into two types in according with origin characteristic (7) that is;

2.2.4.1 **Primary air pollutants**

This is the air pollutant that directly originates and ventilates from source, for example sulfur dioxide, carbon monoxide, nitrogen oxides, ashes and smoke from combustion engine of vehicles and furnace of industry, etc.

2.2.4.2 **Secondary air pollutants**

This is the air pollutant that does not originate and ventilate from source but originate in the atmosphere from chemical reactions between primary air pollutants or chemical reactions between primary air pollutants and other chemical compounds in the atmosphere. For example, ozone occurs from photochemical reactions between nitrogen oxides and hydrocarbons in the atmosphere, which sunlight is a catalyst.

2.3 Particular Matter - 10

2.3.1 The characteristics of the PM_{10}

Dust in the atmosphere is the particles which consist of solid and liquid that disperse in the air and its size is between 0.0002-500 micron. The size of dust that can drift in the air for a long time is not over 10 micron. Because of its low settling velocity, when there are action from external such as air flow, wind currents, etc. The dust can stay longer in the air (8).

From the study of the establishment of the air pollution control strategy for the dust in Bangkok, it was found that the PM_{10} and the $PM_{2.5}$ were the dust that can harm the human's health. Because it can penetrate into the lower part of the human's respiration system while the larger size dust can annoy by reducing the

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visibility and harm material (9). The PM_{10} concentration is highest in winter between November to February and at the Air Quality Monitoring Station in heavy traffic area.

2.3.2 The origin source of dust

The origin source of dust in the atmosphere can be divided into two types including (8):

2.3.2.1 Dust from natural sources, for example soil, sand, rock, steam, smoke from wildfire and salt dust from seawater.

2.3.2.2 Dust from human's activities including:

- Dust from transportation and traffic such as soil dust, sand that is diffused between car running, and smoke from diesel combustion engine, etc.
- Dust from construction such as building and road construction and demolishing, etc.
- Dust from industry such as cement industry, crushing rock, etc.

2.3.3 The impact of PM_{10}

PM_{10} can harm human's health because it can enter into the lower part of respiration system, lung tissue and bring the hazardous substance into human's body. A sensitive group that can easily receive an adverse effect from PM_{10} are children, old people, and those who have a congenital disease of respiration (8). From the study of Chulalongkorn University in 1995, it was found that the students, who live around the area with high dust concentration (PM_{10}>100 $\mu g/m^3$), are sick with respiration disease in higher rate compared to those who live in the lower dust concentration area (PM_{10}>50 $\mu g/m^3$). Moreover, it showed that the severity of disease symptom varied according to the level of dust (10).

Figure 2-3 illustrated that the PM_{10} concentration was highest in winter between November to February and the rate of respiration disease patient was also highest in this period as well.

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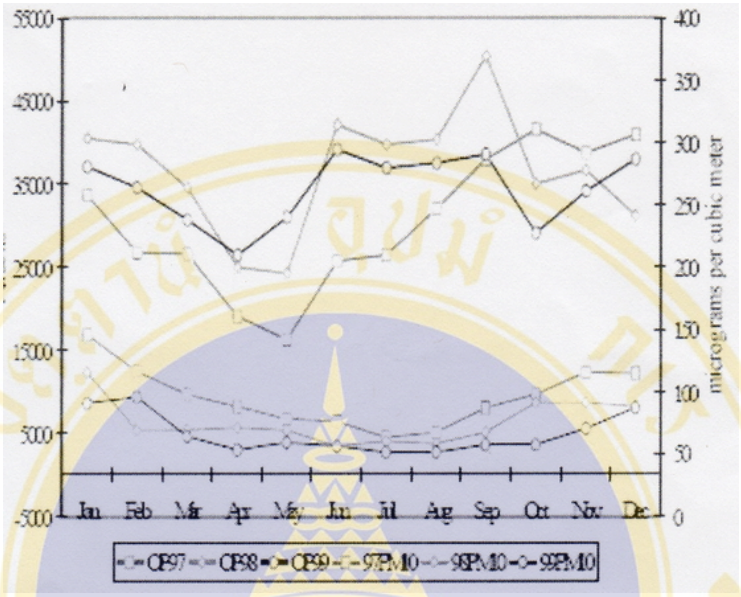

Figure 2-3 The relationship between the PM_{10} and the respiration disease's patient

Source : Department of Policy and Planning, 2002.

From the study of the cost estimation of disease caused by the PM_{10} in Thailand in 2002 of Pollution Control Department, it was found that besides human's health impact, PM_{10} causes economic loss such as the cost of doctor service, medicine, rooms in hospital, other services and revenue from stopping work (7), as shown in Table 2-1.

Table 2-1 The estimation of expenditure for diseases caused by the PM_{10} in 2000.

City	PM_{10} ($\mu g/m^3$)	Population (million)	Mortality Rate	Excess Deaths	Chronic Bronchitis	Cost in million (US$)
Bangkok	64	5.7	0.0065	1,092	4,550	424
Chiang Mai	57	1.6	0.00985	390	1,080	56.8
Nakhon Sawan	51	1.1	0.0058	134	630	26.1
Khon Kaen	66	1.8	0.006	324	1,476	59.2
Nakorn Ratchasima	51	2.6	0.0055	286	1,426	56.8
Songkhla	41	1.2	0.0061	104	464	1.3
Total		14		2,3330	9,626	644.2

Source: Pollution Control Department, 2002.

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2.3.4 The method of monitoring the PM_{10}

The standard method of the PM_{10} monitoring of the Pollution Control Department is a Gravimetric method by using High Volume Air Sampler. In addition, the Pollution Control Department approved another three methods: Beta Ray system tool, Tepper Element Osilating Microbalance system tool, and Micotomus system tool. Each method has a principle including (11):

- High Volume Air Sampler uses principle of air suction from the atmosphere by constant flow rate through inlet and outlet air channels with special design to pick the PM_{10} from the atmosphere. This dust is collected at filter paper all sampling time (24 hours). Both before and after sampling, filter is weighed, after baking to eradicate humid, to find the weight of the PM_{10} collected from sampling. All volumetric of air used in sampling must be adjusted to standard condition at 25 degree celsius and air pressure at 760 mm Hg.
- Beta ray system tool uses principle of Beta ray radiation that radiates to the filter. This system sucks air through the dust size selecting tool for the less than 10 micron selection, and detects the Beta ray absorption efficiency to change to the average of the dust concentration in the atmosphere.
- Tepper Element Osilating Microbalance system tool uses the principle of the air suction through the dust size selecting tool to collect the PM_{10} on filter while it is vibrating, and change value to the average of the dust concentration in the atmosphere.
- Micotomus system tool uses the principle of the air suction through the dust size selecting tool to pick the less than 10 micron dust. The dust will drop on Virtual Impactor which separates dust for two sizes, less than 2.5 micron and 2.5-10 micron. After that filter is weighed to find the total weight of all dust.

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2.3.5 The ambient air standards and AIRVIRO system of Thailand

The ambient air standards of Thailand includes:

- The 24-hour average of the Total Suspended Particulate (TSP) must not exceed 0.33 mg/ m^3 and the 1-year average (Geometric Mean) must not exceed 0.10 mg/ m^3 at 25 °C and 1 atmosphere pressure.

- The 24-hour average of the Particulate Matter < 10 μ (PM_{10}) must not exceed 0.12 mg/ m^3 and 1-year average (Geometric Mean) must not exceed 0.05 mg/ m^3 at 25 °C and 1 atmosphere pressure.

The present Air Quality Management System of Thailand is AIRVIRO SYSTEM that is the computer software which collects and process data such as air quality data, meteorology data,etc. The AIRVIRO SYSTEM used in the many process such as air quality evaluation, policy, etc. The AIRVIRO SYSTEM consists of 5 important parts (12) including;

- Indico Administration used to store air quality data from air quality monitoring station.
- Indico Presentation used to illustrate results in other graph forms.
- Indico Real Time used to automatically illustrate results in other graph forms that show the result of current condition.
- Emission Database used to manage the data of the dust emission form other origin sources.
- Dispersion Model used to assess air quality by using other models including Street Canyon , Gaussion Model and Grid Model.

The air quality monitoring stations send air quality data and meteorological data to the regional center then the regional center send its to central control center in AIRVIRO SYSTEM at the Pollution Control Department, as shown in Figure 2-4.

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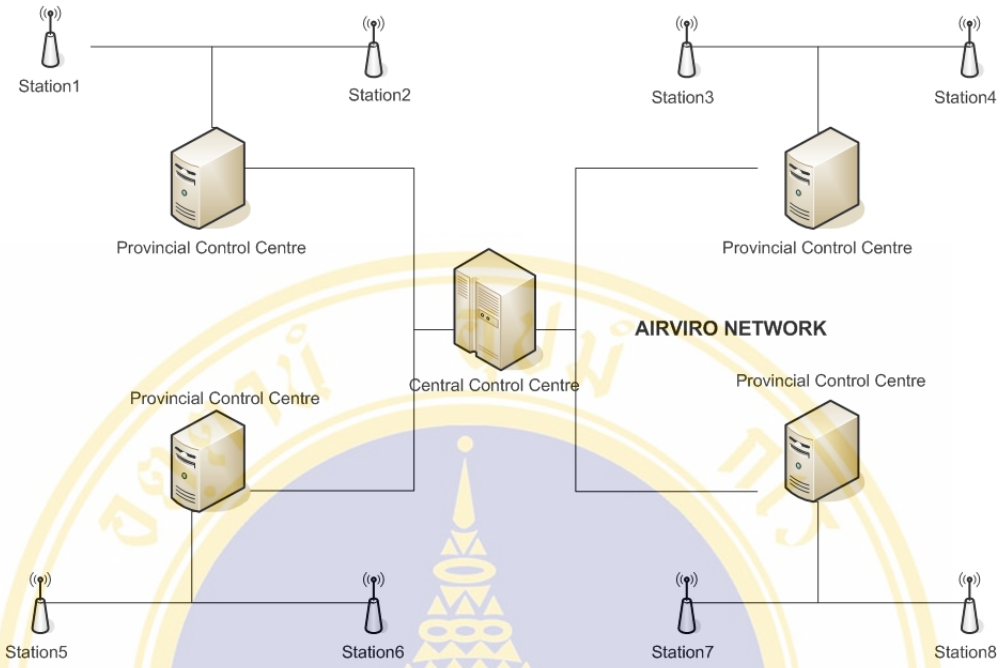

Figure 2-4 The AIRVIRO SYSTEM in Thailand

The air quality data monitoring consists of two parts, i.e.

- Pollutants information by monitoring the pollutants concentration, for example carbon monoxide, dust, nitrogen oxides, ozone, etc.
- Meteorology information by monitoring the conditions of meteorology, such as relative humidity, temperature, pressure, wind direction and wind speed, etc.

2.4 Artificial Neural Networks

2.4.1 The Basic Concept of ANN

ANN is the network designed to be the model that has the performance like the human's brain. In internal evaluation process, each neural has two characteristics, i.e. excitatory which is the method that increases the frequency of the signal; and inhibitory which is the method that reduces the frequency of the signal. ANN has the rate of the extension or shrinkage when the weights are defined for the relation between neural and artificial neural (13), as shown in Table 2-2.

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Table 2-2 Relation between neural and artificial neural source (13)

Index	Neural	Artificial neural
1	Cell	Unit
2	Dendrites	Input Variables
3	Axon	Output Variables
4	Synapse	Weight

For the principle of the basic performance that has many input variables, these input variables have different effects on the output variables depended on weight values, as presented in Figure 2-5.

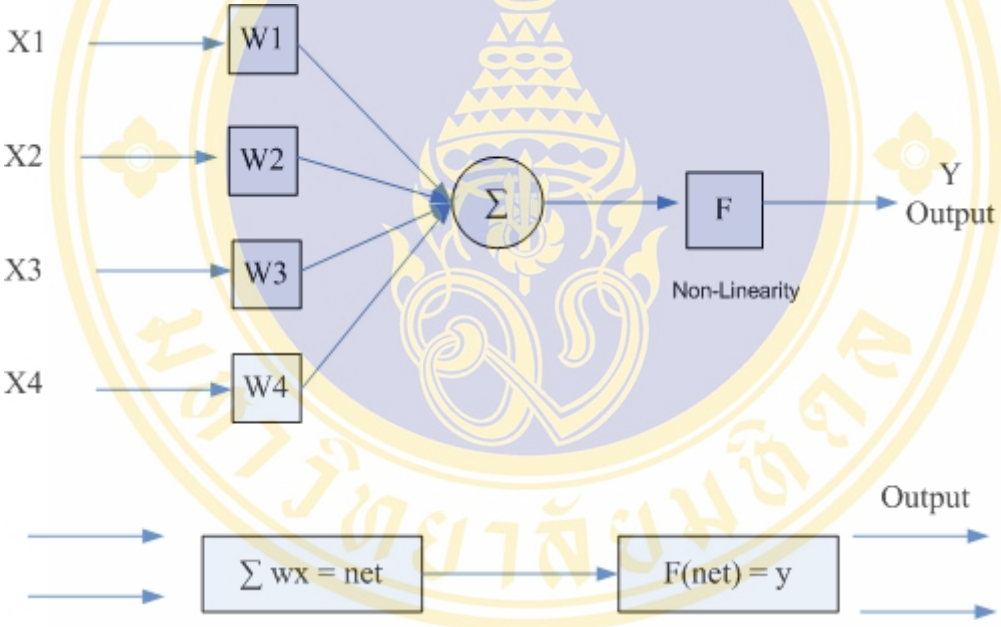

Figure 2-5 The principle of the basic ANN and activation function

Figure 2-5 illustrates the relation between input variables and output variables which has the Non Linear Regression, as the following equations 2.1 and 2.2.

$$Net = \sum WX \quad (2.1)$$

$$F(Net) = Y \quad (2.2)$$

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From the equation 2.2, the Activation Function changes the total signal value to output. Excitatory Function may have various patterns such as Linear Function, Sigmoid Function, Hyperbolic tangent Function, etc.

At the present, ANN is widely used in many types of research such as robot control, predicting, diagnosis and voice analysis for interpretation, etc.

2.4.2 The Pattern of the Learning Process

In theory of ANN, the learning process for weight adjusting helps to make the result closer to the target. The learning process consists of three characteristics including Supervised ,Reinforcement and Unsupervised (14), as shown in Figure 2-6.

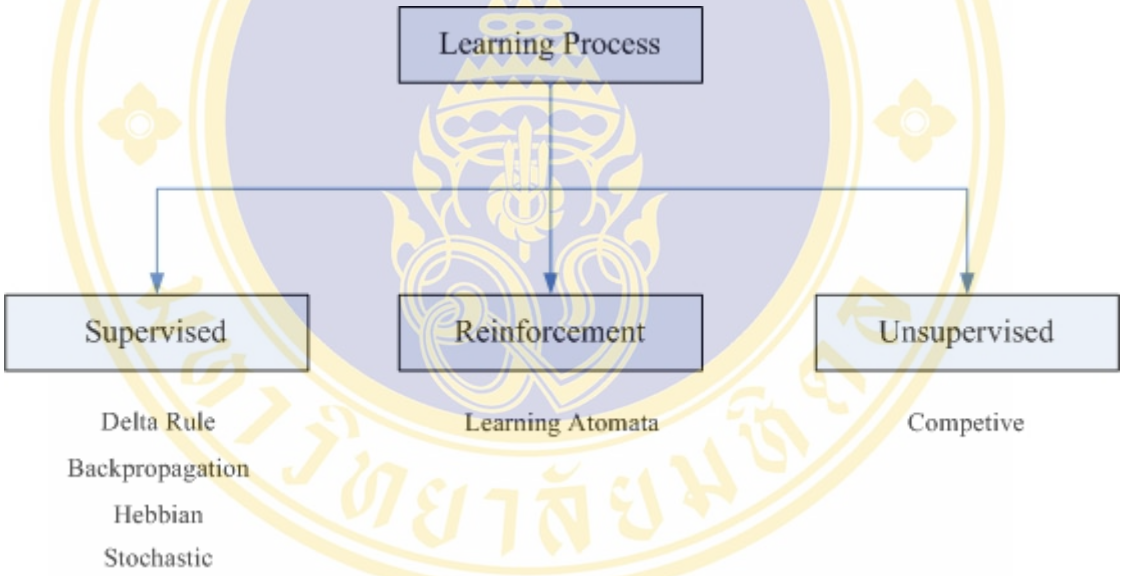

Figure 2-6 The pattern of the learning process

2.4.2.1 **Supervised**

Teacher is assumed to be present during the learning process and each example pattern used to train the network includes an input pattern together with a target or desired output pattern, the correct answer.

2.4.2.2 **Reinforcement**

Teacher is also assumed to be present, but the right answer is not present to the network. Instead, the network is only presented with an

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indication of whether the output answer it computes is right or wrong. The network must then use this information to improve its performance.

2.4.2.3 **Unsupervised**

The network has no feedback on the desired or correct output. There is no teacher to present target patterns. Therefore, the system must learn by discovering and adapting to structure features in the input patterns, that is, by adapting to statistical regularities or clustering of patterns from the input training samples.

2.4.3 The Architecture of ANN

Today, there are more than 22 patterns of applicable network that can divide the learning process, types of learning process, the application and types of the structure (13), as shown in Figure 2-7.

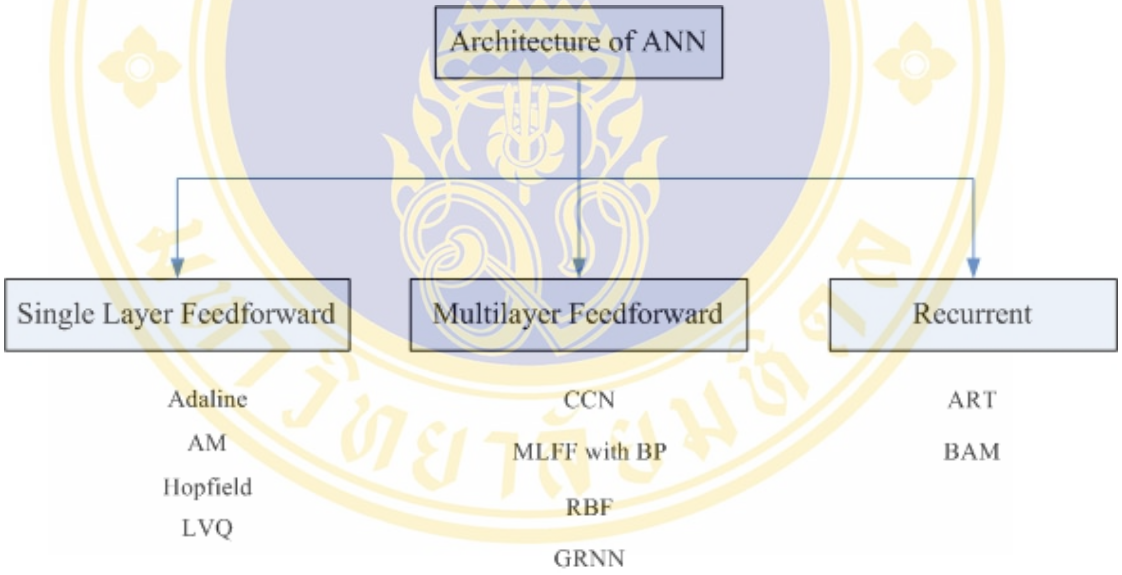

Figure 2-7 The architecture of ANN

From Figure 2-7, three types of ANN structure are presented.

- Single-layer feedforward network, networks with a single layer of computational neurons that process input signals in a feedforward direction.

- Multilayer feedforward network, networks with two or more layers of connections with weights that process the inputs in a forward direction.

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- Recurrent neural network, networks that have feedback connection which propagate the outputs of some neurons back to the inputs of other neurons to perform repeated computations on the signals.

2.4.4 Multilayer Feedforward Network With Backpropagation Learning

The general structure of MLFF network includes a unit in each layer that joined together in the forward characteristic. The MLFF network consists of three layers: input layer, hidden layer and output layer with BP learning process. This is the learning process in type of Supervised of which the Activation Function can find differential. An appropriate weight value finding uses Gradient Descent that will adjust weight value to reduce the calculation error in each round of learning. The pattern of input will send through forward the next layer respectively until the input results are occurred. Then the calculated results are compared with the real data or the target data to find the deviation. This deviation will be used as feedback input data. Meanwhile weight values are adjusted in the hidden layer and output layer, as demonstrated in Figure 2-8.

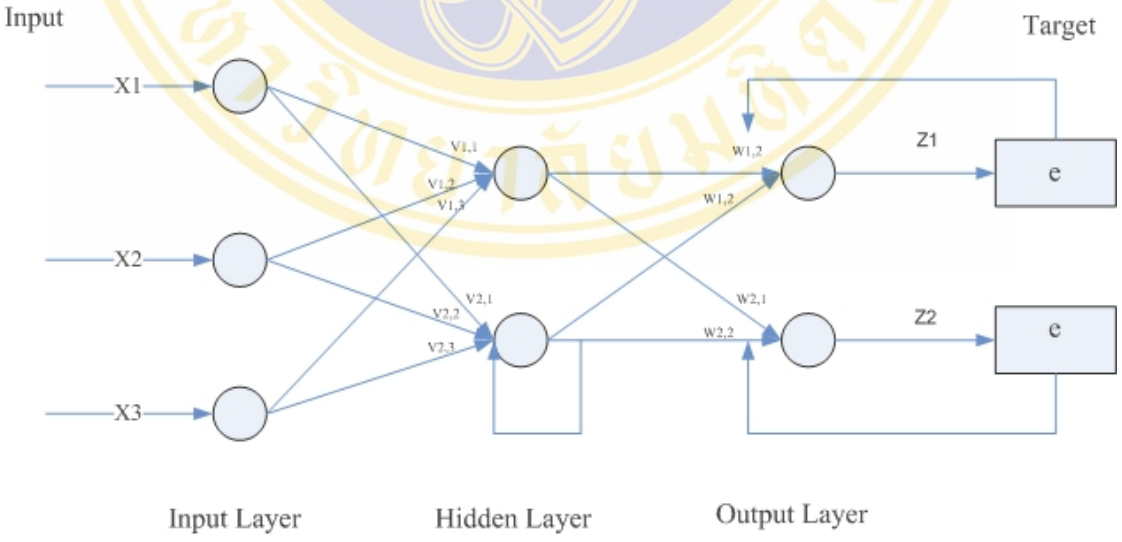

Figure 2-8 Multilayer Feedforward Network with Backpropagation learning

The steps of calculation patterns for the answer and weight adjusted process are as follows:

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Defined $H_j = \sum V_{ji} X_i$ (2.3)

$I_k = \sum W_{kj} Y_j$ (2.4)

Where X = Input data in each Node

Y = Net hidden to output layer

H = Net input to hidden layer

I = Net in output layer

V = weight in hidden layer

W = weight in output layer

The output from the calculation in hidden layer and output layer as the equations 2.5 and 2.6.

$Y_j = F(H_j)$ (2.5)

$Z_k = F(I_k)$ (2.6)

Where F = Function which can find differential

To adjust weight value in output layer, it can be calculated from the equation 2.7.

$W_{kj}^{New} = W_{kj}^{Old} + \eta y_j (t_k - z_k) f'(I_k)$ (2.7)

Where η = Constant

y = Net hidden to output layer

t = Target Data

z = Net output layer

$f'(I_k)$ = Differential order 1 of activation function of net Output

W^{Old} = Old weight in output layer at position (k,j)

W^{New} = New weight in output layer at position (k,j)

To adjust weight value in hidden layer, it can be calculated from the equation 2.8.

$V_{ji}^{New} = V_{ji}^{Old} + \eta x_i f'(H_j) \sum_k (t_k - z_k) f'(I_k) w_{kj}$ (2.8)

Where η = Constant

x = Input data in each node

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t = Target Data

z = Net output layer

$f'(I_k)$ = Differential order 1 of activation function of net Output

$f'(H_k)$ = Differential order 1 of activation function of net Hidden

V^{Old} = Old weight in output layer at position (j,i)

V^{New} = New weight in output layer at position (j,i)

W = Weight in output layer

At the beginning of the learning process, the starting weight value must be defined. If this is close to the real weight value, the answer will converge. In contrast, if the starting value selection is not good, it will affect the repeated calculation again and again till the answer occurs (14). The weight value definition that is too larger or too small, the network architecture will diverge away from the answer. That the weight value definition in range of [-1, 1] is the efficiency way to avoid this problem.

Saelee(13) explained the method and procedure of the calculation in the Backpropagation (BP) learning process by using Gradient Descent to find an appropriate weight value that may easily show the unstable of the result and sometime it diverges to real answer. Thus, if there is the Levenberg - Marquardt application improved from the method of Newton to find an appropriate weight value, it can increase the rapid of real answer converge, and can calculate the weight value adjusting process from the equation 2.9.

$$W_{k+1} = W_k + \Delta W_k \quad (2.9)$$

Therefore $\Delta W_k = -\left[J^T(w_k)J(w_k) + \mu_k I\right]^{-1} J^T(x_k)V(x_k)$ (2.10)

Where $J(w_k)$ = Jacobian Matrix of weights

μ_k = Minimum number which can adjust in each loop

I = Identity Matrix

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$V(x_{k:})$ = Calculate from error in each loop by

$$SSE = \sum_{i=1}^{N} V_i^2$$

Where $V_i = t_i \quad z_i$ (Error Value)

t = Target Data

z = Data in output layer

2.4.5 The Activation Function of The BP Learning Process

The Activation Function that is currently widely used has a lot of patterns, i.e. Linear and non-Linear such as Sigmoid Function and Hyperbolic Function, etc. The Activated Function used in MLFF with BP Learning is the Function that can calculate differential. The Sigmoid Function is the most popular function due to its value of 0-1. However, the Sigmoid Function may have the problem in the answer converge because there is a chance that lowest points occur (13). And the last answer converge will have the characteristic of the learning process that is slower than the Symmetric Function such as Hyperbolic Function. The different Activated Functions of the Backpropagation (BP) learning process are show in Table 2-3.

Table 2-3 BP activation function

Function Type	Function
Sigmoid	$f(x)=1/(1+\exp(-\beta x))$
Hyperbolic Tangent	$f(x)=(1-\exp(-\beta x))/1+\exp(-\beta x)$
Linear	f(x) = x

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2.5 The Statistic Analysis

The statistic analysis is the method used for data inspection, factors analysis and the ANN efficiency monitoring. In efficiency monitoring, the predicting data from the model is compared with the real monitoring data. The deviation analysis of predicting that is widely used includes four methods as follows:

2.5.1 Sum Square Error (SSE)

$$SSE = \sum_{i=1}^{N}(T_i - F_i)^2 \quad (2.11)$$

Where N = Number of data
T = Target Data
F = Forecast Data

2.5.2 Root Mean Square Error (RMSE)

$$RMSE = \sqrt{(\frac{1}{N}\sum_{i=1}^{N}(T_i - F_i)^2)} \quad (2.12)$$

Where N = Number of data
T = Target Data
F = Forecast Data

2.5.3 Mean Absolute Percentage Error (MAPE)

$$MAPE = \frac{1}{N}\sum_{i=1}^{N}\left|\frac{T_i - F_i}{T_i}\right| x100 \quad (2.13)$$

Where N = Number of data
T = Target Data
F = Forecast Data

2.5.4 Standard Deviation (SD)

$$SD = \sqrt{\frac{\sum_{i=1}^{N}(X_i - \overline{X})^2}{N}} \quad (2.14)$$

Where N = Number of data
X_i = Input Data
$\overline{X}$ = Mean of Data set

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2.5.5 Stepwise Regression

The simplest approach to explicitly incorporate the x variables into a model is to assume that a good approximation to the relationship between y and each x is a straight line. The slope of the straight line is denoted by β. If k explanatory variables are identified, β_1 is the partial slope between y and x_1 ; β_2 is the partial slope between y and x_2, and, in general, β_j is the partial slope between y and x_j, where j= 1,2,..., k. The product $\beta_j X_j$ is the contribution to the magnitude of y that is associated with x_j. If we also assume that the value of y is the sum of these $\beta_j X_j$ contributions plus the random component ε, then the regression model we assume is given by

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + ... + \beta_k x_k + \varepsilon \quad (2.15)$$

Where β_0 = The intercept of the line at the origin

β_k = The intercept of the line

X_k = Input data

y = Predicted Value

ε = Constant

2.6 Related Researches

Patricio Perez and Jorge Reyes have compared the predictions produced by three different methods: multilayer neural networks, linear regression and persistence, to predict hourly average concentrations of $PM_{2.5}$ in the downtown area of Santiago, Chile. Overall, the neural network gives the best results. Prediction errors vary from 30% for early hours to 60% for late hours. In order to improve predictions, the effect of noise reduction, rearrangement of the data and explicit consideration of meteorological variables are discussed (15).

Steve Dorling et al. have used MLFF with BP learning forecasting SO_2, PM_{10}, O_3, and NO_2 in Finland. Many parameters are used, such as Concentration data,

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Traffic flow data, Replacement of missing concentration values and Meteorological data. The results show that non-linear NN models perform better than the linear Models and The NN model performance is better for $N0_2$, compared with that for PM_{10} (16).

Chajoulakou A et al. examine the possibility of using neural network methods as tools for daily average particulate matter with PM_{10} concentration forecasting, providing an alternative to statistical models widely used up to this day. Based on data inventory, in a fixed central site in Athens, Greece, ranging over a two-year period, and using mainly meteorological variables as inputs, neural network models and multiple linear regression models were developed and evaluated. Comparison statistics used indicate that the neural network approach has an edge over regression models, expressed both in terms of prediction error (root mean square error values lower by 8.2-9.4%) and of episodic prediction ability (false alarm rate values lower by 7-13%). The results demonstrate that artificial neural networks (ANN), if properly trained and formed, can provide adequate solutions to particulate pollution prognostic demands (17).

M. Cecchettic et al. presents a series of results obtained applying different neural networks approaches to the PM_{10} prediction problem in Milan.The input variables set finally adopted comprises an autoregressive PM_{10} term, NO_x, SO_2 and a wind set of meteorological variables, such as temperature, humidity, wind velocity, solar radiation, atmosphere pressure and Pasquill stability class. The 1-day ahead prediction shows a satisfactory level of accuracy, which may be further improved if a proper deseasonalization approach is adopted, thus transferring some a priori knowledge in the data pre-processing step. Then, researchers tackle the problem of the 2-days ahead prediction; in order to optimize the neural network architecture identification procedure, researchers try a pruning approach besides the usual trial and error one. Prediction performances are very close between the two models, and denote a significant decrease of accuracy with respect to the 1-day case, even though some meteorological improper (i.e. future measures) input is added to the model structure. The results of this research founded correlation between real value and forecast value is 0.94 and EI (1-day ahead prediction) is more than 0.80 but EI(2-day ahead prediction) decrease remains 0.72. (18).

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Edward Lord has compared the predictions produced by three different methods: MLP, MLR and PERSISTENCE. The study sites have 9 stations Lower Fraser Valley This study has 17 factors from 65 factors such as Day of year , Day of week ,Vertical temperature, Horizontal pressure, Occurrence of precipitation , Length of dry spells , Maximum surface temperature anomaly , PM_{10} Tendency , PM_{10} ,O_3, etc. The results show that MLP models are better than persistence but not better than MLR using these predictors (19).

Katanchalee studied relationship between the meteorological parameters and the concentration of $PM_{2.5}$, PM_{coarse} and PM_{10}.The results showed that the meteorological parameters which may be applied over large area in Bangkok are relative humidity and solar radiation with a 1% level of significance, whilst the factors of pressure, wind speed, wind direction and temperature with a 1% level of significance could be obtained from the observation site. The relationship between meteorological parameters and particulate matter concentration showed that the relative humidity, solar radiation and wind direction are affected for PM_{10} and $PM_{2.5}$ at a 5% and a 1% level of significance, respectively, but the relative humidity and wind direction are affected for PM_{coarse} at a 5% level of significance (20).

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CHAPTER III
MATERIALS AND METHODS

3.1 Materials

The hardware and software utilized in this study are as the following:

Hardware:

1. Computer Server: DUAL CPU 3.0 GHz RAM 2 GB SCSI Hard Disk 74.6 GB Raid 1 VGA 8 MB and Accessories
2. Printer
3. Scanner

Software:

1. MATLAB Version 7.0
2. SPSS Version 11.5
3. Microsoft Windows Server 2003 Enterprise Edition
4. Microsoft Office 2003 Professional

3.2 Research Methodology

Research methodology used in developing the PM_{10} concentration prediction model for 24-hour average 1-day in advance in Bangkok area is as follows:

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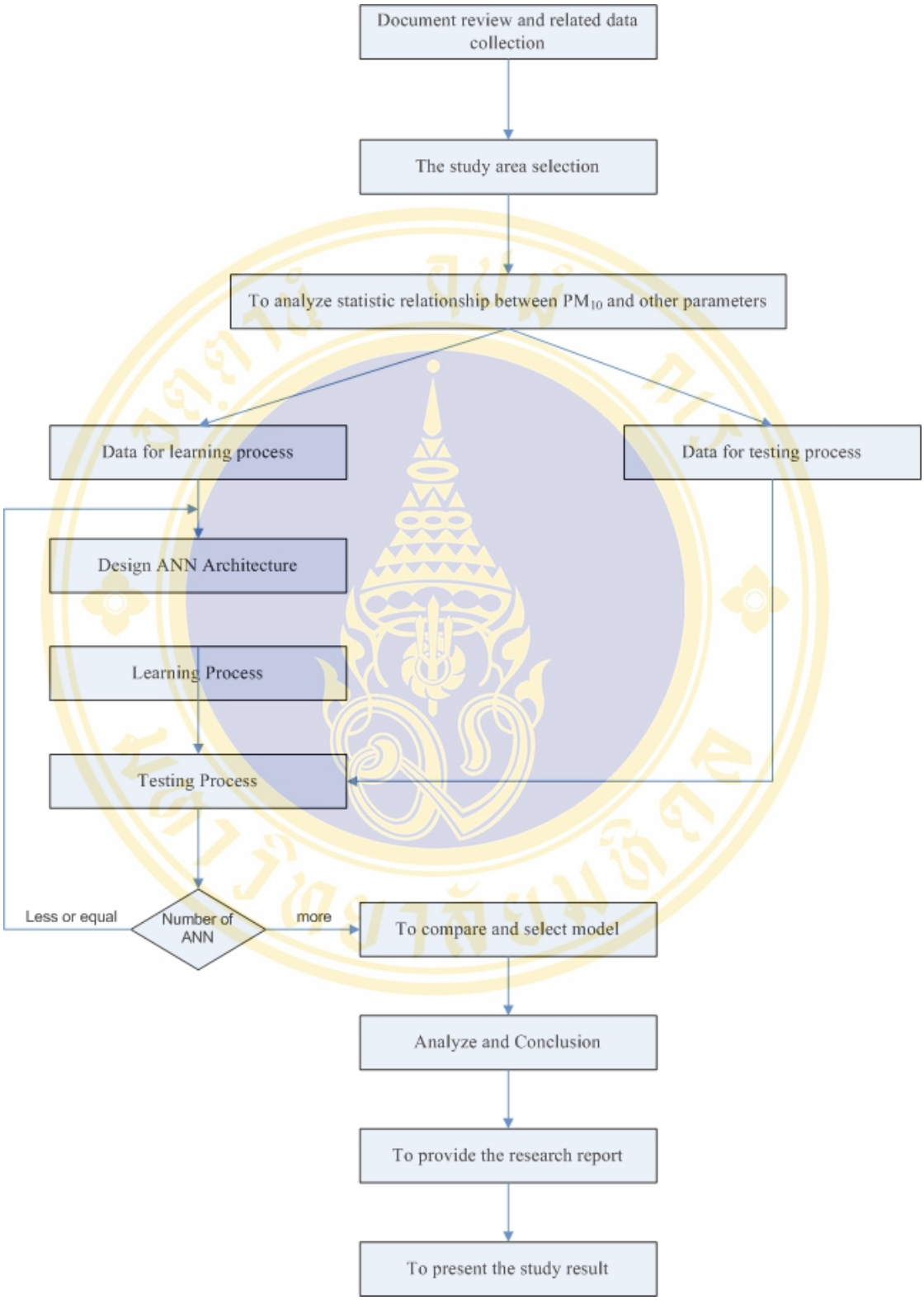

Figure 3-1 Research methodology

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3.2.1 Document review and related data collection.

This step is to study, review document and gather research data from various organizations as the following:

3.2.1.1 To study the characteristics of the study area.

3.2.1.2 To study the characteristics and impact of PM_{10}.

3.2.1.3 To collect the meteorological data, pollutants data and PM_{10} concentration data from the government organization, i.e. the Pollution Control Department and the Meteorological Department from 1st January 2000 to 30th April 2005. Details are shown in Table 3-1.

3.2.1.4 To study theory of ANN.

3.2.1.5 To study other documents and research reports.

From literature reviews, the parameters related with PM_{10} were 26 parameters. Details are as the following:

M. Cecchettic et al. (18) used PM_{10}, NO_x, SO_2 and a wind set of meteorological variables, such as temperature, humidity, wind velocity, solar radiation, atmospheric pressure and Pasquill stability class for input variables in model development.

Edward Lord (19) used 17 factors such as Day of year , Day of week ,Vertical temperature, Horizontal pressure, Occurrence of precipitation , Length of dry spells , Maximum surface temperature anomaly , PM_{10} Tendency , PM_{10} ,CO, O_3, etc for input variables in model development.

Katanchalee (20) studied relationship between the meteorological parameters and the concentration of $PM_{2.5}$, PM_{coarse} and PM_{10}. The results showed that relative humidity, solar radiation, atmospheric pressure, wind speed, wind direction and temperature had related with PM_{10}

Moreover, other parameters will be used in this study, i.e. Mixing Height, Rain, and Non-Methane Hydrocarbons (NMHC).

Therefore, this study will use these parameters which have collected data in Thailand. The data and source of data appear in Table 3-1.

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Table3-1 Data and source of data

Data	Source Of Data
l.PM_{10}	Pollution Control Department
2. Temperature at 2 m.	Pollution Control Department
3. Wind Speed at 10 m.	Pollution Control Department
4. Wind Direction at 10 m.	Pollution Control Department
5. Relative Humidity at 10 m.	Pollution Control Department
6. Solar Radiation	Pollution Control Department
7. Pressure	Pollution Control Department
8. Net Solar Radiation	Pollution Control Department
9. Rain	Pollution Control Department
10. Carbon monoxide (CO)	Pollution Control Department
11. Nitric Oxide (NO)	Pollution Control Department
12. Oxides Of Nitrogen (NOx)	Pollution Control Department
13. Nitrogen Dioxide (NO_2)	Pollution Control Department
14. Sulfur Dioxide ($S0_2$)	Pollution Control Department
15. Ozone (0_3)	Pollution Control Department
16. Total Hydrocarbons (THC)	Pollution Control Department
17. Methane (CH_4)	Pollution Control Department
18. Non -Methane Hydrocarbons (NMHC)	Pollution Control Department
19. Minimum Mixing Height	Meteorological Department
20. Maximum Mixing Height	Meteorological Department

3.2.2 Selection of the study site.

Three stations for urban background Station and two stations for road site station in the Air Quality Monitoring Station of the Pollution Control Department are selected with the following criteria.

- The station collects PM_{10} concentration.
- The station collects the meteorological data.
- The station collects data for more than 5 years.
- The average of PM_{10} concentration exceeded the ambient air standard.

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3.2.3 Preparation and analysis of data.

3.2.3.1 The collected data such as pollutants concentration data and meteorological data, etc. are inspected.

3.2.3.2 The Stepwise Multiple Regression Analysis is employed to analyze the relationship between PM_{10} and other parameters.

3.2.3.3 The data are prepared by the random method (60% of all data in the training process and 40% in the testing process).

3.2.4 The model development

The model development method is described below.

3.2.4.1 Develop the model by using MLFF with BP Learning and using Levenberg-Marquaardt back propagation algorithm (LMBP) to calculate an appropriate weight value and initial weight values which are defined by random.

3.2.4.2 Test the most appropriate number of nodes in the hidden layers in the model development and design. Sigmoid Function is used as the activation function by increasing the number of nodes in the hidden layers by 10 nodes at a time. After the test, the most appropriate number of nodes in the hidden layers is chosen. Then, ANN architecture is tested with the activation function in three types, i.e. Sigmoid Function, Hyperbolic Tangent Function and Linear Function to select the most suitable activation function. Then, the hidden layers are tested to adjust the number of layers to find the most appropriate of ANN Architecture.

3.2.4.3 Establish the training process for each model by using prepared data and define the stop of the training process when Mean Square Error (MSE) = 10^{-5} or Mean Square Error is changing in short term.

3.2.4.4 The MAPE and SD are used in testing process as the indicators of the model efficiency.

3.2.4.5 Choose the best appropriate ANN Architecture for each study site by comparing with MAPE and SD.

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3.2.5 Conclusion

3.2.5.1 Compare, analyze and conclude the most appropriate model development method for prediction of PM_{10} concentration 1-day in advance for each study area.

3.2.5.2 Provide the research report.

3.2.5.3 Present the study results.

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CHAPTER IV
RESULTS AND DISCUSSIONS

4.1 Selection of the study sites

According to Table 4-1, it was found that there were 17 Air Quality Monitoring Stations in Bangkok. Four stations of which meteorological data were not collected, Two stations had been moved to new locations and four stations had not been collected of PM_{10} concentration into AIRVIRO system. Therefore only seven stations are used to compare with number of days exceeding the ambient air standard of PM_{10} for study sites. As a result, the air quality monitoring stations used in this study are as the following:

4.1.1 Urban background Air Quality Monitoring Station

- Nonsi Withaya School station
- Singharach Vitayacom School station
- Klong-Jun Housing Community station

4.2.2 Roadsite Air Quality Monitoring Station

- Chok-Chai Police Station
- Din-Daeng Housing Community station

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Table 4-1 Comparing number and percentage of days that PM_{10} exceeding the ambient air standard in each air quality monitoring station

Station	**Station type**	**Problem**	**Method of monitoring**	**Data in 2001**	**Data in 2002**	**Data in 2003**	**Data in 2004**	**%***
Natural Resources & Environment Policy&Planning	Urban background	Change station	B-Ray	-	-	-	-	-
Bansomdej Chaopraya	Urban background	Data Collect in system at April - Dec.2003	B-Ray					
Ratchaburana Post Office	Urban background	No Data collect	Hi - volume	-	-	-	-	-
The Meteorological Dept.	Urban background	No Data collect	Hi - volume	-	-	-	-	-
Chandrakasem	Urban background	No Data collect	Hi - volume	-	-	-	-	-
Klong-Jun	Urban background	-	B-Ray	0/323	1 / 361	2/362	2/366	0.35
Houykwang Sport Stadium	Urban background	-	B-Ray	0/308	0/308	0/360	1/362	0.08
Nonsi School	Urban background	-	B-Ray	0/338	1 / 341	8/351	20/354	2.1
Singharach school	Urban background	-	B-Ray	2/238	1/360	22 / 365	26 / 365	3.84
Minitry of science and tech.	Road Site	No Meteorological data	B-Ray	-	-	-	-	-
Department of land transport	Road Site	No Meteorological data	B-Ray	-	-	-	-	-
Chulalongkorn Hospital	Road Site	No Meteorological data	B-Ray	-	-	-	-	-
Vongvien 22 circle	Road Site	No Meteorological data	B-Ray	-	-	-	-	-
Thonburi Electric station	Road Site	-	B-Ray	5/290	9/359	2/359	4/361	1.46
Chok-Chai Police Station	Road Site	-	B-Ray	0/352	0/362	1 /365	23 / 364	1.66
Din-Daeng	Road Site	-	B-Ray	2/299	1/360	7/330	12/354	1.64
Ramkhamhaeng University	Urban background	Change station	B-Ray	-	-	-	-	-

* : Percentage of days during 2001 – 2004 that PM_{10} exceeding the ambient air standard

Source: Department of Pollution Control Department

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4.2 Data Collection

Information needed in completing this research requires both primary and secondary sources of data. The secondary data, comprising of data related to the pollutants concentration and meteorological data, are gathered from several relevant departments starting from January 1st, 2000 to April 30th, 2005. On the other hand, the primary data are collected from fieldwork at five air quality monitoring stations as mentioned above. The followings are the summary of the study results.

4.2.1 Chok-Chai Police Station's Air Quality Monitoring Station

The first study site is located at E 0672533 N 1525396, along Lad-Prao Road in the South. The actual building of the station is situated eight meters away from the main road and has many buildings surrounded. The purposes of all buildings are stated below.

There are altogether four residential buildings located in the North, the West, the North East, and the North West. In the South, there is a two-meter high fence bordering the station and Lad-Prao Road. Moreover, Lad-Prao Road is adjacent to both South Eastern and South Western sides of the station. Lastly, the actual building of Chok-Chai Police Station is located in the Eastern side of the station.

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Figure 4-1 Land use of surrounding buildings at Chok-Chai Police Station

4.2.2 Din-Daeng Housing Community's Air Quality Monitoring Station

The second study site is located at E 0667945 N 1521700, eight meters away from the main road. This site is surrounded by congested roads and residential buildings. The followings describe the surrounding areas of the station.

In the North, the East, and the North East, the site is adjacent to Din-Daeng Road. The rest in the South, the West, the South East, the South West, and the North West is surrounded by the four- and five residential buildings and trees.

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Figure 4-2 Land use of surrounding buildings at Din-Daeng Housing Community Station

4.2.3 Klong-Jun Housing Community's Air Quality Monitoring Station

The third study site is located at E 0678314 N 1523688, three hundred meters away from the main road in its South West. This station is mainly surrounded by residential buildings and big trees as detailed below.

In the East and the North East, there are the 1 residential buildings. In the North, there is a 2 residential building. The rest of the surrounding areas in the South, the West, the South East, the South West, and the North West are surrounded by big trees and 2-storey residential buildings.

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Figure 4-3 Land use of surrounding buildings at Klong-Jun Housing Community Station

4.2.4 Nonsi Withaya School's Air Quality Monitoring Station

The fourth study site is located at E 0667677 N 1515658, adjacent to the Bangkok express way in its East. This station is surrounded by a number of trees as it is located in a school. The details of the surrounding areas are described below.

The North, the West, the North East, and the South East of the station are surrounded by school buildings. While the East, the South West, and the South are surrounded by planting areas and trees. A residential village in the North East is still in the middle of the construction.

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Figure 4-4 Land use of surrounding buildings at Nonsi Withaya School Station

4.2.5 Singharach Vitayacom School's Air Quality Monitoring Station

The fifth study site is located at E 0656741 N 1512943, adjacent to a small street - the entrance to Singh Temple where the traffic is very congested. The main road is only fifty meters away from the North Western side of the station. This station is surrounded by a large number of trees and the community as it is located in a school. Below is the details depicting the station's surrounding areas.

In the South and the East of the site, there are big trees. In the opposite directions in both the Northern and the North Eastern sides, the site is adjacent to 2-lane streets. There are altogether two school buildings in these sides, whereas the site in the North West is adjacent to another 2-lane street as well, however without any construction close by. In the Western side, the station is adjacent to the 3-storey residential building. In both South Eastern and South Western sides, the station is surrounded by the community's residential areas.

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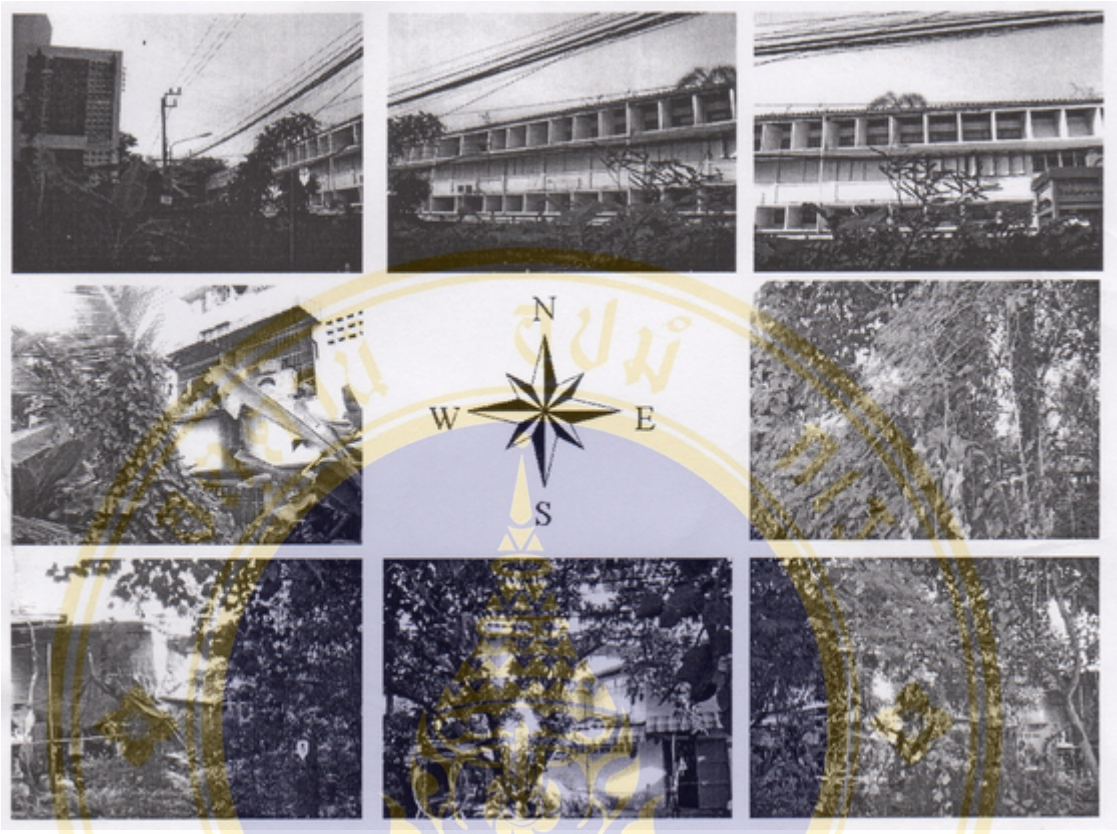

Figure 4-5 Land use of surrounding buildings at Singharach Vitayacom School Station

4.3 The analysis of relationship between input parameters and $PM_{10}(t+1)$

4.3.1 The preparation of data for relationship analysis

Based on the study result, it is found that if the levels of PM_{10} concentration in weekdays and weekends are different, the data set of weekends should be removed because the model will likely contain errors when the data set of weekdays is used to predict PM_{10} concentration level in weekends or the data set of weekends is used to predict PM_{10} concentration level in weekdays. Therefore, the PM_{10} concentration levels of weekdays and weekends should be tested whether they are different by using t-test analysis at 0.05 level of significance.

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1) Chok-Chai Police Station's Air Quality Monitoring Station

The hypothesis is;

H_0 : The PM_{10} concentration between weekdays and weekends are not different.

H_1 : The PM_{10} concentration between weekdays and weekends are different.

From the hypothesis test with t-test analysis at 0.05 level of significance, the results are shown in Tables 4-2 and 4-3.

Table 4-2 The statistical values of the PM_{10} concentration for weekdays and weekends at Chok-Chai Police Station's Air Quality Monitoring Station.

	Days	**N**	**Mean**	**Std. Deviation**	**Std. Error Mean**
PM_{10}	weekends	633	48.45	24.9278149	.9907917
	Weekdays	1237	49.98	26.2103573	.7452262

Table 4-3 The statistical results of the hypothesis test at Chok-Chai Police Station's Air Quality Monitoring Station.

	Levene's Test for Equality of Variances		**t-test for Equality of Means**		
	F	**Sig.**	**t**	**df**	**Sig. (2-tailed)**
Equal variances assumed	.654	.419	-1.211	1868	.226
Equal variances not assumed			-1.231	1331.464	.219

From Table 4-2, it is found that the average of the PM_{10} concentration in weekdays is 49.98 and the average of the PM_{10} concentration in weekends is 48.45. Based on the result of the hypothesis test at 0.05 level of significance from Table 4-3, it can be concluded that the PM_{10} concentration in weekdays is not different from that in weekends at Chok-Chai Police Station's Air Quality Monitoring Station at 0.05 level of significance.

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2) Din-Daeng Housing Community's Air Quality Monitoring Station.

The hypothesis is;

H_0 : The PM_{10} concentration between weekdays and weekends are not different.

H_1 : The PM_{10} concentration between weekdays and weekends are different.

From hypothesis test with t-test analysis at 0.05 level of significance, the results are shown in Tables 4-4 and 4-5.

Table 4-4 The statistical values of the PM_{10} concentration for weekdays and weekends at Din-Daeng Housing Community's Air Quality Monitoring Station.

	Days	**N**	**Mean**	**Std. Deviation**	**Std. Error Mean**
PM_{10}	weekends	604	55.57	23.6340758	.9616569
	Weekdays	1183	57.62	24.3623019	.7083142

Table 4-5 The statistical results of the hypothesis test at Din-Daeng Housing Community's Air Quality Monitoring Station.

	Levene's Test for Equality of Variances		**t-test for Equality of Means**		
	F	**Sig.**	**t**	**df**	**Sig. (2-tailed)**
Equal variances assumed	.092	.762	-1.706	1785	.088
Equal variances not assumed			-1.723	1247.446	.085

From Table 4-4, it is found that the average of the PM_{10} concentration in weekdays is 57.62 and the average of the PM_{10} concentration in weekends is 55.57. Based on the result of the hypothesis test at 0.05 level of significance from Table 4-5, it can be concluded that the PM_{10} concentration in weekdays is not different from that in weekends at Din-Daeng Housing Community's Air Quality Monitoring Station at 0.05 level of significance.

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3) Klong-Jun Housing Community's Air Quality Monitoring Station.

The hypothesis is;

H_0 : The PM_{10} concentration between weekdays and weekends are not different.

H_1 : The PM_{10} concentration between weekdays and weekends are different.

From hypothesis test with t-test analysis at 0.05 level of significance, the results are shown in Tables 4-6 and 4-7.

Table 4-6 The statistical values of the PM_{10} concentration for weekdays and weekends at Klong-Jun Housing Community's Air Quality Monitoring Station.

	Days	**N**	**Mean**	**Std. Deviation**	**Std. Error Mean**
PM_{10}	weekends	681	38.99	22.3259307	.8555315
	Weekdays	1206	44.25	18.9198646	.5448091

Table 4-7 The statistical results of the hypothesis test at Klong-Jun Housing Community's Air Quality Monitoring Station.

	Levene's Test for Equality of Variances		**t-test for Equality of Means**		
	F	**Sig.**	**t**	**df**	**Sig. (2-tailed)**
Equal variances assumed	8.896	.003	-5.424	1885	.000
Equal variances not assumed			-5.181	1229.261	.000

From Table 4-6, it is found that the average of the PM_{10} concentration in weekdays is 44.25 and the average of the PM_{10} concentration in weekends is 38.99. Based on the result of the hypothesis test at 0.05 level of significance from Table 4-7, it can be concluded that the PM_{10} concentration in weekdays is different from that in weekends at Klong-Jun Housing Community's Air Quality Monitoring Station at 0.05 level of significance.

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4) Nonsi Withaya School's Air Quality Monitoring Station.

The hypothesis is;

H_0 : The PM_{10} concentration between weekdays and weekends are not different.

H_1 : The PM_{10} concentration between weekdays and weekends are different.

From hypothesis test with t-test analysis at 0.05 level of significance, the results are shown in Tables 4-8 and 4-9.

Table 4-8 The statistical values of the PM_{10} concentration for weekdays and weekends at Nonsi Withaya School's Air Quality Monitoring Station.

	Days	**N**	**Mean**	**Std. Deviation**	**Std. Error Mean**
PM_{10}	weekends	609	54.17	22.085751	.894960
	Weekdays	1194	56.81	22.253494	.644015

Table 4-9 The statistical results of the hypothesis test at Nonsi Withaya School's Air Quality Monitoring Station.

	Levene's Test for Equality of Variances		**t-test for Equality of Means**		
	F	**Sig.**	**t**	**df**	**Sig. (2-tailed)**
Equal variances assumed	.144	.704	-2.388	1801	.017
Equal variances not assumed			-2.394	1232.307	.017

From Table 4-8, it is found that the average of the PM_{10} concentration in weekdays is 56.81 and the average of the PM_{10} concentration in weekends is 54.17. Based on the result of the hypothesis test at 0.05 level of significance from Table 4-9, it can be concluded that the PM_{10} concentration in weekdays is different from that in weekends at Nonsi Withaya School's Air Quality Monitoring Station at 0.05 level of significance.

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5) Singharach Vitayacom School's Air Quality Monitoring Station.

The hypothesis is;

H_0 : The PM_{10} concentration between weekdays and weekends are not different.

H_1 : The PM_{10} concentration between weekdays and weekends are different.

From hypothesis test with t-test analysis at 0.05 level of significance, the results are shown in Tables 4-10 and 4-11.

Table 4-10 The statistical values of the PM_{10} concentration for weekdays and weekends at Singharach Vitayacom School's Air Quality Monitoring Station.

	Days	**N**	**Mean**	**Std. Deviation**	**Std. Error Mean**
PM_{10}	weekends	604	53.79	26.4795793	1.0774388
	Weekdays	1186	55.71	27.2093088	.7900875

Table 4-11 The statistical results of the hypothesis test at Singharach Vitayacom School's Air Quality Monitoring Station.

	Levene's Test for Equality of Variances		**t-test for Equality of Means**		
	F	**Sig.**	**t**	**df**	**Sig. (2-tailed)**
Equal variances assumed	.484	.487	-1.414	1788	.157
Equal variances not assumed			-1.427	1242.973	.154

From table 4-10, it is found that the average of the PM_{10} concentration in weekdays is 55.71 and the average of the PM_{10} concentration in weekends is 53.79. Based on the result of the hypothesis test at 0.05 level of significance from Table 4-11, it can be concluded that the PM_{10} concentration in weekdays is not different from that in weekends at Singharach Vitayacom School's Air Quality Monitoring Station at 0.05 level of significance.

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It is found that three Air Quality Monitoring Stations of which the PM_{10} concentration in weekdays is not different from that in weekends, i.e. Chok-Chai Police Station's Air Quality Monitoring Station, Din-Daeng Housing Community's Air Quality Monitoring Station and Singharach Vitayacom School's Air Quality Monitoring Station. The other two Air Quality Monitoring Stations of which the PM_{10} concentration of weekdays is different from that in weekends include Klong-Jun Housing Community's Air Quality Monitoring Station and Nonsi Withaya School's Air Quality Monitoring Station.

For the relationship analysis between other parameters and the PM_{10} concentration using Stepwise Multiple Regression Analysis, the parameters that have relationship between independent variables must be removed to prevent the Multi-Collinearity problem.This study found that there are two groups of the parameters which have relationship between independent variables as the following.

1) Nitrogen oxides group includes NO,NO_2 and NO_x. In this study, NO_x is selected for analysis of its relationship with PM_{10}. NO_x is calculated from the summation of NO and NO_2 as appeared in the equation 4.1.

$$NO_x = NO + NO_2 \quad (4.1)$$

2) Hydrocarbons group includes THC,CH_4 and NMHC. In this study, NMHC is selected for analysis of its relationship with PM_{10}. NMHC is calculated from the difference between THC and CH_4 as appeared in the equation 4.2. NMHC is mainly originated from an automobile, a major source of PM_{10}.

$$NMHC = THC - CH_4 \quad (4.2)$$

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4.3.2 The result of the analysis on the relationship between other parameters and PM_{10}(t+1)

The results of the analysis on the relationship between other parameters and the PM_{10} 1-day in advance (PM_{10} (t+l)) using Stepwise Multiple Regression Analysis at the significant level of 0.05 are described as the following.

1) Chok-Chai Police Station's Air Quality Monitoring Station

According to the results, five parameters are related to PM_{10}(t+1) at Chok-Chai Police Station: 1)The PM_{10} at present day (PM_{10}(t)); 2) NO_x; 3)Wind Direction (SE); 4) O_3; and 5) Minimum Mixing Height, as appeared in Table 4-12.

Table 4-12 The statistical values of the parameters significantly related to PM_{10}(t+l) at Chok-Chai Police Station's Air Quality Monitoring Station.

Parameters	**Sig.**	**Standardized Coefficients (Beta)**	**Partial Correlations**	**R Square**
PM_{10} (t)	.000	.855	.850	.822
NO_x	.000	.019	.203	
Wind Direction (SE)	.013	.063	.141	
O_3	.031	.062	.122	
Minimum Mixing Height	.038	-.052	-.118	

Table 4-12 shows the statistical values of the parameters that are significantly related to the (PM_{10}(t+l)) at Chok-Chai Police Station's Air Quality Monitoring Station. PM_{10} (t) scores highest in its relationship with PM_{10}(t+l) with positive relationship. The second is NO_x, followed by Wind Direction (SE) and O_3 with positive relationship, respectively.The least is the Minimum Mixing Height with negative relationship. The Partial Correlation values of these parameters are .850, .203, .141, .122 and -.l 18, respectively. R Square equals to 0.822.

2) Din-Daeng Housing Community's Air Quality Monitoring Station

According to the results, six parameters are related to PM_{10}(t+1) at Din-Daeng Housing Community station: 1)PM_{10}(t); 2)Temperature; 3)Pressure; 4)Wind Direction (NE); 5)Rainy Season; and 6) Relative Humidity as appeared in Table 4-13.

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Table 4-13 The statistical values of the parameters significantly related to PM_{10}(t+l) at Din-Daeng Housing Community's Air Quality Monitoring Station**.**

Parameters	**Sig.**	**Standardized Coefficients (Beta)**	**Partial Correlations**	**R Square**
PM_{10} (t)	.000	.703	.728	.725
Temperature	.000	-.110	-.188	
Pressure	.002	.078	.122	
Wind Direction (NE)	.014	.056	.096	
Rainy Season	.015	-.060	-.094	
Relative Humidity	.030	-.049	-.085	

Table 4-13 shows the statistical values of the parameters related to PM_{10}(t+l) at Din-Daeng Housing Community's Air Quality Monitoring Station. It is found that PM_{10}(t) has highest positive relation with PM_{10}(t+l). The second is Temperature with negative relation. The third is Pressure, the fourth is Wind Direction (NE) and the fifth is Rainy Season with positive relation. The last one is the Relative Humidity with negative relation. The Partial Correlation values of these parameters are .728,-.188,.122,.096,-.094 and -.085, respectively with the R Square equals to .725.

3) Klong-Jun Housing Community's Air Quality Monitoring Station**.**

According to the results, six parameters are related to PM_{10}(t+1) at Klong-Jun Housing Community station: 1) PM_{10}(t); 2) Temperature; 3) SO_2; 4) Relative Humidity; 5) O_3; and 6) Rainy season as appeared in Table 4-14**.**

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Table 4-14 The statistical values of the parameters significantly related to $PM_{10}(t+l)$ at Klong-Jun Housing Community's Air Quality Monitoring Station.

Parameters	**Sig.**	**Standardized Coefficients (Beta)**	**Partial Correlations**	**R Square**
$PM_{10}(t)$	.000	.583	.625	.677
Temperature	.000	-.248	-.364	
SO_2	.000	-.137	-.226	
Relative Humidity	.001	-.134	-.205	
O_3	.020	.107	.146	
Rainy Season	.029	-.089	-.137	

Table 4-14 shows the statistical values of the parameters related to $PM_{10}(t+l)$ at Klong-Jun Housing Community's Air Quality Monitoring Station. It is found that the parameter with the highest relation on $PM_{10}(t+l)$ is $PM_{10}(t)$ with positive relation. The second is Temperature, the third is SO_2 and the fourth is Relative Humidity with negative relation. The fifth is O_3 with positive relation. The last one is the rainy season with negative relation. The Partial Correlation values of these parameters are .625, -.364; -.226, -.205, .146 and -.137, respectively with the R Square equals to .677.

However, using the Correlation analysis to find relationship between the $PM_{10}(t+l)$ and SO_2, we found that the Correlation Coefficient is equivalent to 0.034. This value yields positive relation. It can be concluded that the relationship between $S0_2$ and $PM_{10}(t+l)$) is the synthetic relation. Thus, SO_2 parameter will be removed when analyzing the relationship between other parameters and the $PM_{10}(t+1)$.

Finally, the result shows that five parameters are related with $PM_{10}(t+1)$ at Klong-Jun Housing Community's Air Quality Monitoring Station 1)$PM_{10}(t)$; 2)Temperature; 3) Relative Humidity; 4) the rainy season; and 5)Weekdays as appeared in Table 4-15 below.

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Table 4-15 The statistical values of the parameters significantly related to PM_{10}(t+l) at Klong-Jun Housing Community's Air Quality Monitoring Station after removal of the SO_2 parameter.

Parameters	**Sig.**	**Standardized Coefficients (Beta)**	**Partial Correlations**	**R Square**
PM_{10}(t)	.000	.609	.676	.680
Temperature	.000	-.243	-.368	
Relative Humidity	.000	-.151	-.239	
Rainy Season	.002	-.119	-.188	
Weekdays	.034	.072	.126	

Table 4-15 shows the statistical values of the parameters related to PM_{10}(t+l) at Klong-Jun Housing Community's Air Quality Monitoring Station. It is found that the parameter with the highest relation on PM_{10}(t+l) is PM_{10}(t) with positive relation. The second is temperature, the third is Relative Humidity and the fourth is rainy season with negative relation. The last is Weekdays with positive relation.The Partial Correlation values of these parameters are .676,-.368, -.239, -.188 and .126, respectively with the R Square equals .680.

4) Nonsi Withaya School's Air Quality Monitoring Station

According to the results, five parameters are related with PM_{10}(t+1) at Nonsi Withaya School station: 1) PM_{10} (t); 2) Wind Speed; 3) Minimum Mixing Height; 4) Relative Humidity; and 5) O_3, as appeared in Table 4-16.

Table 4-16 The statistical values of the parameters significantly related to PM_{10}(t+l) at Nonsi Withaya School's Air Quality Monitoring Station

Parameters	**Sig.**	**Standardized Coefficients (Beta)**	**Partial Correlations**	**R Square**
PM_{10} (t)	.000	.499	.626	.869
Wind Speed	.000	-.308	-.558	
Minimum Mixing Height	.000	-.209	-.497	
Relative Humidity	.001	-.226	-.416	
O_3	.004	.209	.371	

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Table 4-16 shows the statistical values of the parameters related to PM_{10}(t+l) at Nonsi Withaya School's Air Quality Monitoring Station. It is found that the parameter with the highest relation on PM_{10}(t+l) is PM_{10}(t) with positive relation. The second is Wind Speed, the third is Minimum Mixing Height and the fourth is Relative Humidity with negative relation. The last is O_3 with positive relation. The Partial Correlation values of these parameters are .626, -.558,-.497,-.416 and .371, respectively with the R Square equal to .869.

5) Singharatch Vitayacom School's Air Quality Monitoring Station

According to the results, five parameters are related with PM_{10}(t+1) at Singharach Vitayacom School Station: 1)PM_{10}(t); 2)Relative Humidity; 3)Temperature; 4) Wind Speed; and 5) Wind Direction (NW), as appeared in Table 4-17.

Table 4-17 The statistical values of the parameters significantly related to PM_{10}(t+1) at Singharach Vitayacom School's Air Quality Monitoring Station

Parameters	**Sig.**	**Standardized Coefficients (Beta)**	**Partial Correlations**	**R Square**
PM_{10}(t)	.000	.599	.624	.722
Relative Humidity	.000	-.228	-.297	
Temperature	.000	-.185	-.295	
Wind Speed	.001	-.140	-.194	
Wind Direction (NW)	.008	.086	.149	

Table 4-17 shows the statistical values of the parameters related to PM_{10}(t+l) at Singharach Vitayacom School's Air Quality Monitoring Station. It is found that the parameter with the highest relation on PM_{10}(t+l) is PM_{10}(t) with positive relation. The second is Relative Humidity, the third is Temperature and the fourth is Wind Speed with negative relation on PM_{10}(t+l). The last is the Wind Direction (NW) with positive relation. The Partial Correlation values of these parameters are .624,-.297, -.295, -.194 and .149, respectively with the R Square equal to .722.

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4.3.3 The parameters related with $PM_{10}(t+1)$

This study found that there are 11 parameters related with $PM_{10}(t+1)$. They are PM_{10} (t), Relative Humidity , Wind Direction , Temperature , Season, Wind Speed , Ozone , Minimum Mixing Height, Pressure , NO_x and Days(Weekdays). The parameters that have positive relation with $PM_{10}(t+1)$, i.e. $PM_{10}(t)$, Wind Direction, Ozone, Pressure, Days(Weekdays) and NO_x. The parameters that have negative relation with $PM_{10}(t+1)$, i.e. Relative Humidity, Temperature, Season, Wind Speed and Minimum Mixing Height. Details are as the following.

1. $PM_{10}(t)$

This parameter is found to have the relationship with $PM_{10}(t+1)$ at all Air Quality Monitoring Stations in the study area. If the $PM_{10}(t)$ concentration is high, this will highly affect the trend of PM_{10} concentration in the following day (t+1).

2. Relative Humidity

This parameter is found to have the relationship with $PM_{10}(t+1)$ at four Air Quality Monitoring Stations, i.e. Din-Daeng Housing Community's Air Quality Monitoring Station, Klong-Jun Housing Community's Air Quality Monitoring Station, Nonsi Withaya School's Air Quality Monitoring Station and Singharach Vitayacom School's Air Quality Monitoring Station. As the relative humidity in the atmosphere will help in mixing particles of solid and liquid, this results in Mass Concentration increase and the PM_{10} concentration decrease.

3. Wind Direction

This parameter is found to have the relationship with the $PM_{10}(t+1)$ at three Air Quality Monitoring Stations, i.e. Chok-Chai Police Station's Air Quality Monitoring Station, Din-Daeng Housing Community's Air Quality Monitoring Station and Singharach Vitayacom School's Air Quality Monitoring Station. As the wind direction gives the big impact to PM_{10} concentration, wind blows dust from that direction and affects the PM_{10} concentration to increase.

4. Temperature

This parameter is found to have the relationship with the $PM_{10}(t+1)$ at three Air Quality Monitoring Stations, i.e. Din-Daeng Housing Community's Air Quality Monitoring Station, Klong-Jun Housing Community's Air Quality Monitoring

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Station and Singharach Vitayacom School's Air Quality Monitoring Station. Due to high temperature condition, air mass will lift up and carry the PM_{10} up to the high atmosphere level. This affects the PM_{10} to decrease.

5. Seasonal

This parameter is found to have the relationship with the $PM_{10}(t+1)$ at two Air Quality Monitoring Stations, i.e.. Din-Daeng Housing Community's Air Quality Monitoring Station and Klong-Jun Housing Community's Air Quality Monitoring Station. Due to the rainy season with high water volume, this affects PM_{10} to reduce.

6. Wind Speed

This parameter is found to have the relationship with the $PM_{10}(t+1)$ at two Air Quality Monitoring Stations, i.e. Nonsi Withaya School's Air Quality Monitoring Station and Singharach Vitayacom School's Air Quality Monitoring Station. High wind speed blows dust away from an area that affects dust reduction.

7. Ozone

This parameter is found to have the relationship with the $PM_{10}(t+1)$ at two Air Quality Monitoring Stations, i.e. Chok-Chai Police Station's Air Quality Monitoring Station and Nonsi Withaya School's Air Quality Monitoring Station. Congested traffic at that area increases the dust concentration and ozone..

8. Minimum Mixing Height

This is found to have the relationship with the $PM_{10}(t+1)$ at two Air Quality Monitoring Stations, i.e. Chok-Chai Police Station's Air Quality Monitoring Station and Nonsi Withaya School's Air Quality Monitoring Station. Low Minimum Mixing Height affects the mix of dust to be at low level. This affects the density of the PM_{10} to increase as it cannot drift to the air.

9. Pressure

This parameter is found to have the relationship with the $PM_{10}(t+1)$ at one Air Quality Monitoring Station, i.e. Din-Daeng Housing Community's Air Quality Monitoring Station. Because of the high pressure, the dust cannot drift to the atmosphere thus increase the density of dust.

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10. NO_X

This parameter is found in the relationship between the $PM_{10}(t+1)$ at one Air Quality Monitoring Stations, i.e. Chok-Chai Police Station's Air Quality Monitoring Station. Highly congested traffic yields high NO_x and dust concentration in that area.

11. Days (Weekdays)

This parameter is found in the relationship between the $PM_{10}(t+1)$ at one Air Quality Monitoring Stations, i.e. Klong-Jun Housing Community's Air Quality Monitoring Station. Highly congested traffic during weekdays yields high dust concentration in that area.

Table 4-18 Summary of the parameters significantly related to $PM_{10}(t+1)$ in each Air Quality Monitoring Station

	Chok-Chai	**Din-Daeng**	**Klong-Jun**	**Nonsi**	**Singharach**
1.$PM_{10}(t)$	X	X	X	X	X
2.Relative Humidity		X	X	X	X
3.Wind Direction	X	X			X
4.Temperature		X	X		X
5.Seasonal		X	X		
6.Wind Speed				X	X
7.Ozone	X			X	
8.Minimum Mixing Height	X			X	
9.Pressure		X			
10.NO_X	X				
11.Days (Weekdays)			X		

From Table 4-18 it is found that the parameters related with $PM_{10}(t+1)$ are different in each air quality monitoring station. The parameters related with $PM_{10}(t+1)$ do not depend on type of air quality monitoring station but it depends on physical characteristic and the land use around each station area.

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4.4 The data preparation and model design

4.4.1 The data preparation of the model development

The data are prepared from other parameters of which relations are analyzed with the $PM_{10}(t+1)$. These analyzed data are used in the training process and testing process. This prepared data is shown in Table 4-19.

Table 4-19 Data preparation

ANN Model No.	**Training Data (Year)**	**Testing Data (Year)**	**Predict Target**
ANN 1	60% of data	40% of data	PM_{10} (t+l)Chok-Chai Police Station
ANN 2	60% of data	40% of data	PM_{10} (t+l) Din-Daeng Housing Community
ANN 3	60 % of data	40 % of data	PM_{10} (t+l)Klong-Jun Housing Community
ANN 4	60% of data	40% of data	PM_{10} (t+l)Nonsi Withaya School
ANN 5	60% of data	40% of data	PM_{10} (t+l) Singharach Vitayacom School

Table 4-19 shows the random to be used data for training process (60% of data) and the testing process (40% of data). Then, the data will be transformed to suit the activation function as the following.

1. Sigmoid Function

Data Pre-Process

New(p) = (old(p) - min(p)) / (max(p) - min(p))

Data Post-Process

old(p) = {new(p) * (max(p)-min(p))} + min(p)

2. Hyperbolic

Data Pre-Process

New(p) = {2*(old(p) - min(p)) / (max(p) - min(p))} – 1

Data Post-Process

Old(p) = {0.5 * (new(p)+l) * (max(p) - min(p))} + min(p)

Where ; P : Set Of Data

Old(p) : Original data

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New(p): New Data

max(p): Maximize Of Data

min(p) : Minimize Of Data

3. Linear Function

Data transform is not necessary in this activation function

4.4.2 The ANN design

MLFF Network with BP learning of ANN consists of three layers including input layer, hidden layer and output layer. Based on the analysis of the relationship between other parameters and $PM_{10}(t+1)$ in each study station, ANN can be designed as in the following Table 4-20.

Table 4-20 ANN Design

ANN Model No.	**Number Of Input Node**	**Number Of Hidden Node**	**Number Of Output Node**	**Activate Function**	**Layer In Hidden**
ANN 1	5	1 Vary to 100 Increment Step By 10	1	Sigmoid ,Hyperbolic Tangent ,Linear	1 to 3
ANN 2	6	1 Vary to 100 Increment Step By 10	1	Sigmoid ,Hyperbolic Tangent, Linear	1 to 3
ANN 3	5	1 Vary to 100 Increment Step By 10	1	Sigmoid ,Hyperbolic Tangent, Linear	1 to 3
ANN 4	5	1 Vary to 100 Increment Step By 10	1	Sigmoid ,Hyperbolic Tangent ,Linear	1 to 3
ANN 5	5	1 Vary to 100 Increment Step By 10	1	Sigmoid ,Hyperbolic Tangent ,Linear	1 to 3

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4.5 The model development and testing

The model development and testing yield a result in according to each study station as the following.

1. Chok-Chai Police Station's Air Quality Monitoring Station (ANN 1)

Five parameters are used as input data in the model development and testing to predict the $PM_{10}(t+1)$ concentration 1-day in advance at the Chok-Chai Police Station's Air Quality Monitoring Station. They include PM_{10} (t), NO_x, Wind Direction (SE), O_3 and Minimum Mixing Height. The results of the model development and testing are shown in Table 4-21.

Table 4-21 The results of the model development and testing for ANN 1

Architecture	Activation Function	Train (MSE)	Test (MAPE)	Test SD	Test Min (MAPE)	Test Max (MAPE)
5-10-1	Sigmoid	0.00255394	14.43	12.45	0.05	82.77
5-20-1	Sigmoid	0.00244466	14.83	13.02	0.11	94.11
5-30-1	Sigmoid	0.00127261	16.07	14.92	0.00	110.63
5-40-1	Sigmoid	0.00165176	16.34	15.86	0.08	111.57
5-50-1	Sigmoid	0.00055655	22.91	32.71	0.00	384.48
5-60-1	Sigmoid	0.00112024	18.23	19.78	0.05	216.7
5-70-1	Sigmoid	0.00173075	15.41	12.74	0.04	95.43
5-80-1	Sigmoid	0.00056001	21.88	23.85	0.08	220.05
5-90-1	Sigmoid	0.00158024	17.16	23.42	0.04	461.76
5-100-1	Sigmoid	0.00042102	24.32	27.24	0.06	272.58
5-10-1	Hyperbolic	0.00924065	13.66	11.98	0.06	76.17
5-10-1	Linear	n/a	n/a	n/a	n/a	n/a
5-10-10-1	Hyperbolic	0.102352	47.16	51.89	0.77	751.81
5-10-10-10-1	Hyperbolic	0.00204607	26.18	37.06	0.00	385.79

n/a = Matrix is close to singular or badly scaled. Result may be inaccurate.

Table 4-21 shows the results of the model development and testing at the Chok-Chai Police Station's Air Quality Monitoring Station. The appropriate number of Node in the hidden layer is 10. The appropriate Activation Function is Hyperbolic Tangent Function. The appropriate number of the Hidden Layer is 1. The best

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Architecture is 5-10-1 (Hyperbolic Tangent). The model performance are MAPE = 13.66, SD = 11.98 and correlation(r) = 0.900 at 0.01 level of significance.

The mathematical model for ANN1 can be calculated from the equation 4.1.

$$PM_{10}(t+1) = f\left(\left(\sum_{j=1}^{10} w_{1j}\, f\left(\left(\sum_{i=1}^{5} v_{ji} x_i\right) + b_j\right)\right) + b_o\right) \qquad (4.1)$$

Where
- f = Hyperbolic Tangent Function
- j = Number node in hidden layer
- w = Weight values in output layer are shown in Table B-2
- v = Weight values in hidden layer are shown in Table B-1
- x = Input data
- b = Bias values in hidden layer are shown in Table B-3
- b_o = Bias value in output layer are shown in Table B-3

2. Din-Daeng Housing Community's Air Quality Monitoring Station (ANN 2)

Six parameters are used as input data in the model development and testing to predict the $PM_{10}(t+1)$ concentration 1-day in advance at the Din-Daeng Housing Community's Air Quality Monitoring Station. They include $PM_{10}(t)$, Temperature, Pressure, Wind Direction (NE) ,Rainy Season and Relative Humidity. The results of the model development and testing are shown in Table 4-22.

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Table 4-22 The results of the model development and testing for ANN 2

Architecture	Activation Function	Train (MSE)	Test (MAPE)	Test SD	Test Min (MAPE)	Test Max (MAPE)
6-10-1	Sigmoid	0.00500554	18.71	15.88	0.09	108.14
6-20-1	Sigmoid	0.00397352	19.61	18.08	0.05	195.65
6-30-1	Sigmoid	0.00373498	18.46	15.13	0.09	102.90
6-40-1	Sigmoid	0.00358572	19.59	18.28	0.09	181.22
6-50-1	Sigmoid	0.00362197	19.21	16.35	0.08	120.05
6-60-1	Sigmoid	0.00431560	19.32	16.50	0.14	124.94
6-70-1	Sigmoid	0.00262482	21.70	19.01	0.04	117.79
6-80-1	Sigmoid	0.00407785	18.44	14.98	0.08	103.09
6-90-1	Sigmoid	0.00300593	20.79	17.68	0.04	134.88
6-100-1	Sigmoid	0.00094446	41.97	49.26	0.09	420.52
6-80-1	Hyperbolic	0.00993649	24.42	20.88	0.05	152.23
6-80-1	Linear	n/a	n/a	n/a	n/a	n/a
6-80-80-1	Sigmoid	0.00098365	44.56	31.06	0.05	180.71
6-80-80-80-1	Sigmoid	0.00305433	19.6	15.51	0.04	115.52

n/a = Matrix is close to singular or badly scaled. Result may be inaccurate.

Table 4-22 shows the results of the model development and testing at the Din-Daeng Housing Community's Air Quality Monitoring Station. The appropriate number of Node in hidden layer is 80 Node. The appropriate Activation Function is Sigmoid Function. The appropriate number of the Hidden Layer is 1 Layer. The best of Architecture is 6-80-1 (Sigmoid). The model performance are MAPE = 18.44, SD = 14.98 and correlation(r) = 0.784 at 0.01 level of significance.

The mathematical model for ANN2 can be calculated from the equation 4.2.

$$PM_{10}(t+1) = f\left(\left(\sum_{j=1}^{80} w_{1j}\, f\left(\left(\sum_{i=1}^{6} v_{ji} x_i\right) + b_j\right)\right) + b_o\right) \qquad (4.2)$$

Where f = Sigmoid Function

j = Number node in hidden layer

w = Weight values in output layer are shown in Table B-5

v = Weight values in hidden layer are shown in Table B-4

x = Input data

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b = Bias values in hidden layer are shown in Table B-6

b_o = Bias value in output layer are shown in Table B-6

3. Klong-Jun Housing Community's Air Quality Monitoring Station (ANN 3)

Five parameters are used as input data in the model development and testing to predict the $PM_{10}(t+1)$ concentration 1-day in advance at the Klong-Jun Housing Community's Air Quality Monitoring Station. They include $PM_{10}(t)$, Temperature, Relative Humidity ,Rainy Season and Weekdays. The results of the model development and testing are shown in Table 4-23.

Table 4-23 The results of the model development and testing for ANN 3

Architecture	**Activation Function**	**Train (MSE)**	**Test (MAPE)**	**Test SD**	**Test Min (MAPE)**	**Test Max (MAPE)**
5-10-1	Sigmoid	0.00497418	19.23	18.44	0.15	145.14
5-20-1	Sigmoid	0.00462849	18.73	16.77	0.00	120.95
5-30-1	Sigmoid	0.00262213	26.09	25.80	0.04	224.60
5-40-1	Sigmoid	0.00320067	21.08	19.77	0.03	126.86
5-50-1	Sigmoid	0.00316784	22.86	22.7	0.04	181.44
5-60-1	Sigmoid	0.00170530	30.52	32.03	0.03	258.25
5-70-1	Sigmoid	0.00105590	36.85	37.74	0.09	329.92
5-80-1	Sigmoid	0.00038192	66.23	81.37	0.00	620.70
5-90-1	Sigmoid	0.00372396	21.62	20.28	0.04	178.08
5-100-1	Sigmoid	0.00015971	73.20	96.36	0.15	622.86
5-20-1	Hyperbolic	0.02166670	18.74	17.42	0.06	123.97
5-20-1	Linear	n/a	n/a	n/a	n/a	n/a
5-20-20-1	Sigmoid	0.00030134	47.16	22.13	0.02	235.43
5-20-20-20-1	Sigmoid	n/a	n/a	n/a	n/a	n/a
5-20-20-1	Hyperbolic	0.00121556	64.58	48.77	0.01	431.88
5-20-20-20-1	Hyperbolic	0.01327210	42.95	37.56	0.05	251.65

n/a = Matrix is close to singular or badly scaled. Result may be inaccurate.

Table 4-23 shows the results of the model development and testing at the Klong-Jun Housing Community's Air Quality Monitoring Station. The appropriate number of Node in hidden layer is 20 Node. The appropriate Activation Function is

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Sigmoid Function. The appropriate number of the Hidden Layer is 1 Layer. The best of Architecture is 5-20-1 (Sigmoid). The model performance are MAPE = 18.73, SD = 16.77 and correlation(r) = 0.812 at 0.01 level of significance.

The mathematical model for ANN3 can be calculated from the equation 4.3.

$$PM_{10}(t+1) = f\left(\left(\sum_{j=1}^{20} w_{1j}\, f\left(\left(\sum_{i=1}^{5} v_{ji} x_i\right) + b_j\right)\right) + b_o\right) \qquad (4.3)$$

Where
- f = Sigmoid Function
- j = Number node in hidden layer
- w = Weight values in output layer are shown in Table B-8
- v = Weight values in hidden layer are shown in Table B-7
- x = Input data
- b = Bias values in hidden layer are shown in Table B-9
- b_o = Bias value in output layer are shown in Table B-9

4. Nonsi Withaya School's Air Quality Monitoring Station (ANN 4)

Five parameters are used as input data in the model development and testing to predict the $PM_{10}(t+1)$ concentration 1-day in advance at the Nonsi Withaya School's Air Quality Monitoring Station. They include $PM_{10}(t)$, Wind Speed, Minimum Mixing Height , Relative Humidity and O_3. The results of the model development and testing is shown in Table 4-24.

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Table 4-24 The results of the model development and testing for ANN 4

Architecture	Activation Function	Train (MSE)	Test (MAPE)	Test SD	Test Min (MAPE)	Test Max (MAPE)
5-10-1	Sigmoid	0.00518587	17.08	13.48	0.14	78.03
5-20-1	Sigmoid	0.00334449	21.14	24.54	0.16	270.22
5-30-1	Sigmoid	0.00165804	21.50	17.86	0.29	146.9
5-40-1	Sigmoid	0.00486265	18.33	14.84	0.06	84.24
5-50-1	Sigmoid	0.00196000	24.15	20.28	0.26	120.84
5-60-1	Sigmoid	0.00041038	38.39	49.00	0.13	434.89
5-70-1	Sigmoid	0.00138157	24.42	20.16	0.27	156.26
5-80-1	Sigmoid	0.00090053 9.6	24.74	21.51	0.07	170.78
5-90-1	Sigmoid	xl0-8	59.46	63.44	0.04	436.33
5-100-1	Sigmoid	0.00460000	18.54	15.28	0.05	97.56
5-10-1	Hyperbolic	0.01976370	18.31	13.95	0.15	80.05
5-10-1	Linear	n/a	n/a	n/a	n/a	n/a
5-10-10-1	Sigmoid	0.001494550	24.19	18.89	0.19	145.51
5-10-10-10-1	Sigmoid	0.000110522	27.77	21.05	0.13	203.11

n/a = Matrix is close to singular or badly scaled. Result may be inaccurate.

Table 4-24 shows the results of the model development and testing at the Nonsi Withaya School's Air Quality Monitoring Station. The appropriate number of Node in hidden layer is 10 Node. The appropriate Activation Function is Sigmoid Function. The appropriate number of the Hidden Layer is 1 Layer. The best of Architecture is 5-10-1 (Sigmoid). The model performance are MAPE = 17.08, SD = 13.48 and correlation(r) = 0.817 at 0.01 level of significance.

The mathematical model for ANN4 can be calculated from the equation 4.4.

$$PM_{10}(t+1) = f\left(\left(\sum_{j=1}^{10} w_{1j}\, f\left(\left(\sum_{i=1}^{5} v_{ji} x_i\right) + b_j\right)\right) + b_o\right) \qquad (4.4)$$

Where f = Sigmoid Function

j = Number node in hidden layer

w = Weight values in output layer are shown in Table B-11

v = Weight values in hidden layer are shown in Table B-10

x = Input data

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b = Bias values in hidden layer are shown in Table B-12

b_o = Bias value in output layer are shown in Table B-12

5. Singharach Vitayacom School's Air Quality Monitoring Station (ANN 5)

Five parameters are used as input data in the model development and testing to predict the $PM_{10}(t+1)$ concentration 1-day in advance at the Singharach Vitayacom School's Air Quality Monitoring Station. They include PM_{10} (t), Relative Humidity , Temperature, Wind Speed and Wind Direction (NW). The results of the model development and testing are shown in Table 4-25.

Table 4-25 The results of the model development and testing for ANN 5

Architecture	**Activation Function**	**Train (MSE)**	**Test (MAPE)**	**Test SD**	**Test Min (MAPE)**	**Test Max (MAPE)**
5-10-1	Sigmoid	0.00561665	20.80	21.53	0.04	222.70
5-20-1	Sigmoid	0.00525490	23.65	24.92	0.03	234.42
5-30-1	Sigmoid	0.00343280	32.08	40.21	0.02	396.34
5-40-1	Sigmoid	0.00527029	22.95	22.51	0.10	199.65
5-50-1	Sigmoid	0.00255094	31.29	22.50	0.10	199.65
5-60-1	Sigmoid	0.00217563	40.55	69.78	0.16	664.16
5-70-1	Sigmoid	0.00164614	51.34	95.43	0.00	704.83
5-80-1	Sigmoid	0.00422648	23.94	23.64	0.04	190.64
5-90-1	Sigmoid	0.00084209	48.22	78.49	0.04	687.32
5-100-1	Sigmoid	0.00058003	72.72	114.71	0.07	712.17
5-10-1	Hyperbolic	0.02013810	22.45	22.55	0.03	230.15
5-10-1	Linear	n/a	n/a	n/a	n/a	n/a
5-10-10-1	Sigmoid	0.00468563	26.08	25.78	0.05	195.67
5-10-10-10-1	Sigmoid	0.00197418	33.97	45.81	0.03	401.22

n/a = Matrix is close to singular or badly scaled. Result may be inaccurate.

Table 4-25 shows the results of the model development and testing at the Singharach Vitayacom School's Air Quality Monitoring Station. The appropriate number of Node in hidden layer is 10 Node. The appropriate Activation Function is sigmoid Function. The appropriate number of the Hidden Layer is 1 Layer. The best

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of Architecture is 5-10-1 (Sigmoid). The model performance are MAPE = 20.80, SD = 21.53 and correlation(r) = 0.773 at 0.01 level of significance.

The mathematical model for ANN5 can be calculated from the equation 4.5.

$$PM_{10}(t+1) = f\left(\left(\sum_{j=1}^{10} w_{1j}\, f\left(\left(\sum_{i=1}^{5} v_{ji} x_i\right) + b_j\right)\right) + b_o\right) \qquad (4.5)$$

Where f = Sigmoid Function

j = Number node in hidden layer

w = Weight values in output layer are shown in Table B-14

v = Weight values in hidden layer are shown in Table B-13

x = Input data

b = Bias values in hidden layer are shown in Table B-15

b_o = Bias value in output layer are shown in Table B-15

The results showed that at each study site, it required a different appropriate activation function for the PM_{10} concentration prediction, i.e. the Hyperbolic Tangent function was the appropriate activation function for Chok-Chai Station and the Sigmoid Function was the appropriate activation function for Din-Daeng Housing Community Station, Klong-Jun Housing Community Station, Nonsi Withaya School Station, and Singharach Vitayacom School Station.

In addition, the appropriate number of node were also different in each study site. The appropriate number of node in hidden node at Chok-Chai, Nonsi Withaya School, and Singharach Vitayacom School stations were 10 nodes whereas at Din-Daeng Housing Community station and Klong-Jun Housing Community station were 80 and 20 nodes, respectively. The Linear function could not be applied as Activation Function in this study because the model output was badly scaled or the matrix was close to singular that possibly affected accuracy of the result.

Moreover, it was found that a few of the ANN architecture that had small errors in the learning process when putting them into the model testing, showed large errors. This might due to the reason that the ANN had Over Training and the model would remember the data pattern in the learning process. However, some data groups that were tested in this model might have pattern different from the data groups in the learning process and would result in large errors in the testing process.

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The values of MAPE, SD and r for ANN1, ANN2, ANN3, ANN4, and ANN5 were 13.66, 18.44, 18.73, 13.48, and 20.80; 11.98, 14.98, 16.77, 13.48, and 21.53; 0.900, 0.784, 0.812, 0.817, and 0.773, respectively.

The highest r value obtained from the Chok-Chai Police station was a little less than 0.94 obtained from the study of Cecchettic and others (18) in the Milan area, Italy. However, the other four stations were all less than that obtained from Milan. Therefore, it appears that the model performance in this study was not as good as that obtained in the Milan area.

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CHAPTER V
CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

1.The PM_{10}(t+1) showed a relationships with five to six different input parameters in each air quality monitoring station as follows. The PM_{10} (t) showed a relationship with PM_{10}(t+1) in all five air quality monitoring stations whereas the relative humidity showed a relationship in four stations; the wind direction and the temperature showed a relationship in three stations; the seasons, the wind speed, the ozone concentration, and the minimum mixing height showed a relationship in two stations; and the pressure, the NO_X ,and the weekdays showed a relationship in only one station.

2.The model development for the prediction of the PM_{10} concentration 1-day in advance obtained from each monitoring station in this study was all different. Therefore, some modifications were required before they could not be applied to other areas.

3.The model performance indicators showed that the ranges of MAPE, SD, and r were 13.48-20.80, 13.48-21.53, and 0.773-0.900, respectively. The model performance appeared not to be as good as that obtained from the study of Cecchettic and others (18).

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5.2 Recommendations for further study

1. Other input parameters such as number, type, and engine type of automobiles should be employed as input data in the study of model development.

2. Other learning processes such as Automata and Hebbian, etc. and the ANN such as Time Delay Neural Network (TDNN) and Radial Basis Function (RBF), etc. should be investigated.

3. Due to the limitation of Hardware, the number of Hidden Nodes or Hidden Layers cannot be set at values higher than 100 nodes and 3 layers. The increase of Hidden Nodes or Hidden Layers will likely improve the model performance.

4. The PM_{10} concentration prediction model and Geographic Information System (GIS) should be applied together in order to be able to illustrate the distribution of particular matter in the Spatial demonstration.

5. A Specific Software should be developed in order to allow the users to be able to continue updating the model by using the most recent data set in the learning process to yield more accurate output.

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APPENDIX

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APPENDIX A
RELATIONSHIP BETWEEN REAL AND PREDICTED VALUES

The relationship between real and predicted values in each study sites are shown as follows:

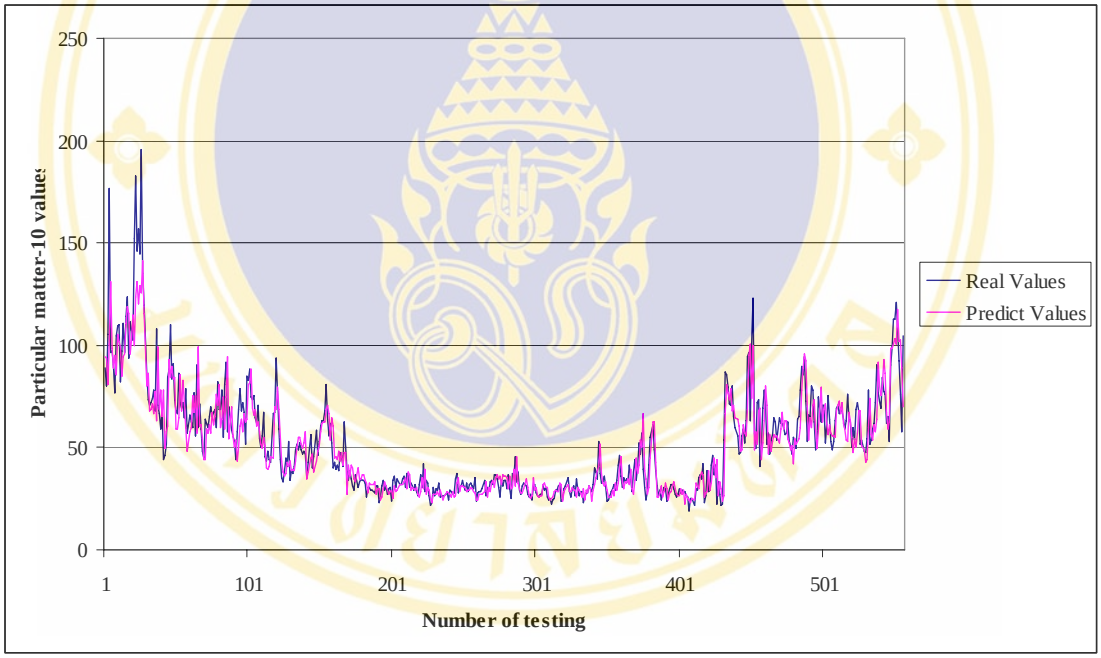

Figure A-1 The Relationship between real and predicted values of ANN1

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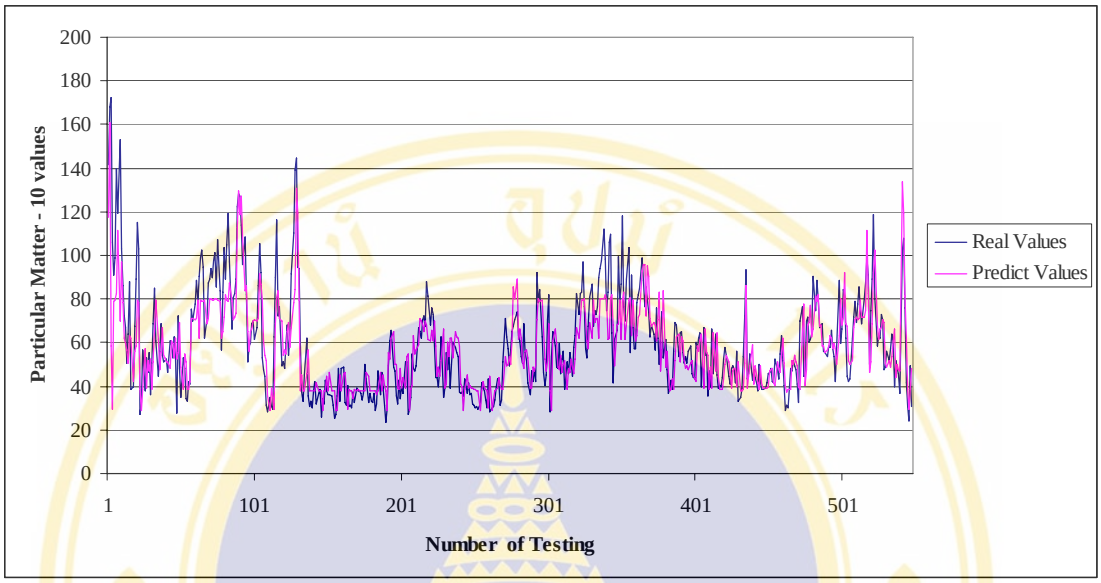

Figure A-2 The Relationship between real and predicted values of ANN2

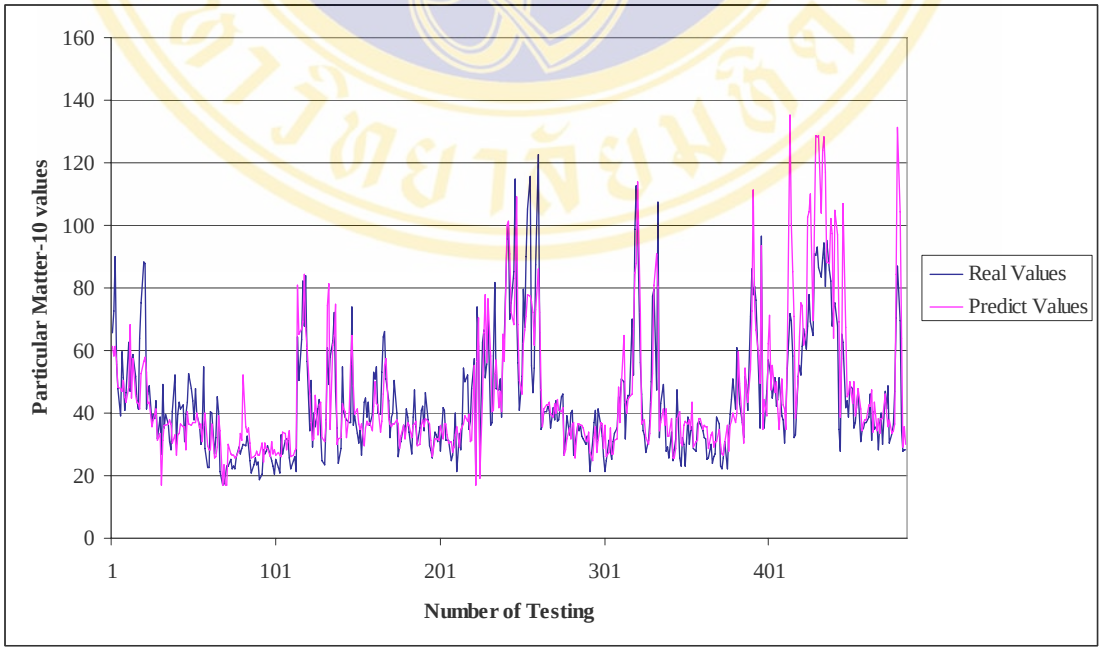

Figure A-3 The Relationship between real and predicted values of ANN3

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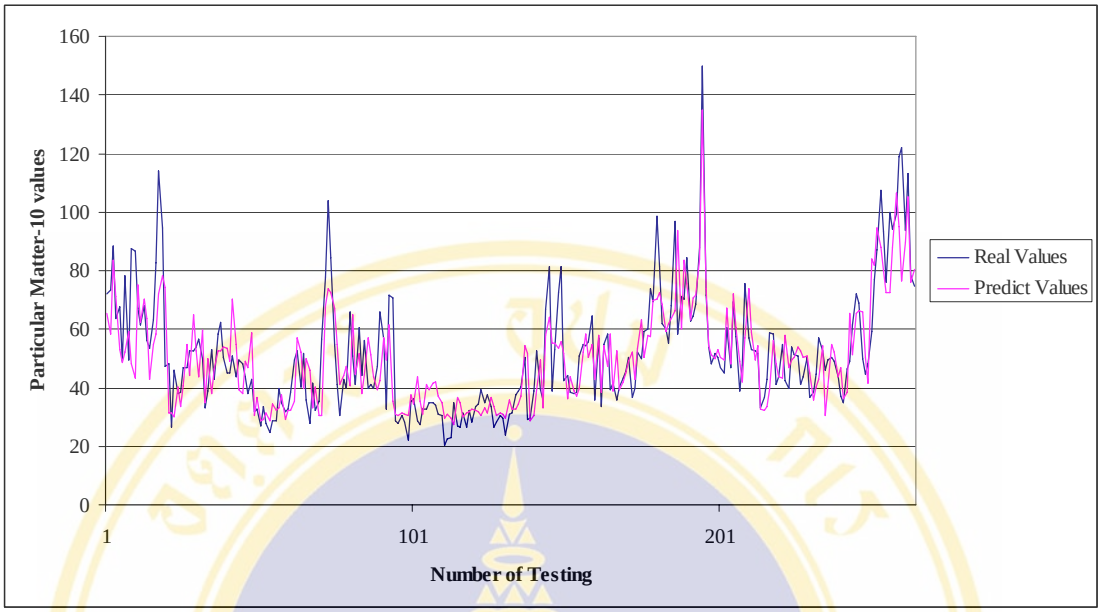

Figure A-4 The Relationship between real and predicted values of ANN4

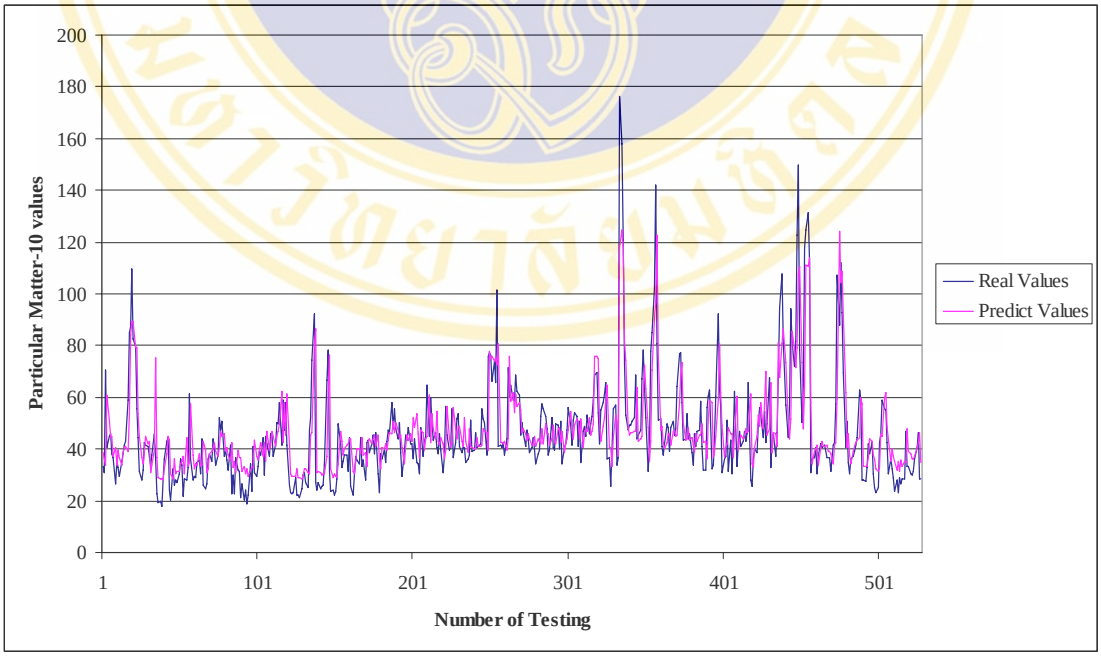

Figure A-5 The Relationship between real and predicted values of ANN5

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APPENDIX B

THE WEIGHT AND BIAS VALUES OF MODEL

The weight values in each study sites are shown as follows:

Table B – 1 Weight values in hidden layer of ANN1

# of hidden node	Minimum Mixing Height ($x_{1)}$	NO_x (x_2)	O_3 (x_3)	PM_{10} (t) ($x_{4)}$	Wind Direction (SE) (x_5)
1	0.0017	0.0040	0.0437	-0.0699	0.2150
2	-0.0798	0.0203	0.0783	-0.0258	-0.4212
3	-0.0022	-0.0027	0.2243	0.0705	-0.6837
4	0.0012	-0.0296	-0.0794	0.0611	-3.3539
5	-0.0282	-0.0246	-0.0709	-0.0487	-0.5738
6	0.0023	-0.0211	-0.0809	0.1201	-2.5021
7	-0.0024	-0.0151	-0.1286	0.0499	0.4090
8	0.0124	0.0131	-0.0581	0.1465	2.7423
9	0.0217	0.0244	0.1942	0.0183	0.2224
10	0.0004	0.0064	0.0668	-0.0004	1.1789

Table B – 2 Weight values in output layer of ANN1

# of hidden node	Weight Value	# of hidden node	Weight Value
1	-0.2655	6	0.1484
2	-0.1354	7	0.2023
3	0.0433	8	-0.7963
4	0.1648	9	-0.0077
5	-0.0145	10	0.3276

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Table B – 3 Bias values in hidden layer and output layer of ANN1

# of hidden node	Bias Value	# of hidden node	Bias Value	Bias Value in Output Node
1	-0.0258	6	-2.4693	-0.0669
2	-1.7006	7	0.0395	
3	-6.8079	8	0.3908	
4	-1.2477	9	-1.6384	
5	1.7537	10	-1.6487	

Table B – 4 Weight values in hidden layer of ANN2

# of hidden node	Rainy Season (x_1)	PM_{10} (t) (x_2)	Pressure (x_3)	Relative Humidity (x_4)	Temperature (x_5)	Wind Direction (NE) (x_6)
1	3.3873	-1.0089	-0.0299	-0.2861	-0.5443	6.147
2	3.9945	0.2286	0.2118	0.1855	0.3388	-0.3202
3	5.5172	0.2556	0.0488	0.5874	0.5845	4.6031
4	-4.0787	-1.8242	0.0401	1.1135	0.4131	2.6134
5	-1.8286	0.1096	-0.652	0.6849	-0.7773	-3.7371
6	-0.0309	-0.1482	-0.2453	0.0281	0.0946	0.1916
7	-6.4745	-0.8095	-2.5363	0.8038	-0.2264	-2.001
8	-4.6074	0.1435	-3.3063	-0.2475	-0.514	4.8175
9	80.1088	5.232	-0.5839	-1.3728	1.0535	23.1027
10	-2.8017	-0.0213	-2.618	1.006	-0.2848	-7.2376
11	-0.3413	0.8204	0.2825	-0.339	-1.2876	3.1131
12	7.7642	-0.8769	-0.378	-0.8124	0.5306	0.2848
13	-4.8562	0.2915	-0.1238	-0.126	-0.2763	-4.9709
14	6.4502	-0.8503	0.4685	0.4535	0.1463	4.0899
15	2.2866	-0.802	0.063	0.2733	0.2788	-6.2866
16	4.7734	0.0416	2.4876	0.2077	-0.222	5.6631
17	-0.1571	3.2695	0.2469	-6.3042	-8.5379	-4.6566
18	7.0467	-0.6993	-3.0054	0.0428	-0.6121	-4.8624
19	-2.4152	-1.7877	-0.4568	2.567	-0.49	3.0168
20	0.5839	0.3443	-0.1233	-0.3342	-0.4883	-9.4109
21	-4.409	0.4635	0.3979	0.6028	-0.8463	-2.2421
22	0.0113	0.6073	0.959	0.3675	-1.001	-3.983
23	-1.0508	-0.49	0.3369	0.3266	0.4573	-6.9012
24	2.5698	-0.6314	-0.6443	0.4653	0.1825	-6.331

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# of hidden node	Rainy Season (x_1)	PM_{10} (t) (x_2)	Pressure (x_3)	Relative Humidity (x_4)	Temperature (x_5)	Wind Direction (NE) (x_6)
25	2.5998	0.2746	0.5861	-0.9962	0.5343	-1.3662
26	6.6158	1.0789	-0.4689	-0.1986	-0.346	4.561
27	-4.8621	-0.3207	0.6216	0.8639	-1.0072	5.8534
28	-5.768	0.9293	-0.1632	-0.9716	-1.3363	-6.9551
29	1.525	0.9956	0.4444	-1.527	-0.572	5.7069
30	7.2465	-0.2247	0.2731	0.5589	-0.3825	5.557
31	-5.8641	0.3381	0.2736	-0.2936	-0.4647	2.8274
32	5.8628	-0.5667	-2.2865	-0.0847	-0.3749	7.2123
33	-6.3803	0.4767	0.1426	-0.0195	1.3287	2.2905
34	0.529	-0.0501	0.893	-3.9971	0.9946	4.8418
35	-4.916	-0.2891	0.6424	0.3359	-0.0753	-2.4482
36	4.0361	0.0434	0.0334	-1.1278	-1.4067	7.0243
37	-4.4602	0.1752	0.4007	-0.2994	-1.682	-2.3145
38	6.5657	0.05	-1.2688	-0.1981	-1.7876	-6.7426
39	-6.4305	1.2242	0.7416	-1.0637	-0.2715	3.8097
40	0.351	-1.1124	-0.0734	0.8397	0.0077	6.4769
41	5.5437	-0.6366	-0.4438	0.7477	-1.6204	-4.8744
42	6.282	-0.799	-0.2117	-1.2253	-0.1216	-1.1497
43	-2.5419	-1.4529	-0.3315	-0.0341	0.2151	-6.2963
44	-0.4199	-0.1998	-0.0732	0.3343	-0.6934	-1.061
45	-0.5738	1.1478	1.3231	-0.4794	0.9764	6.2054
46	-7.8237	-0.4281	0.3324	-0.6453	0.5145	-2.211
47	-6.0294	0.3042	1.351	0.167	-0.2039	-4.4653
48	1.2239	-0.0243	1.1224	-0.6717	-1.1431	-2.9864
49	3.7645	-0.788	-0.4671	0.1005	0.108	3.5516
50	-1.6503	0.2565	0.4104	-0.4798	-1.1497	2.5301
51	-1.8465	0.554	0.7712	-1.8426	-0.3207	5.2139
52	-3.365	-0.7913	0.6599	1.6029	-0.8095	5.1515
53	13.3778	-0.2959	-0.0243	-0.2939	1.7706	-0.6631
54	2.9582	-2.1456	-0.4695	1.7096	-0.7837	2.1806
55	-4.413	-0.0701	0.1019	-0.124	0.1372	-7.4943
56	8.0822	0.3857	0.1041	-1.1463	0.413	0.7134
57	5.0541	-1.2877	-8.5609	-0.3891	-0.2303	-1.4059
58	-4.5782	-1.3751	0.25	1.0186	-0.0574	6.2002
59	5.6577	-1.2437	0.1922	-0.1118	0.4365	5.4218

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# of hidden node	Rainy Season (x_1)	PM_{10} (t) (x_2)	Pressure (x_3)	Relative Humidity (x_4)	Temperature (x_5)	Wind Direction (NE) (x_6)
60	3.4289	0.5304	1.4293	1.3961	-0.2967	-0.5098
61	-0.659	0.0785	-0.093	0.0081	-0.4349	-0.6343
62	-9.4998	0.2973	-0.0694	-0.0628	0.2239	3.1223
63	-3.7451	-0.4057	-2.5914	0.0853	1.1232	-8.0936
64	-9.1161	-6.4409	-0.1303	1.5261	1.9073	-4.8086
65	-6.8708	0.5262	2.7872	0.6067	0.5187	-0.1766
66	4.5582	-0.0221	-0.3045	0.5477	0.5991	-5.8967
67	-6.5901	-0.1681	0.1534	-0.5696	-0.0302	-5.6587
68	-1.8921	10.848	-2.0182	3.0651	24.0968	22.6028
69	3.4742	-0.5907	0.4362	0.3652	-1.3339	6.2608
70	-2.9821	-0.1335	-0.0541	0.1371	0.6809	0.2246
71	-3.7847	-0.1308	-1.9714	0.3477	-0.9919	-4.2535
72	-2.8863	0.9628	1.2276	-1.6753	-0.0598	-1.5432
73	-5.6895	0.9537	-0.038	0.8216	0.2061	4.0041
74	6.7033	0.5301	-0.0047	1.2745	0.4734	-5.4263
75	6.5124	-0.3755	0.3876	0.0513	0.5859	0.1757
76	-3.1861	0.1609	-0.6157	0.9924	0.5934	-0.6356
77	1.4832	-0.9184	0.0541	0.5194	0.8693	-3.777
78	-4.5464	0.1776	0.3449	0.0232	-0.6455	-1.7063
79	1.7208	0.215	1.2486	0.9378	-1.7418	6.4244
80	-2.3817	1.4051	1.0073	-0.0809	-0.7391	3.7406

Table B – 5 Weight values in output layer of ANN2

# of hidden node	Weight Value	# of hidden node	Weight Value	# of hidden node	Weight Value
1	0.5109	27	-0.4781	53	-1.9473
2	-0.0779	28	0.6876	54	-1.2190
3	0.5301	29	-0.9039	55	0.0690
4	-1.0424	30	-0.6870	56	-0.8248
5	-1.1998	31	1.2468	57	-1.2143
6	-0.9074	32	0.0541	58	-0.0181
7	-0.2479	33	-0.1753	59	-0.3288
8	-0.0210	34	1.2394	60	0.7618
9	0.5018	35	-0.5637	61	-10.7347

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# of hidden node	Weight Value	# of hidden node	Weight Value	# of hidden node	Weight Value
10	-0.1725	36	-0.7438	62	-0.3980
11	0.8467	37	-0.6119	63	0.0020
12	0.6320	38	0.2310	64	-0.6036
13	-0.2377	39	0.3181	65	0.0151
14	-0.8130	40	-1.5779	66	-1.5081
15	0.9482	41	-0.7384	67	0.6793
16	-0.2012	42	-0.3639	68	-0.2881
17	5.7169	43	-0.8403	69	-0.0682
18	0.6615	44	-0.2292	70	-1.4541
19	-1.0749	45	0.2199	71	-0.9019
20	0.0831	46	-0.3238	72	0.6820
21	0.5811	47	0.4238	73	-0.6638
22	-0.2830	48	0.9120	74	-0.4095
23	-0.1869	49	0.4630	75	-1.3276
24	-0.9762	50	0.0551	76	-0.3670
25	-0.1405	51	0.5051	77	0.2188
26	0.7745	52	-0.2037	78	0.4943
				79	0.1468
				80	-0.6837

Table B – 6 Bias values in hidden layer and output layer of ANN2

# of hidden node	Bias Value	# of hidden node	Bias Value	Bias Value in Output Node
1	-181.4959	41	147.4877	2.6924
2	-71.0591	42	129.7767	
3	-69.7252	43	132.8252	
4	-144.4541	44	212.8455	
5	250.2464	45	176.8440	
6	189.1236	46	33.3050	
7	6.7653	47	-127.0094	
8	169.0908	48	149.2782	
9	46.8078	49	114.5771	
10	150.7731	50	-184.7464	
11	-131.4381	51	162.0218	
12	-91.3937	52	-27.1591	

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# of hidden node	Bias Value	# of hidden node	Bias Value	Bias Value in Output Node
13	266.9031	53	23.5187	
14	-217.6377	54	-93.2337	
15	-134.9047	55	97.6323	
16	-137.9168	56	115.0168	
17	-93.0331	57	90.1217	
18	56.0254	58	113.2055	
19	132.1270	59	-103.2655	
20	11.6904	60	-252.1565	
21	-10.7772	61	70.2821	
22	-152.4212	62	-30.9789	
23	-126.0267	63	174.6084	
24	28.6410	64	135.0972	
25	-127.9998	65	88.6288	
26	10.3161	66	-38.0098	
27	144.5512	67	-2.1476	
28	-19.6292	68	-214.5020	
29	-115.1844	69	131.0886	
30	-77.8038	70	28.8709	
31	-145.4651	71	-18.0013	
32	-126.3133	72	-197.2369	
33	-111.9664	73	89.4770	
34	-229.4973	74	-211.0737	
35	-228.1739	75	-211.8332	
36	11.2810	76	176.9638	
37	-34.7334	77	-168.0378	
38	-121.1632	78	-185.2355	
39	21.4019	79	-165.9811	
40	-15.5181	80	-189.6632	

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Table B – 7 Weight values in hidden layer of ANN3

# of hidden node	Weekdays (x_1)	Rainy Season (x_2)	$PM_{10}(t)$ (x_3)	Relative Humidity (x_4)	Temperature (x_5)
1	3.5104	5.8057	-0.3025	0.4159	-1.0319
2	-3.229	-4.7304	-0.0124	-0.3812	2.3702
3	-13.2988	10.4958	-2.2902	-4.7892	19.0633
4	-7.0086	2.8861	-0.9571	-0.084	-0.5135
5	3.4228	-7.2084	1.148	-0.0318	-0.2163
6	5.2618	2.9126	-0.6543	4.1526	-14.5035
7	42.2979	42.7589	-0.2325	1.0709	-2.1831
8	0.8084	0.2302	-0.0922	0.0855	-0.4851
9	-1.7123	1.287	0.046	-0.0115	0.0751
10	-3.9964	5.5983	0.1904	-0.2773	-0.1415
11	-37.6961	27.6448	2.8042	2.8788	-12.2401
12	0.4201	-8.6839	-0.9062	-1.5919	-0.9742
13	-2.1184	-6.4583	1.7989	-0.1736	-0.2602
14	7.2299	-0.9857	0.0242	-0.0258	-0.0636
15	2.6917	-7.1171	0.1621	0.6941	-4.4905
16	1.6103	2.9877	-4.0359	-9.4258	39.8639
17	3.1676	5.1444	0.1945	0.2546	0.2812
18	-2.4934	-2.5718	-0.2861	5.6848	-19.9623
19	-0.2459	-0.6829	-0.2013	-0.0235	0.0884
20	18.9359	18.2258	1.6431	-0.0039	-2.586

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Table B – 8 Weight values in output layer of ANN3

# of hidden node	Weight Value	# of hidden node	Weight Value
1	-3.4040	11	0.4251
2	0.3325	12	-3.3737
3	0.1577	13	2.2446
4	-2.1832	14	2.3564
5	-2.7238	15	-2.4963
6	-1.7906	16	-0.4558
7	-0.9473	17	-4.3696
8	6.2145	18	1.4479
9	8.4258	19	-16.3152
10	0.8442	20	0.2279

Table B – 9 Bias values in hidden layer and output layer of ANN3

# of hidden node	Bias Value	# of hidden node	Bias Value	Bias Value in Output Node
1	28.5335	11	17.0919	0.2732
2	22.1079	12	21.1533	
3	1.3623	13	24.4755	
4	4.8915	14	-4.4706	
5	9.0121	15	14.3165	
6	1.5341	16	14.1085	
7	-25.4994	17	-28.9073	
8	16.9691	18	-0.7573	
9	-7.7152	19	0.9132	
10	11.7556	20	-0.1421	

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Table B – 10 Weight values in hidden layer of ANN4

# of hidden node	Minimum Mixing Height	0_3	PM_{10} (t)	Relative Humidity	Wind Speed
1	-0.0189	3.6635	-0.8574	-1.6452	-1.4671
2	0.0433	-0.1948	-0.2917	-0.0191	4.9604
3	-0.1257	6.6378	0.3101	0.8047	0.034
4	0.1398	-0.6763	-0.1712	0.2857	10.5634
5	-0.3858	-2.3454	0.0322	0.0617	6.0815
6	-0.172	0.2834	0.415	-0.1387	-0.1534
7	-0.0815	0.2769	0.066	1.3981	0.2088
8	-0.1992	-1.0388	0.8921	0.1788	4.3932
9	0.0379	-0.4674	-0.8775	1.3545	-4.8489
10	-0.0004	0.0161	0.0376	-0.0049	-0.1046

Table B – 11 Weight values in output layer of ANN4

# of hidden node	Weight Value	# of hidden node	Weight Value
1	-7.6876	6	-1.2168
2	-1.1517	7	-0.3465
3	-0.2081	8	-0.7443
4	-10.4639	9	-0.9514
5	-1.2610	10	22.6407

Table B – 12 Bias values in hidden layer and output layer of ANN4

# of hidden node	Bias Value	# of hidden node	Bias Value	Bias Value in Output Node
1	6.3151	6	-1.3933	-9.7237
2	9.8039	7	-3.3508	
3	6.9526	8	5.2158	
4	-9.9045	9	2.2436	
5	5.1713	10	1.8883	

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Table B – 13 Weight values in hidden layer of ANN5

# of hidden node	$PM_{10}(t)$ (x_1)	Relative Humidity (x_2)	Temperature (x_3)	Wind Speed (x_4)	Wind Direction (NW) (x_5)
1	0.002	0.1342	0.3188	0.1104	11.6881
2	0.3813	0.2599	0.5148	-2.1674	-0.0564
3	-0.2979	-0.399	0.1597	2.9923	0.1459
4	0.0633	0.0106	0.155	0.2176	-0.4071
5	-1.6113	-0.5691	-0.5239	-1.7343	-2.1103
6	-0.128	-0.5177	0.8098	7.3594	-12.9564
7	0.6814	-1.6296	-4.4422	-35.8071	49.8784
8	0.3076	0.1688	-4.5071	-2.895	13.0714
9	0.1789	0.2775	0.9553	-3.0849	-0.0689
10	-0.0111	0.0576	0.8941	5.1932	-1.9547

Table B – 14 Weight values in output layer of ANN5

# of hidden node	Weight Value	# of hidden node	Weight Value
1	-1.0746	6	-0.5006
2	13.0425	7	0.4252
3	1.8252	8	-2.1859
4	1.7061	9	12.5326
5	-0.4713	10	-40.5901

Table B – 15 Bias values in hidden layer and output layer of ANN5

# of hidden node	Bias Value	# of hidden node	Bias Value	Bias Value in Output Node
1	-18.7399	6	20.8552	13.8394
2	-14.3259	7	181.5925	
3	-13.7573	8	58.5012	
4	-8.6752	9	-16.0279	
5	105.4243	10	-22.6303	

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