University of Bahrain

College of Engineering



Department of Mechanical Engineering

Assessment, Control and Management of the Odor in Tubli Sewage Treatment Plant

A Thesis Submitted in Partial Fulfilment of the Requirements for the Master's degree in engineering management

Prepared by:

Noor A. Abu Hassan

20035248

Supervised by:

Elamin M. Elkanzi

Professor

December 2017

UNIVERSITY OF BAHRAIN

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Deanship of Graduate Studies

قسم الهندسة الميكانيكية
DEPT. OF MECHANICAL ENGINEERING
UNIVERSITY OF BAHRAIN

Thesis Discussion Committee Decision

Student Name: نور عبدالعظيم البرهم	Student ID: 20035218
Department: Mech. Engineering	College: Engineering
Program: Master in Engineering Management	
Thesis Title: Assessment, Control and Management of the odor in Tubli Sewage Treatment Plant	
Supervisor Name: Dr. Elamin M. Elkanzi	Student GPA:

The Discussion Committee met on 1/11/2017 (day and date) 1/11/2017 in Hall no. ___ (hall/room no.) ____. Upon discussing the student whose details are stated above in public, the discussion committee recommends the following:

The student awarded grade – A – In the thesis subject _____

☐ Without making any changes to the thesis
☑ After making the modifications attached with this decision

Discussion Committee Members Approval:

Name		Signature
1. Prof. E.M. Elkanzi	(Advisor)	
2. Prof. A. Rahim Agag	(Internal Examiner)	
3. Prof. Ismail Al Maday	(External Examiner)	

University of Bahrain
Deanship of Graduate Studies
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جامعة البحرين
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Dissertation Deposit Form

Author: Noor A. Shaheed Abu Hassan

Thesis Title: Assessment, Control and Management of the odor emissions from Tubli Sewerage Treatment Plant

Year: 2017/2018

College: Engineering Email: nabuhassan@yahoo.com

Department: Mechanical Contact No: 363102310

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Abstract

Odor associated with Tubli sewage treatment plant (STP) is common concern of the public. Due to the increase in development around the STP more people are exposed to the odors. The low detection threshold value for the odorous gases would make controlling the odor dispersion a quite challenging. In this research Tubli STP odor problem is evaluated using dispersion modelling and community survey. The assessment results showed that the populated surrounding area is fallen within the STP odor influential area therefore, odor management and control measures are required. The study recommend: improved odor management plan and installation of odor monitors at the facility fence-line. Moreover, the recommendation concluded that the most suitable control measures for Tubli STP would be a combination of installation of chemical scrubber for the inlet chamber and effective vegetative buffer zone which will dilute the odorous gases to considerable level.

Dedication

I dedicate this study for the future researchers in this field.

.

Acknowledgment

I thank all my family members for their constant support and patience during my studies in all my life. Many thanks to Mrs. Asma Jassim Murad, Assistant Undersecretary of Sanitary Engineering Affairs for her kind support and permission to conduct this study in the first place. Extended gratitude to my direct manager engineer Omar A. Ramadan for his support and guidance, also, for Mr. Rajith Chandran for his assistance and professional advice, and Mr. Ebrahim BuHassain, Mrs. Hanan Haider from Supreme Council of Environment.

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Chapter 1

Introduction to the Study

1.1 Introduction

1.2 Research Problem

1.3 Research Questions

1.4 Research Objectives

1.5 Research Significance

1.6 Research's Terminologies

Chapter 1

1.1 Introduction

Foul odor emitted from Tubli Sewage Treatment Plant (Tubli STP) in the Kingdom of Bahrain became a national concern in the past 15 years. Residents in Tubli Area and by-passers along the nearby main highway, Shaikh Isa Bin Salman, have raised several odor complaints[1] over the years. Although the government spent great efforts to address these complaints and operate the odor control unit located within the plant; foul odor problem associated with Tubli STP remains a source of nuisance to residents living in the vicinity of Tubli STP.

Tubli STP is the main and the largest STP in the Kingdom and it was built in the early eighties on an isolated land parcel away from residential areas and far away from sensitive receptors. Since then, Tubli STP was expanded three times and the buffer area around the plant reduced to few meters in some locations. Residential areas constructed south and west of the plant put their residents within the odor influence zone of the plant. There residents have complained about the foul odor emitted from the plant and described the odor at their residences as clearly or strongly detected. Recently rapid residential developments in Bahrain have dramatically increased sewage influent into Tubli STP which is currently operating beyond its design capacity. The large volume of influent to the plant has placed pressure on the operation and maintenance of the plant causing the increase of periodical emission of foul odor from different sources in the plant, namely tanker disposal area, inlet area (headworks), and the sludge thickening area.

Defining the extent of odor impact area known as plum and proposing odor control measures is instrumental to this study; a

[1] Based on MOWUP complaints register and newspaper headlines.

qualitative method is used to identify the limit through field survey targeting the potential sensitive receptors within the odor impact area. In addition the quantitative approach is adopted through using the air dispersion model, where the model will be validated using the results from field survey. Moreover, the effect of odor control measures will be evaluated using air dispersion model, the simulation of the reduced emission rate at the odor source will indicate the most feasible controlling method by containing FOP limits within the STP boundary.

1.2 Research Problem

Foul odor is reported by residents living in the nearby areas of Tubli Sewage Treatment Plant. Foul odor has been lately considered a major nuisance to the neighbouring areas. Odor emissions from the sewage treatment works can have detrimental impact on the quality of the local environment for people living close by. The usual effect of bad odors is nuisance, but in more serious cases may lead to nausea and headache and thus it is often regarded as an indicator for possible health risk. Odor pollution has distinctly different characteristics and is undoubtedly the most complex of all of air pollution problems. Assessing Tubli STP odor problem and trying to understand its extent would be the starting point to manage the problem and control its impact.

1.3 Research Questions

The proposed research is trying to find answers for the following questions: What is the area currently impacted by Tubli STP odor?; What are the sources of this odor?; How does the odor disperse in the atmosphere?; How to control the odor at the source to the acceptable level?

1.4 Research Objectives

1. To identify the impacted area by the foul odors (Foul Odor Plume) emitted from Tubli wastewater treatment plant.
2. To draw the odor plume and validate it with the public questionnaire results.
3. To simulate the odor dispersion in the atmosphere using an atmospheric dispersion model.
4. To propose methods to suppress the foul odor plume.

1.5 Research Significance

Over the years there were complaints raised by the residents of the areas adjacent to the STP, never the less, it was ever known that the Tubli STP odor was a source of inconvenience and concerns to the general citizens of the Kingdom of Bahrain. This was reflected in the national newspaper headlines and even the titles of the municipal and governor council's statements. Based on available researches and documents in Bahrain, Gulf and Arabian world none of the published researches addressed the odor dispersion associated with Tubli STP. This study will provide a better understanding and solution for the assessment, control and management of the odor.

1.6 Terminologies of the Research

1.6.1 Definitions of the research

Odor: the chemical composition that stimulate human olfactory reaction. In this research the "odor" will be used to of the Sewage distinguished smell emitted from the STP and particularly H_2S organic and non- organic smell.

Headworks: the inlet chamber in the sewage treatment plant, usually this is the first point to receive the sewage flow.

Odor Contour: is graphical representation of equal odor concentration lines. The odor contour maps used widely for odor impact assessment studies.

Ambient Air Quality Standard: are standards established to set the maximum limit of pollutant in outdoor air usually set by each country environment protection authority. In Bahrain Supreme Council of Environment (SCE) is the responsible authority to set this standard.

Sensitive Receptor: group of people located within the influence of the STP odor or all people who are potentially exposed to the odor.

1.6.2 Abbreviations of the Research

H_2S	Hydrogen Sulphide
BOD	Biological Oxygen Demand
DO	Dissolved Oxygen
MOWMU	Ministry of Works, Municipalities and Urban Planning
ppm	parts per million
ppb	parts per billion
OSHA	Occupational Safety and Health Administration
SEA	Sanitary Engineering Affairs
STP	Sewage Treatment Plant
SCE	Supreme Council of Environment
WHO	World Health Organization

Chapter 2

Theoretical Framework and Previous Studies

2.1 Litrature review

2.2 Previous studies

Chapter 2

Theoretical Framework and Previous Studies

2.1 Literature Review

Odors are very commonly associated with the sewage treatment plants. The processes of collection, transmission and treatment of the wastewater promote odor emission. Significant amounts of unpleasant odorous substances can be emitted from manholes and joints, also, the collection of the sewage effluent in the STP allow these odorous gases to be released in the atmosphere, which is the source of the problem and public complaints. The primary odours from sewage treatment works are biogenic, in which a product of the degradation of organic matter by microorganisms under anaerobic conditions is formed. The development of anaerobic conditions in sewage is often referred to as "septicity". Septicity can be onset by elevated temperature, high biological oxygen demand (BOD), high sulphate levels and the presence of reducing chemicals. Anaerobic activity leads to the production of methane, hydrogen Sulphide (H_2S), ammonia (NH_3), organic Sulphur, thiols (mercaptans), amines, indole and skatole (DEFRA, 2006), Table (2.1) shows common gases associated with the sewage treatment works. Each of these odorous gases have distinguished odor characteristic, for example Ethyl Mercaptan have the smell of decayed cabbage, where is the Methyle amine smell is more like fishy. Mollecular weight of the odorous gas plays main role in volatility (Sengupta, A. 2014) and therefore, the gases with high molecular weight is less disperse that the ones that have lighter molecular weight. For this reason it is most likely

that H_2S is often selected to be the reasons behind the STP's odor around the world. (DEFRA, 2006)

Table (2.1)
List of the odorous gases associated with the sewage treatment works.
(Tchobanoglous, G.et al, 2003)

Odorous Compound	Chemical Formula	Molecular Weight	Odor Threshold ppm_v^*	Characteristic odor
Ammonia	NH_3	17	46.8	Pungent, irritating
Chlorine	Cl_2	71	0.314	Pungent, suffocating
Crotyl mercaptan	CH_3-CH=CH-CH_2-SH	90.19	0.000029	Skunklike
Dimethyl sulfide	CH_3-S-CH_3	62	0.0001	Decayed cabbage
Diphenyl sulfide	$(C_6H_5)_2S$	186	0.0047	Unpleasant
Ethyl mercaptan	CH_3CH_2-SH	62	0.00019	Decayed cabbage
Ethyl sulfide	$(C_2H_5)_2SH$	90.21	0.000025	Nauseating odor
Hydrogen sulfide	H_2S	34	0.00047	Rotten eggs
Indole	C_8H_6NH	117	0.0001	Fecal, nauseating
Methyl amine	CH_3NH_2	31	21	Ptrid, fishy
Methyl mercaptan	CH_3SH	48	0.0021	Decayed cabbage
Skatale	C_9H_9N	131	0.019	Fecal odor,
Sulfur dioxide	SO_2	64.07	0.009	Pungent, irritating
Trimethyl amine	$(CH_3)_3N$	59	0.0004	Pungent, fishy
***Parts per million (weight by volume).**				

The hydrogen sulfide is known for its rotten egg smell, it is slightly heavier than air and have a very low odor perceiving threshold value (0.00047 ppm), as the human nose is able to perceive H_2S presented in low concentrations even lower than the standard health specifications, therefore, the unpleasant complaints in these cases may not be related to a health risk rather than associate with the odor tolerance of the residents. The standard recommended values for H_2S varies from country to another, many countries have short term standard for around 30 minutes that ranges from 6 to 210 ppb. For example the current California Ambient Air Quality Standard (CAAQS) for Hydrogen Sulfide is 0.03

ppm (30 ppb, 42 mg/m^3) for one hour, this was first adopted in 1969 and was based on the geometric mean of odor threshold measured in adults. Based on the literature the purpose of this experiment was to decrease odor annoyance. Since then no much variation in this standard were adopted, in matter of fact US Environmental Protection Agency (EPA) adopted the same standard and threshold values (Collins, J. et al., 2000). In the other hand, World Health Organization (WHO) recommends that in order to avoid substantial complaints about odor annoyance, 30-minute average hydrogen sulfide concentrations should not exceed 5 ppb, which is relatively low concentration and require odor control measures. However, the aim of the Ambient Air Quality Standard (AAQ) is to provide limits is which minimal adverse health effect can be expected. Supreme Council of Environment (SCE) in Kingdom of Bahrain recommended 30 ppb for one hour as ambient air quality standard for H_2S (Bu Hassin, E.; et al, 2011) Table (2.2) shows the AAQ adopted standard.

Table (2.2)

H_2S AAQS adopted in different countries (Bu Hussien, E., et al, 2011; Collins, J. et al., 2000).

Country	**H_2S concentration (ppb)**		
	Annual	Daily	Hourly
Bahrain	-	-	30
Kuwait	6	30	140
KSA	-	30	140
California	-	-	30
EU	-	100	-
Japan	-	40	100
Maine, USA	1	-	30[2]

2 The standard for 30 minutes

In the other hand, studies showed that 30 ppb of H_2S would be detectable by 83% of the population and would be discomforting to 40% of the population (Maine Department of Health & Human Services, 2006) discomforting is includes signs of nausea and headache. However, Hydrogen sulfide (H_2S) is an extremely hazardous, toxic compound it is a colorless, and high concentrations of H_2S can overwhelm olfactory glands, resulting in a loss of smell. This loss of smell can lead to a false sense of security that is very dangerous, most deaths incidents associated with acute H_2S exposure. The Occupational Safety and Health Administration (OSHA) which is an agency of United States Department of Labor have put standard for H_2S exposure, there is two types of limits: Permissible exposure limit (PEL) which specify 10 ppm for 8 hours working shift, 20 ppm as industrial ceiling limit, and 50 ppm for general industry peak limit. The other type is the immediately dangerous to life and health (IDLH), where concentration level interferes with the ability to scape. Table (2.3) shows H_2S concentration with the health symptoms and effects as listed by (OSHA,2017). Hydrogen Sulfide is toxic in high concentration and in acute exposure to the H_2S the nervous system get effected, at concentrations of 15 mg/m^3 and above, it causes conjunctival (eye membrane) irritation where it is affects the sensory nerves and the pain is diminished rapidly and the tissue damage is greater and at higher concentration (70 mg/m^3) serious eye damage is occurred. Where at higher concentration (above 225 mg/m^3, or 150 ppm), hydrogen sulfide has paralyzing effect on the olfactory perception so that the odour can no longer be recognized as warning signal. At concentration higher than 400 mg/m^3 there is strong stimulation of the central nervous system which lead eventually to unconsciousness and death (WHO, 2000). However,

Hydrogen Sulfide is an odorant causes nuisance at concentration is far below the health hazard thresholds value.

Table (2.3)

Health symptoms and effects for H_2S concentration, (OSHA, 2017)

H_2S concentration (ppm)	**Symptoms and effects**
0.00011 – 0.00033	Typical Background concentrations
0.01-1.5	Odor threshold (when rotten egg is first noticeable to some). Odor becomes more offensive at 3-5 ppm.
2 – 5	Prolonged exposure may cause nausea, tearing of the eyes, headaches or loss of sleep. Airway problems (bronchial constriction) in some asthema patients.
20	Possible fatigue, loss of appetite, headache, irritability, poor memory, dizziness.

There is no specific concentration in that specify the limits in which the odor nuisance starts to appear, half hour average concentration exceeding 7µg/m^3 are likely to produce substantial complaints. H_2S is very common in waste treatment works and it is originally produced when the Sulfate - reducing bacteria consume sulfate oxygen for organic process, these bacteria grow in a "slime layer" that coats normally the sewer's wetted perimeter, these bacteria use oxygen in the most readily available form: first, from elemental oxygen then, nitrate oxygen then, sulfate oxygen. As nitrate is usually not available in wastewater, bacteria will consume sulfate oxygen after depleting elemental oxygen, leaving bi-

sulfide ions to combine with hydrogen to form aqueous H_2S. (Sengupta, A., 2014). Figure 2.1 illustrates these reactions:

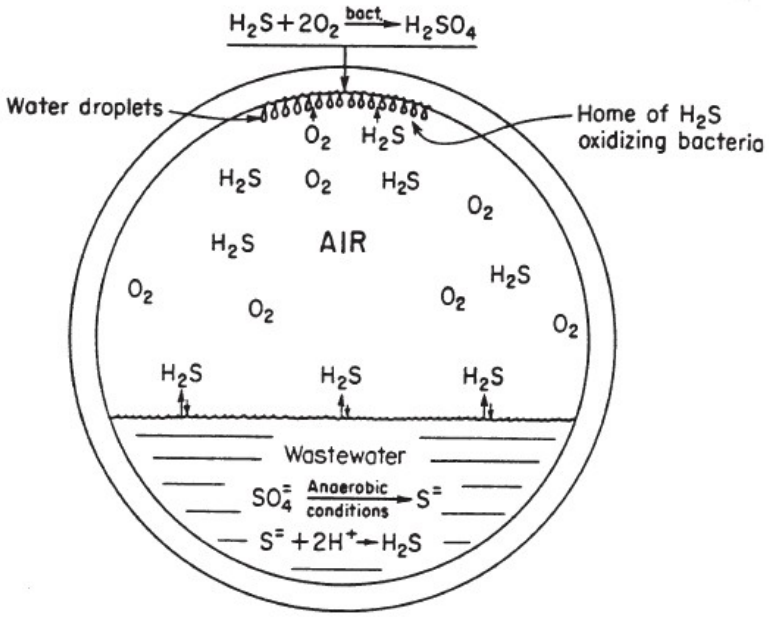


Figure (2.1)

H_2S production Reactions process (Churchill, P.1999)

The emission of the H_2S compounds from the water to air phase depends on a number of other characteristics like the temperature, pH level of the medium and other factors. Turbulent wastewater also facilitates the release of H_2S to the atmosphere. The rate of sulfide production in wastewater depends on different factors identified as follows:

1) Concentration of organic matter and nutrients:

A high concentration of organic matter will increase the bacterial growth and thus deplete dissolved oxygen DO and increase the sulfide production. This can be measured by the Biochemical Oxygen Demand (BOD) count.

2) Level of dissolved oxygen (DO):

The dissolved oxygen level in the wastewater is the determining parameter for breaking down of the carbonaceous matter occurring either in an aerobic or anaerobic situation. Aerobic bacteria generally dominate the outer layer of the biofilm (the coated layer) at a DO concentration more than 1mg/l. On the other hand, an increased DO will reduce the sulfide formation by limiting the food supply to the anaerobic bacteria. A low level of DO favors growth of anaerobic microorganisms and subsequent sulfide production. In the other hand, if the oxygen concentration is high, there will be no sulfide build-up; if it is low, then sulfide build-up is expected.

3) pH of the wastewater:

The pH is the controlling factor for dissociation of hydrogen sulfide in to dissolved hydrogen sulfide gas (H_2S), hydrogen sulfide ion (HS-), and sulfide ion (S2-) in wastewater. This distribution of dissolved H_2S: HS- is approximately 50:50 at pH 7, whereas at pH 6, the distribution changes to 90 percent dissolved H_2S: 10 percent HS-in wastewater approximately. This dissolved hydrogen sulfide is released to the atmosphere from the solution and is influenced under turbulent conditions. As it is rare to achieve an equilibrium condition, therefore, H_2S concentration in a sewer atmosphere is difficult to predict on the basis of sulfide concentration in wastewater in a sewer. In a field investigation found that a decrease in pH increased the hydrogen sulfide gas emission in a sewer atmosphere (Sengupta, A. 2014).

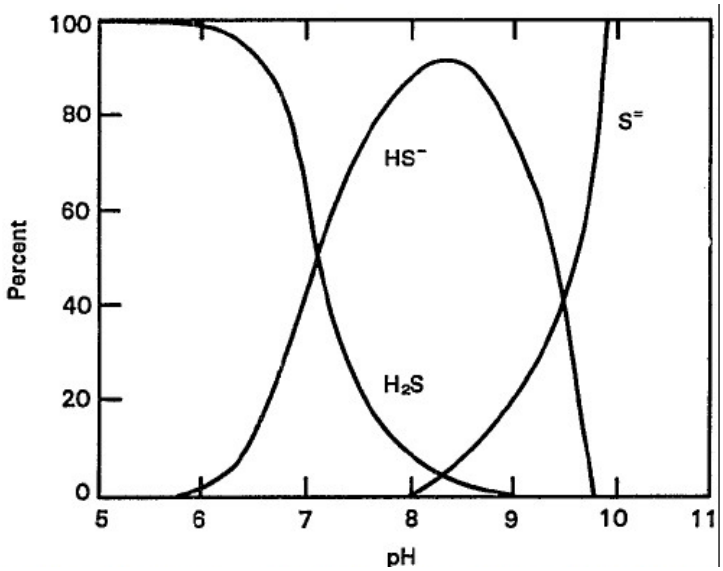


Figure (2.2)

H_2S gas generated based on the pH level in Sewage effluent.

Many studies and experiments indicate that the main source of the odorous emissions in a wastewater plant is the first treatment stage, while the odorous emission is reduced while the treatment stages are progressed, this indicate that the collecting system has more influence in odor formation than treatment stages (Carrera-Chapelo, F. et al, 2014). The main odorous emissions are emitted from the inlet areas, especially when the incoming sewage is septic. Therefore, primary tanks will promote the odorous emission formed by sewerage system where these tanks are in direct contact with atmosphere and also, by means of the turbulence generated at the inlet or outlet weirs, in addition, odorous emissions are more emitted in sludge handling and treatment stages. (Talaiekhozani, A., et al, 2015; Sengupta, A. 2014; Tchobanoglous, G., et al, 2003). Odorants in the wastewater can be released to atmosphere by mass transfer from the liquid phase to air. This can happen whenever wastewater is in direct contact with the atmosphere, particularly in open process units at wastewater treatment plants. It is very essential to be able

to quantify the odors in order to manage and control the odor at the first place, The quantification of the problem allow the operator and the plant designer to make informed decisions on the choice of processes, odor treatment technology, and any modification on the odor control schemes (Gostelow, P. et al, 2000). Odors may be difficult to measure, the response of the human is subjected to many attributes that are related to the person himself. Although the understanding of the odor existing had advance over the years, the link between odorant properties and odor perception is not clear, and this is due to the lack of comprehensive understanding for the olfaction. (Sengupta, A. 2014; Gostelow, P. et al, 2000) factors like age, gender, and personal sensitivity to perceive and distinguish the odor is making the quantification of the odor a more complicated issue rather than a direct procedure. Odors usually are represented by different type of expressions, for example the odor is the perceived effect of the detected chemical compound, where the odorant is the chemical compound responsible of the odors. The odor dimensions which can be measured usually fall in the following four groups:

a. Concentration: the physical concentration of odorants or the chemical compound.
b. Intensity: magnitude of perceived sensation
c. Characteristics: the properties that distinguish one odor from another.
d. Hedonic tone: scale of the sensation of odor perceiving like pleasantness or unpleasantness.

Odor concentration is the most frequently measured parameter and can be measured analytically or by sensory means. However, Odorant concentration is the only odor dimension that can be measured

analytically. The remaining parameters can only be measured using sensory methods. Where the intensity is usually represented using a subjective category scale (i.e. faint, moderate, and strong). Alternatively, Concentration and intensity are related where the perceived intensity increases with increasing odor concentration, although the relationship is not linear (Gostelow, P. et al, 2000). There are two approaches for odor measurement that are usually referred to: the analytical and sensory measurements. The Analytical measurements concern the physical or chemical properties of the odorous compounds, the advantage of the analytical approach is the objectivity, repeatability and accuracy, moreover, odorants may be present in very small concentrations, where the limit of analytical detection may be below the threshold of human smelling capacity. However, it is difficult to relate analytical measurements to the intensity of odor as perceived by a human observer especially for the cases of odors mixtures. In many cases, a particular odorant may be dominant and can give an indication of the overall odor concentration. This is certainly the case for many sewage treatment odors, as H_2S is often present in concentrations far higher than other odorants (Sengupta, A. 2014; Capelli, L. et al, 2013). In the other hand, the Sensory measurements is to employ the human nose as the odor detector, this will allow direct relating to the properties of odors as experienced by humans. There are many factors other than the properties of the odor sample itself that may influence the perception of an odor the most principal factor is the variability in the sense of smell between different observers. This is usually overcome to a certain extent by using a panel of several observers, the result being expressed by some measure of central tendency of the individual results. Factors such as the order in which samples are presented, the environment in which the testing takes place

and the flow rate of the carrying gas stream are all important. Under calm meteorological conditions, odorous gases that develop at treatment facilities tend to hover over the source point of generation like: inlet unit and sludge thickening facilities, because the odorous gases are denser than air, meteorology plays major role in dispersion of the odors. The dispersion of odors is the reason behind residence complaints, depending on the local meteorological conditions, it has been observed that odors may be measured at undiluted concentrations at great distances from point of generation. (Tchobanoglous, G.; et al, 2003). Metrological data like temperature, wind speed and direction, humidity, solar radiation are all influential in odor dispersion. Ground level concentration of contaminants are primarily controlled by two meteorological elements: wind direction and speed, which transport the particles, and turbulence and mixing highlight of the lower atmosphere boundary layer, which mainly influence the dispersion. Material emitted into the atmosphere is moved by the general or man wind but it is the turbulent fluctuations that cause its dispersion and dilution away from a source. It is important to note that for a given wind speed and direction and a given emission the turbulence in the atmosphere can give rise to a wide range of possible downwind pollution distributions. The level of turbulence in the atmosphere varies significantly with different atmospheric conditions. Hot summer days result in intense convective turbulence being generated by the heating of the lower atmosphere by the ground. Moreover, strong winds result in mechanical turbulence arising from interactions of the wind with the ground and obstructions such as trees and buildings. Different meteorological conditions result in different behavior of pollutant emitted into the atmosphere (Simms, K.L.; et al, 1999). To study an odor impact especially those from wastewater plants, there are

one or two approaches: odor mapping and dispersion modelling studies, in addition to the community survey. Odor mapping approach involves taking measurements of H_2S concentration at various locations near to the waste-water treatment site and contouring the results. When using the community surveys the level of annoyance of the STP odor is assessed based on the population responses. While using the dispersion modeling defines the relationship between the emission source and the receptor using mathematical techniques using matrix inversion solving methods. The odor impact studies are prepared to verify the compliance of the facility emissions with the standard allowable concentration. Dispersion model plays effective role in predicting the concentration in a given location. Moreover, for new or proposed odor emission sources, dispersion modeling is the only method to determine compliance, since the potential odor emission source does not yet exist. In modeling applications, a source may be characterized as a point, area or volume source. There are several type of sources to be identified, in general: the source type might be point, area, and volume. A point source is characterized as a vertical discharge through a stack for vent. It is described by the temperature and velocity of the exhaust gas, effective diameter of the open area, and release height. An area source is characterized as open area where emissions are released passively through the open area, as would be the case for a quiescent basin or landfill or actively as would be the case for an aeration basin or biofilter. It is describe by the horizontal length and width of the surface area, and effective release height. A volume source is characterized as a horizontal release or vent that cannot be defined as either a point or area source. It may be louver vent on the side of a building or mobile source. It is defined as having an initial horizontal and vertical dimension, as may be

described in the modeling guidance, and initial release height. The transport of the odor phenomenon has been termed the puff movement of odors. The most common method used to mitigate the effects of the odor puff is to install barriers to induce turbulence, thus breaking up and dispersing the cloud of concentrated odors, and/or to use wind generators to maintain a minimum velocity across the source. Most of odor regulation over the world is defined based on the application of dispersion modelling. (Capelli L.; et al, 2013). Modeling the odor dispersion from the source needs the characteristics of the emissions but also the meteorological conditions, typically wind direction and atmospheric stability. It is plays major role in odor dispersion of the STP. (Carrera-Chapelo, F.; et al, 2014) An atmospheric model is a mathematical representation of the dynamical processes, physical, chemical, and relative, producing in the atmosphere. Moreover, even the most sophisticated atmospheric dispersion model cannot predict the precise location, magnitude and timing of ground-level concentrations with 100% accuracy. However, most models used today, especially the US EPA approved models, have been through a thorough model evaluation process and the modelling results are reasonably accurate, provided an appropriate model and input data are used. There are five types of models for dispersion based on the theory:

a. Simplest models are analytical stationary plume models, which are Gaussian models (turbulent dispersion is parameterized) with empirical coefficients derived from experimental campaigns (traditional ones / very cheap) Gaussian models. The meteorological conditions are assumed to remain constant during the dispersion from source to receptor, which is effectively instantaneous. Emissions and meteorological conditions can vary from hour to hour

but the model calculations in each hour are independent of those in other hours. Due to this mathematical derivation, it is common to refer to Gaussian-plume models as steady-state dispersion models.

b. More advanced are hybrid models, dispersion is parameterized from meteorological data giving information about thermal and mechanical structure of the lower atmospheric layers. Puff Models, representing a plume by a series of independent elements evolve in time as a function of temporary and spatially varying meteorological conditions.
c. Lagrangian practical models and Evlerin grid models (3D Models) more advanced tools for atmospheric dispersion simulation. First simulate movement of particle in the air 3D turbulence field. Then numerically solve the diffusion equations of the pollutant emitted in 3D subdivided in grids of variable dimensions.
d. Most Complex models are fluid dynamic models solve 3D equations for wind, temperature, humidity, and concentrations.

The new generation dispersion models adopt a more sophisticated approach to describing diffusion and dispersion using the fundamental properties of the atmosphere rather than relying on general mathematical approximation. This enables better treatment of difficult situations such as complex terrain and long-distance transport. There are many types of software for dispersion model; the following are the most common used in the industry: 1) AERMOD, 2) CALPUFF, 3) ISCST3, 4)AUSPLUME, 4)CTDMPLUSE, and 5)BREEZE. AERMOD and CALPUFF are most common used software. AERMOD is a steady-state plume model that incorporates air dispersion based on planetary boundary layer turbulence structure and simple/ complex terrain effect (Carrera-Chapelo, F., 2014). There are several methods to manage and reduce the sewage odor, it

worth to mentioned that, although that the chronic odor problems at treatment facilities, approaches to solving these problems may include:

(l) Control of odor-causing wastewaters discharged to the collection system and treatment plant that creates odor problems.

(2) Control of odors generated in the wastewater collection system.

(3) Control of odors generated in wastewater treatment facilities.

(4) Installation of odor containment and treatment facilities.

(5) Application of chemicals to the liquid phase.

(6) Use of odor masking and neutralizing agents.

(7) Use of turbulence inducing structures and facilities.

(8) Establishment of buffer zones.

For large area sources following methods can be used to reduce odor complaints, and controlling the odor emissions:

1) Excluding development close to the site: development close to the site is to be excluded. A reasonable "buffer zone" around the area sources has to be determined. The actual size of the zone depends upon a number of factors, including the size of the area from which odor emanates, the intensity of the odor being emitted, the duration and frequency of the odor emissions, the actual process being undertaken, the topography of the site, the weather conditions that prevails at the site. Green belt development in the buffer zone may help at least partially to mitigate / obfuscate the odor.

2) Ensuring that the operation is carried out under the best management practices**:** best management practices (BMP) vary depending upon the industry producing the odor. For all new developments, BMPs starts with the site selection and the building of the facilities.

3) Nozzles, sprayers and atomizers that spray ultra-fine particles of water or chemicals can be used along the boundary lines of area sources to suppress odors. Rotary atomizer is one such technique widely recommended for effective control of odor in case of area sources. The Atomizer uses centrifugal action by a spinning inner mesh to force droplets on to an outer mesh which "cuts" the water into atoms. The rotary atomizer produces millions of microscopic droplets of water up to 238 billion from single little droplets that are thinner than a human hair and a fine spray which covers up to 30 meters. This creates a fine mist, which is more effective with minimal use of water and electricity. There are a large number of chemicals and proprietary products that claim to reduce odor when they are applied to area sources. Atmospheric odors that are contained in a restricted area can be oxidized by atomization of the chlorine dioxide. Odor from sources such as holding ponds, lagoons, and sewage pre or post treatment effluent can be controlled by atomized spray of chlorine dioxide.

To reduce odor, chemicals have to be applied over very large area, the cost of materials and labor would be very high. The large quantity of these compounds required could cause pollution. The spray / atomizer techniques are used to conceal or mask odor also from building and fugitive sources.

2.2 Previous studies

Information from previous studies provided good references for this study, reviewing the most related papers help to develop the assessment plan as well as to identify the design parameters and the measurements tools and techniques. There was several papers reviewed however, the most relevant ones are described below with the most important findings.

Reference title: "Odour Assessment for Chelmsford Water recycling center"; Shafibeik O.; Anglian Water Services Ltd, England, 2015.

An existing sewage STP located in Chelmsford, England were assessed against the odorous emissions, the researcher preformed a complete odor risk assessment where the odor sources identified following at the site using portable Jerome gold film resistance meter for the location where H_2S gas is less than 2 ppm and a portable custodian gas detector fitted with pumped aspirator is used for the areas where more than 50 ppm H_2S gas concentration is expected. For the odor impact assessment the researcher used dispersion modelling to verify the areas impacted by the STP odorous emissions, AERMOD (release 8.8.9) was used. The meteorological data used were for three consecutive years. For H_2S gas measurements the summer adjustments, the researchers multiplied the data they have by a factor of 2. The measurements then modelled and the modelling results were also compared with the complaints registered between tear 2008 to 2014 a total of seven years.

Benefits of the study: in this study the STP located in near residential areas, the purpose of the study was to identify the area impacted by the STP odorous emissions and to evaluate whether the area surrounding the

STP can be invested for developments. The researcher used AERMOD to model the H_2S gas dispersion as the odor indication. The researcher also compared the results with the pervious complaints registry and confirmed that based on the odor modeling complaints fall within the impacted area. Assessment methodology used in this study was adopted for the odor assessment of Tubli STP where: Dispersion modelling is used as well as historical complaints review. In the other hand the units used to describe the odor was in European odor units (OU_E) where all the measurements taken for Tubli STP were in ppm.

Reference: "Comparison of Methods Used to Measure Odour at Wastewater Treatment Plant Fencelines'', Witherspoon, J.R. and Barnes, J.L., Ch2mHill,Inc, 2004.

In this study the researchers performed an odor impact assessment for a STP located in USA using dispersion modelling that used source measured inputs. The model predicted results where verified at fenceline using data gather using the ambient odour measurements and metering devices. The researcher used Dilution to threshold ration (D/T) to measure the odor samples collected on site. The researchers hope that the study would help prioritize odor control works for the odor sources.

Benefits of the study: In this study the researcher used the ambient air and meter devices to verify the modelled results, this study concluded that these tools are useful and sufficient to understand the impact of the STP odor impact in area surrounding, for Tubli STP odor assessment this approach is adopted, modelled valued compared with field measure data.

Reference: "Odour measurements for sewage treatment works"; Gostelow, P.; Parsons, S.A. and Stuetz, R.M. school of water sciences, Granfield University, 2000.

In this study the researchers performed detailed comparisons between sensory and analytical measurements, where in sensory measurements the human nose were employed to detect the odor. The researches provided six categories for the odor level scale starting from no odor to very strong odor is perceived. The researcher stated that these scales are ordinal and that the differences between the values are not likely to be equal.

<u>*Benefits of the study:*</u> the scale used in Tubli STP odor assessment is the based on the six scales provided in this paper. These scales are the bases of the community surveys used.

Reference: "Odour Nuisance & Dispersion Modelling: an objective approach to a very subjective problem"; Simms, K.L.; Wilkinson, S.; Bethan, S. Cambridge Environmental Research consultants Limited. 1999.

In this study the researchers used two approaches to draw the contour map of odor which is represented by H_2S, the first approach is odor mapping and the other is dispersion modelling, the odor mapping involve taking readings of the concentrations at various locations on or near to the STP, however the researchers suggest that this method have its own limitation as these values shows the ground level only and provide existing condition rather than prediction. In addition in this study the researchers present the main factors that influence the odor nuisance

dispersion and how using a dispersion modelling may help the prediction of potential complaint occurrence. The researcher also focuses on the meteorological condition and how the wind direction plays major role in odor dispersion. Also, the researchers discussed the effect of buildings on the odor dispersion and how the existing buildings in the vicinity of the STP have direct effect on the odor dispersion. The study recommends that the buildings to be modelled separately.

Benefits of the study: this study cover to approaches for odor impact studies, with each method advantages and disadvantages, for Tubli STP assessment dispersion modelling is used and field measurements collected to be compared with the predicted values. However, the surrounding buildings were not part of the modelling practice, the study recommended to include modelling the buildings separately.

Reference title: '' Odour Impact Assessment by Community Survey"; Brancher, M. and Lisboa H., Journal of Chemical Engineering Transaction, Volume 40, 2014.

This study is performed to assess the odor impact on the area surrounding an existing operational food factory, the researcher used the community surveyed to identify the extend of the area impacted by the odor, the area identified by a 2 Km radius circle and the population sample where estimated for 395 respondents. The researchers divided the area into five sub-areas to monitor and assess the community responses.

Benefits of the study: the community survey is a useful tool to assess the odors. The population sample for the assessment is identified as minimum 395 respondents. The measurements parameters used for the

community survey were several like: annoyance level, hedonic tone, period of time at which the odor annoyance is occurred in addition to the connection between the response and the weather condition. For surveying the area around the odor sources in order to perform an odor assessment the minimum population sample is identified using the statistical equation with the tolerable error of 5%, the same was used for Tubli community questionnaire.

Subject	Author	Findings	Comments	Reference
1. Odor (H_2S) formation	Churchill, P. and Elmer, D. (1999)	Most of H_2S emissions formed in the collection system in anaerobic activities, and it is released in the STP where the impact of the odorous emissions are larger due to the process turbulence and direct exposure to the atmosphere.	In this paper the author descript the process of the H_2S formation with more details, focus of the H_2S as the source of the odor.	Hydrogen Sulfide odor control in wastewater collection systems. Churchill, P., & Elmer , D. (1999).
	Talaiekhozani, A., Bagheri, M., Goli, A., Khoozani, M. (2015)	Sulfur cycle, H_2S emission to air. An overview of principles of odor production, emission, and control methods in wastewater collection and treatment systems.		

Subject	Author	Findings	Comments	Reference
2. Community Survey	Brancher, M. and Lisboa H.,	Community survey is a useful tool to assess the odors. The population sample for such assessment is identified as minimum 395 respondents with tolerable error of 5%. there are connection between the odor annoyance and the weather condition.	This approach is adopted in Tubli STP study.	Odour Impact Assessment by Community Survey"; Brancher, M. and Lisboa H., Journal of Chemical Engineering Transaction, Volume 40, 2014.
3. STP Odor impact studies.	Simms, K.L.; Wilkinson, S.; Bethan, S.	This study cover to approaches for odor impact studies, with each method advantages and disadvantages, the first method is odor mapping and the other one	For Tubli STP assessment dispersion modelling is used and field measurements collected to be	Odour Nuisance & Dispersion Modelling: an objective approach to a very subjective problem"; Simms,

Subject	Author	Findings	Comments	Reference
		is dispersion modelling. The study used H_2S gas to be representing the odor.	compared with the predicted values. However, surrounding buildings were not part of the modelling practice, the study recommended to include modelling the buildings separately.	K.L.; Wilkinson, S.; Bethan, S. Cambridge Environmental Research consultants Limited. 1999.

Subject	Author	Findings	Comments	Reference
4. Methods to measure the odorous gas emissions	Capelli, L., Sironi, S., Rosso, R., and Guillot, J. (2013).	There are several methods to measure and quantify the odors in wastewater plants. In this paper the researchers describe each method and compare their outcome.		Measuring odours in the environment vs. dispersion modelling: A review", Journal of Atmospheric Environment, volume (79), Pages 731-743
5. STP odor source.	Carrera-Chapelo, F., Donoso-Bravo, A., Souto, J.A., Filipi, G.(2014).	Primary treatment and sludge treatment are the main odor sources in a plant.		Modeling the Odor Generation in WWTP: An Integrated Approach Review. Water, Air, and Soil Pollution, Springer Verlag, 2014, 225, pp.1 - 15.

Subject	Author	Findings	Comments	Reference
6.Validating the dispersion model	Capelli, L., Sironi, S., Rosso, R., and Guillot, J. (2013).	This paper presents several measurement methods in addition to the validation approaches.		Measuring odours in the environment vs. dispersion modelling: A review", Journal of Atmospheric Environment, volume (79), Pages 731-743
7. Sensory and analytical measurements.	Gostelow, P.; Parsons, S.A. and Stuetz, R.M.	In this study the researchers performed detailed comparisons between sensory and analytical measurements. The researches provided six categories for the odor level scale starting from no odor to very strong odor is perceived.	The six scales is used in Tubli STP odor assessment for the community survey.	Odour measurements for sewage treatment works”; Gostelow, P.; Parsons, S.A. and Stuetz, R.M. school of water sciences, Granfield University, 2000.

Subject	Author	Findings	Comments	Reference
8. Dispersion model and verification by field data.	Witherspoon, J.R. and Barnes, J.L.	In this study the researchers performed an odor impact assessment for a STP located in USA using dispersion modelling The model predicted results where verified at fenceline using data gathered using the ambient odour measurements and metering devices.	In this study the researcher used the ambient air and meter devices to verify the modelled results, this study concluded that these tools are useful and sufficient for Tubli STP odor assessment this approach is adopted.	Comparison of Methods Used to Measure Odour at Wastewater Treatment Plant Fencelines'', Witherspoon, J.R. and Barnes, J.L., Ch2mHill,Inc, 2004.

Subject	Author	Findings	Comments	Reference

Chapter3

Methods and Procedures

3.1 Research methodology

3.2 Research procedure

3.3 Data collection

3.4 Initial Investigation

Chapter 3

Methods and Procedures

3.1 Research methodology

The main aim of this research is to assess, manage and control the odor problem associated with the sewage treatment works at Tubli STP. Therefore this research consist of two parts the first part is assessing the odor associated with Tubli STP and the other part is studying the feasibility of odor management and controlling measures. In order to assess the odor first the odor needs to be quantified, there is several techniques to quantify the odor emissions all these techniques are summed under the analytical and sensory measurements, both approaches will be used for the odor assessment in this research. The current odor emissions inside the STP is carefully quantified and then compared with the average gas levels for similar plants. Following the quantification of the odor emissions the dispersion model will be utilized in order to draw the odor contours. The odor contours drawn by the model will mimic the dispersion of the odor emissions from the source points inside the STP to the area surround. In attempt to examine how residents of these surrounding area is perceiving the STP's odor emissions a questionnaire is distributed to the residents to record their perception of the odor extent. Based on resident's responses the odor contour lines will be drawn. Finally, both drawings will be compared and a more comprehensive odor contour map will be presented.

3.2 Research procedure

The procedures used in the development of this research were divided into three parts, the first part focused on the complaints register

and the analysis of the complaints during the past ten years. Number and occurrence of the complaints often provide indication for the severity of the problem, if any, although in some cases residents do not raise complaint for some reasons, especially if the problem is existed for long time (DEFRA, 2006). The second part of assessment procedure focuses on the drawing the odor contour map using the atmospheric dispersion model. The third part of the assessment procedure represents statistical approach to identify the impacted area by the odor and the resident's perceivable range for the odor associated by Tubli STP. Eventually, the research is concluded by theoretical review for the available odor control and mitigation measures in order to provide critical review for these means with respect to Tubli STP capacity and condition.

Complaints analysis

Complaints for Tubli STP odor related issues are registered in the MOWMU public relation (PR) unit, these complaints usually received personally by the STP's surrounding areas residents or collected from the newspapers articles. In some cases these complaints are raised by the governor council representatives. The registered complaints were requested from the PR and were reviewed to identify the most frequent complaints location, these locations will be compared later with the odor contour maps produced by the dispersion model and compared by the questionnaire.

Odor contour maps

In order to identify the impacted area by the Tubli STP odor emissions and draw odor contour map. The odor contour map is graphical

representation of equal odor concentration lines. The odor contour maps used widely for the odor impact assessment when:

1. Proposals for a new and expansion of an existing odorous facility.
2. Proposals for sensitive land use near an existing odorous facility.
3. Investigation of complaints of odor from existing facilities.
4. Setting of license conditions for new facility.
5. Buffer definition studies for the land zone identification.
6. Assessing odor during contaminated site remediation.
7. Determination of odor emission rates before and after a plant upgrade in order to quantify emission reduction.

Using dispersion modelling

In order to draw the odor contour map for Tubli STP dispersion model is used. Atmospheric dispersion modelling is the mathematical simulation of how a pollutant disperses in ambient atmosphere. The software use and solve mathematical equations and algorithms which simulate and mimic the pollutant dispersion. The dispersion models are used to estimate or to predict the downwind concentrations of air pollutants emitted from sources such as wastewater treatment plants, industrial plants and vehicular traffic (Shafibeik,A. 2015). There is several well developed dispersion model software; the selection of the model type is depend on the requirement of the model use, location size, sensitivity of the pollutant and the associated potential risks. According to Environment Protection Agency (EPA) AERMOD is recommended and approved for the odor impact assessment study. AERMOD is a steady state plum model where it the concentration distribution is assumed to be Gaussian in both vertical and horizontal direction. (EPA, 2016), also, AERMOD is suitable for the simple and complex terrine locations and for

receptors located less than 20 kilometer distant from the odor resource and the coastal fumigation is neglected. Therefore AERMOD (8.8.2) is used for simulate the odor (H_2S) dispersion. The model input requirements includes: historical meteorological data, odor emission rates from individual odor sources, local terrine data, odor source location, characteristics and dimensions (EPA, 2004).

Using the questionnaire

Moreover, to have a more realistic overview of the actual perceiving range to Tubli STP odor emissions, the community questionnaire is used; the questionnaire is prepared by the researcher to measure the level of odor that the respondent perceives generally as well as during the summer season. The researcher hope that this would represent the two modelling scenario of the odor perceiving in normal case scenario and summer as the worst case scenario. The respondent is requested to choose from a scale of six levels starting from no odor as the lowest level in the scale up to very strong odor is perceived. The scale used six levels or categories: 1) no odor is perceived, 2) odor is barely perceivable, 3) odor is faintly perceivable, 4) odor is clearly perceivable, 5) odor is strongly perceivable and 6) odor is very strongly perceivable. Appendix 1 shows the questionnaire model distributed to the residents in areas surrounding the STP, located within 2.5 km in radius where the STP is centre, these areas are identified as follow: Tubli, Zinj, Bilad Alqadim, Um Al Hassam, Alkawara, Adari, Isa Town and Nabih Saleh.

3.3 Data collection

The collection of data is an important stage in any research the main purpose of this step to understand the existing condition and identify the major challenges before performing the assessment. For this study the information was collected through the following channels:

a) Site visits and visual inspection for the STP facility and different treatment stages.
b) Complaints register and previous H_2S gas measurements from MOWMU.
c) Field measurements inside Tubli STP facility and random selected locations surrounding the STP.
d) Community questionnaire; dedicated for the residents of the areas surrounding Tubli STP.

Pervious H_2S gas measurements

Supreme Council of Environment (SCE) was approached for any historical H_2S measurements in area surrounding Tubli STP these data will enable the understanding whether H_2S gas concentration is detectable in area surrounding the STP and at what concentration. The data received from the SCE is showing in table 3.1 this data show gas concentration measured between year 2009 to 2011 by two monitoring stations located in Nabih Saleh more than 3 kilometers distanced from Tubli STP and in Manama area located at distance more than 5 kilometers, as shown in Figure (3.1)

Table (3.1)

H_2S gas concentration measured by SCE between the years 2006- 2011.

Year	Month	Location	H_2S (ppb)		
			Mean	Max	# Ex.
2006	January	N/A	N/A	N/A	N/A
	February	N/A	N/A	N/A	N/A
	March	N/A	N/A	N/A	N/A
	April	N/A	N/A	N/A	N/A
	May	N/A	N/A	N/A	N/A
	June	N/A	N/A	N/A	N/A
	July	MANAMA	4.0	25.9	0.0
	August	MANAMA	4.6	41.6	2.0
	September	MANAMA	N/A	N/A	N/A
	October	MANAMA	6.3	41.6	2.0
	November	MANAMA	14.8	63.4	11.0
	December	MANAMA	9.0	29.1	0.0
	Annual (max)		8.5	63.4	15.0
2007	January	MANAMA	6.4	24.9	0.0
	February	MANAMA	1.6	20.3	0.0
	March	MANAMA	1.2	11.0	0.0
	April	MANAMA	N/A	N/A	N/A
	May	MANAMA	N/A	N/A	N/A
	June	MANAMA	16.6	26.7	0.0
	July	MANAMA	N/A	N/A	N/A
	August	MANAMA	N/A	N/A	N/A
	September	MANAMA	N/A	N/A	N/A
	October	MANAMA	N/A	N/A	N/A
	November	MANAMA	1.9	16.6	0.0
	December	MANAMA	N/A	N/A	N/A
	Annual (max)		3.7	26.7	0.0
2008	January	MANAMA	8.1	20.5	0.0
	February	MANAMA	4.4	22.8	0.0
	March	MANAMA	6.9	60.2	3.0
	April	MANAMA	4.7	29.3	0.0
	May	MANAMA	5.1	20.8	0.0
	June	MANAMA	4.0	44.6	2.0
	July	MANAMA	3.3	33.6	1.0
	August	MANAMA	12.0	33.5	1.0
	September	NABIH SALEH	22.0	893.1	70.0
	October	NABIH SALEH	11.7	196.1	43.0
	November	NABIH SALEH	9.0	37.4	1.0
	December	NABIH SALEH	14.9	118.1	48.0
	Annual (max)		8.79	893.1	169.0

Table (3.1)

H_2S gas concentration measured by SCE between the years 2006 -2011

Year	Month	Location	H_2S (ppb)		
			Min.	Max.	#Ext.
2009	January	NABIH SALEH	9.6	167.5	19.0
	February	NABIH SALEH	11.9	69.6	56.0
	March	NABIH SALEH	22.4	497.8	43.0
	April	NABIH SALEH	20.1	816.3	91.0
	May	NABIH SALEH	56.8	941.2	201.0
	June	NABIH SALEH	109.3	1045.0	374.0
	July	NABIH SALEH	14.7	239.4	27.0
	August	NABIH SALEH	N/A	N/A	N/A
	September	NABIH SALEH	21.8	25.3	0.0
	October	NABIH SALEH	14.7	133.9	18*
	November	NABIH SALEH	12.0	332.5	42.0
	December	NABIH SALEH	8.9	163.3	24.0
	Annual (max)		26.42	1045.0	877.0
2010	January	NABIH SALEH	10.7	150.4	39.0
	February	NABIH SALEH	10.9	111.5	18.0
	March	NABIH SALEH	26.5	793.0	102.0
	April	NABIH SALEH	24.5	444.1	135.0
	May	NABIH SALEH	16.4	195.0	85.0
	June	NABIH SALEH	15.3	117.8	61.0
	July	NABIH SALEH	10.8	92.9	20.0
	August	NABIH SALEH	19.2	508.2	53.0
	September	NABIH SALEH	N/A	N/A	N/A
	October	NABIH SALEH	26.85	57.16	11
	November	NABIH SALEH	N/A	N/A	N/A
	December	NABIH SALEH	N/A	N/A	N/A
	Annual (max)		18.05	793.0	524.0
2011	January	NABIH SALEH	N/A	N/A	N/A
	February	NABIH SALEH	N/A	N/A	N/A
	March	NABIH SALEH	6.4	42.27	0
	April	NABIH SALEH	8.7	406.27	29
	May	NABIH SALEH	16.4	204.37	104
	June	NABIH SALEH	22.7	787.72	76
	July	NABIH SALEH	22.6	448.49	106
	August	NABIH SALEH	19.6	526.24	81
	September	NABIH SALEH	11.7	425.51	49
	October	NABIH SALEH	5.5	74.39	22
	November	NABIH SALEH	3.2	177.30	9
	December	NABIH SALEH	3.8	72.51	5
	Annual (max)		11.8	787.7	481.0

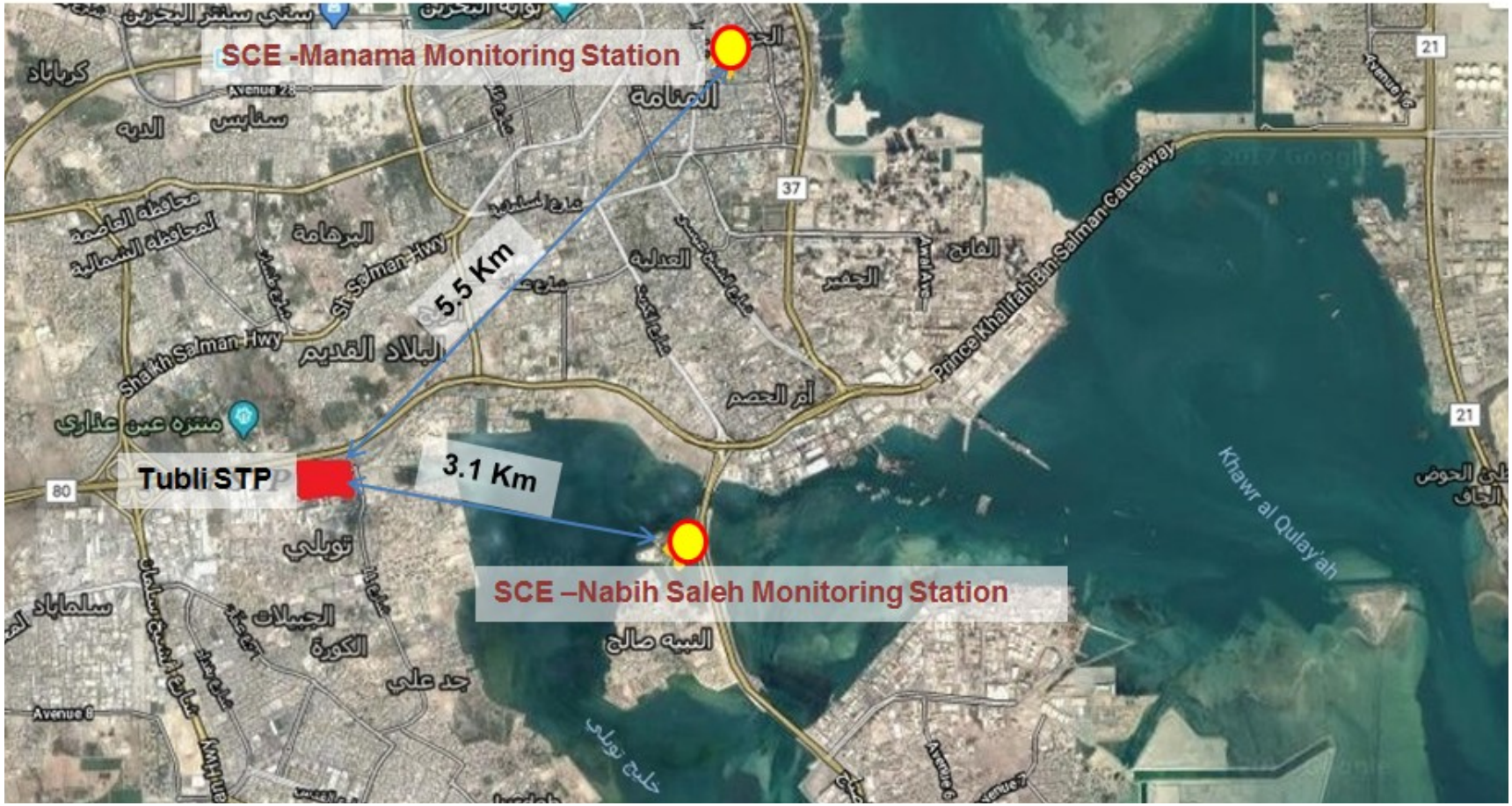


Figure (3.1)

Location of the SCE monitoring stations.

Unfortunately, the location for both stations is bit far from Tubli STP and therefore, the source(s) of the measured H_2S gas cannot be identified. Moreover, when comparing the average monthly values over the five years the level of the H_2S gas is low and considerably lower than 1 ppm. Also, the monitoring stations measured few times in which the gas concentration exceeded the SCE limits of 30 ppb. The provided measurements indicate that H_2S gas exist in the atmosphere in areas distanced from the plant. There was no further investigation done to confirmed the source of the H_2S gas and accordingly cannot be directly related to Tubli STP.

3.4 Initial investigation

Tubli STP is the main sewage treatment plant in Bahrain where most of swage flow generated from the populated area in Bahrain Island is treated currently,(2017), the plant received more than 300,000 m^3/day; this number is increased in winter due to illegal stormwater dumping into the sewer collection system. The plant also, receives the sewage transported by tankers, where an average of 250 tankers is dumping their loads into the STP every day, the treatment technology used is activated sludge with tertiary treatment in order to treat the wastewater for high quality treated sewage effluent (TSE). Figure (3.2) shows aerial view of the STP where different stages of the treatment.



Figure (3.2)

Aerial view of Tubli STP, Bahrain, Google maps 2017

The treatment of sewage start by receiving the sewage flow from the collection network in the inlet area as well as the sewage unloaded from the tankers, the sewage go through screening and sent to the aeration tanks where air is pumped to the flow. In the next step the flow is sent to the clarifiers and then to the ozone plant for the final treatment. Several site visits were conducted to the plant during the study period and the gas measurement were performed for points inside and outside the plant. During the site visits it was noted that the majority of the treatment area is open and exposed freely to the atmosphere. It worth to mentioned that there is no gas monitors installed inside the plant or on the boundary wall, similarly, there was no operational odor control unit at the time of the investigation. The only odor control unit is installed at the collection point of the tanker unloading area.

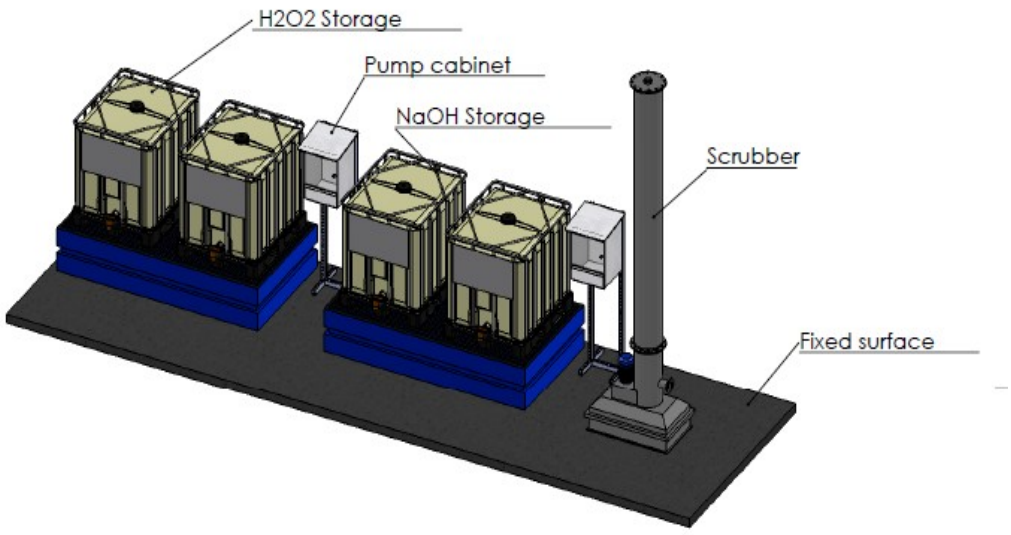


Figure (3.3)
Odor control unit at the tanker unloading area.

The type of the odor unit is chemical scrubbing where the H_2S gas is absorbed to a level of less than 1ppm, the chemical scrubbing unit was not operating due to the unavailability of the chemicals used in the

market. The recorded measurement of H_2S gas at the tanker unloading area is high around170 ppm, (p2m, 2014).

Site Visits

Several visits conducted to Tubli STP site during the development of the study, the information collected during these visits are very essential for the development of the study. The main purpose of these visits is:

1. Identify the treatment stages inside the STP facility.
2. Overall visual inspection of the STP.
3. Identify the most units that emitting odorous gases.
4. Observe the normal operation mode of the STP.
5. Get familiar to the different treatment stages.
6. Perform field measurements to the different treatment units inside the STP as well as in the area surrounding the facility.

The visits performed between the periods from September 2017 to December 2017. The initial investigation for the area inside the STP showed that most detected odors were emitted from sewage inlet, tankers unloading area and the sludge return these areas is presented in figure (3.4).



Figure (3.4)

Most odor detected areas inside Tubli STP.

Gas Measurements

Moreover, the odor was clearly perceived in the areas right outside the boundary walls of the STP. For the initial investigation purposes gas monitor device was used to measure the level of the H_2S gas in the atmosphere the measurements took in several locations around the STP as shown in figure (3.5) it was noticed that the odor is clearly observed however the odor was not detectable by this device. The threshold value of the gas monitor device is 1 ppm. It was concluded that the gas concentration is less than 1 ppm right outside the STP boundary.



Figure (3.5)
Location of the gas measurements right outside the STP boundary wall, less than 1 ppm.

Therefore ambient air quality (AAQ) monitor was used to measure the gas concentration in areas outside the STP. The Threshold value of detection for these devices is usually small and it is suitable of the purpose of this study. The device used in the study is using technology of Photo Ionization Detectors (PID) in measuring the gas concentration. Usually the PID measure low levels of the gases and VOCs (volatile

organic compounds) and provides a compact, accurate and reliable real-time gas monitoring. Figure (3.6) shows the device.



Figure (3.6)

Photo illustrating the AAQ device used to take the measurements.

Chapter 4

Results, Discussion and Recommendations

4.1 Research results

4.2 Discussion of results

4.3 Study's Recommendations

4.4 Future Work

Chapter 4: Results, Discussion, and Recommendations

4.1 Research results

Tubli STP Odor complaints

Odor complaints usually provide good indication for the real extend of the area impacted by the STP odor, complaints analysis is a qualitative method for assessment which is subjective to the personal capability for perceiving the STP odor. Complaint registers usually kept by the operating authority; similarly MOWMUP keeps the complaints records of Tubli STP, the complaints usually received either directly from the residents, or published in the newspapers, in some critical cases complaints received from the municipal councils. As part of this research the complaints record will be reviewed in attempt to identify a common pattern for the odor complaint, therefore, complaints over the last 10 years were requested from public relation office (PR) of MOWMU, this office is independent entity for Tubli STP operation directorate. PR representatives received the complaints, record them electronically and coordinate with relevant sections to issue the reply for each complaint. PR representatives provided the complaints list for six years only for the period extended between years 2010 to 2016. Records dated before year 2010 were recorded manually and none of the old records were available at the request time. Complaints list received are shown in Table (4.1).

Table (4.1)

Odor complaints associated with Tubli STP for the period between years 2010 to 2016, MOWMU.

No.	Date of complaint	Complaint Description	Location
1	26.10. 2010	Nuisance odor emissions from Tubli STP.	Tubli, Block 711.
2	16 .06. 2013	Nuisance odor emissions from Tubli STP. This complaints raised by residents of Tubli area.	Tubli area.
3	15.06. 2014	Nuisance odor emissions from Tubli STP is perceived continually.	Tubli, Block 711.
4	17.08. 2014	Nuisance odor emissions from Tubli STP is perceived inside the house. Request for compensation.	Tubli area, block 711, road 1118.
5	15.10. 2014	Nuisance odor are perceived inside the Houses located along Road 1118.	Tubli, Road No. 1118 Block 711
6	21.01. 2015	Nuisance odor emissions are perceived.	Tubli, Road No. 1118 Block 711.
7	29.09.2015	Nuisance odor emissions from Tubli STP.	Not specified.

The total recorded complaints received that related the odor associated with Tubli STP are seven complaints for the period between 2010 until 2016 which is one complaint per year in average. Based on the literature there is no standard number of complaints that need a statuary or correction orders, usually STP operators would target for one complaint in a year as very good record as zero complaint in a year is unrealistic and hard to achieve. Also, it worth to note that the absence of complaints does not necessary indicate STP odor is controlled neither that additional odor abatement measures are not needed. The graphical location of the registered complaints in relation to the STP is shown in figure (4.1). All complaints location are in close proximity of the plant and concentrated in the residential eastern side and particularly block 711, it worth to note that the area surrounding the STP is mostly of commercial or light industrial nature except of block 711 which has more residential distribution this may play factor in raising complaints in this particular area comparing to other sides.



Figure (4.1)

Recorded Complaints locations.

Odor complaints and metrology

The most influential factor in odor dispersion other than the odor source and emission rate is the metrology and particularly wind direction and speed, when comparing two location distanced equally from the odor source the chance that the odor complaint raised from one location rather than the other would be based on the wind direction where wind transmit the odor in almost the same direction. Figure (4.2) shows the prevailing[3] wind direction corresponding for each complaint.

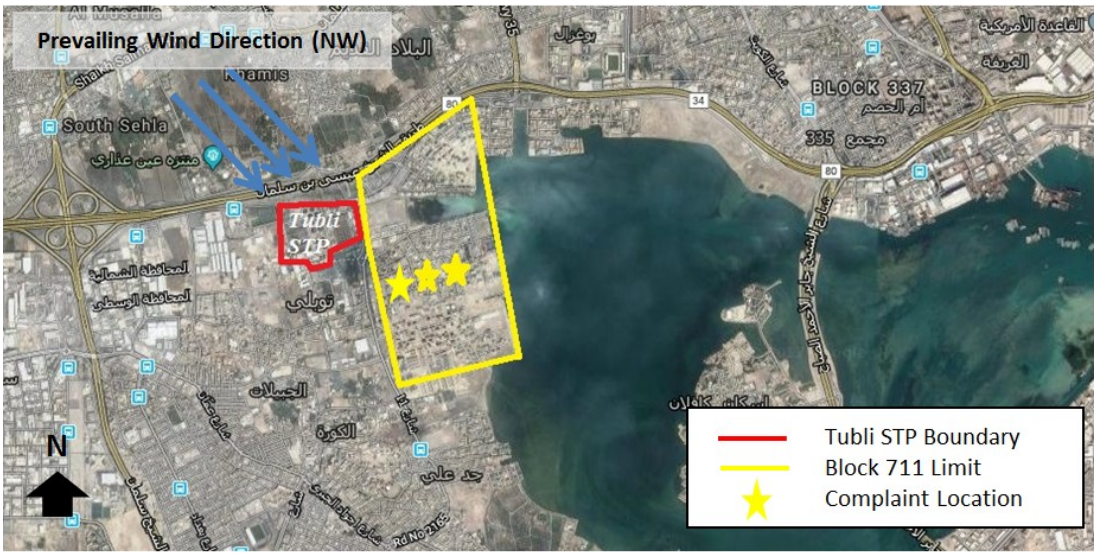


Figure (4.2)

Wind direction and complaint location

As for Tubli STP odor complaints record shown in Table (4.1) the following observations are made:

1. Total number of complaints over the past six years are relatively small, an average of one complaint per year, this does not reflect a catastrophic situation.
2. These complaints show occasional and scattered incidents over the year odor nuisance dispersion.

[3] As per the data provided by Airport metrological station based on statistics between 06/2005 to 11/2017 daily from 7 am to 7 pm local time.

3. The most frequently complaints located in road 1118 and block 711, this road located near the STP location, where the residential area is located this might be influencing the concentration of the complaints comparing to the other area surrounding the STP where commercial and light industrial developments are distributed.
4. Based on the complaints dates it seems that there is no seasonal differences 57% (4 out of 7) complaints recorded in winter (September, October & January), and 43% of total complaints recorded in summer (June & August).
5. Direction of the prevailing wind is in the same direction of the recorded complaints. .
6. No complaints were recorded in years 2011 and 2012.

Discussion

The number of complaints recorded is shockingly small, it was expected at before initiation of the research that there would be a larger number of recorded complaints, therefore, it is expected that there are residents who are impacted from the STP's odor who do not raise complaint; based on the literature there are several factors behind this situation like that the residents may get used to the frequent smell. As specified by British department of the environment food and rural affairs (DEFRA), these factors called distortion factors and include the following, (DEFRA, 2006):

1. Lack of confidence that a complaint will bring any improvement,
2. Uncertainty over whom to complain to,

3. Concern for unintended consequences such as a lowering of property values if the problem were to feature prominently in the newspaper.

Moreover, based on the complaints received it was noticed that most complaints raised by residents of block 711 at Tubli area, there is no evidence that other surrounding areas are impacted by Tubli STP odor. In order to have better understanding of the odor problem extent, quantitative method is selected; the use of the atmospheric dispersion modelling will facilitate a graphical simulation for the odor dispersion from the source at the STP to the surrounding atmosphere.

Odor source identification

Odor source and location inside the STP facility is crucial for the assessment of the odor dispersion at the atmosphere. The typical process of handling the sewage associate with emission of odorous gases, the quantifying of emission level of these odorous gases will indicate important parameter in odor assessment equation. For this research the analytical measurement approach is selected to quantify the odor emissions inside the STP. An air quality monitor device shown in figure (4.3) is used to take the measurements at different treatment stages inside the STP facility. The monitor used has low threshold value (0.003 ppm) and more varied detection range, the device model type is: Gray Wolf 10.6ev PID lamp. This monitor is Photo Ionization Detector that is usually used outdoor for ambient air quality assessments.



Figure (4.3)

Air quality monitor used in taken measurements of odorous gases, in the photo the LCD monitor is shown.

In order to identify the source of the odor inside the STP facility and the type of odor gases emitted from the STP, several measurements were taken in eight locations; these locations represent the different treatment stages inside the STP facility. The gas concentration level for selected odorous gases measured will be average and used as representative value for the relevant treatment stage. The eight treatment stages listed as follow: location No.1 and location No.2 inlet area: the first point to receive the sewage flow from the network, location No. 3 primary treatment, location No. 4 tankers unloading area: this is dedicated area for the sewage tankers to discharge their sewage loads, location No.5 sludge return area, location No. 6 Sludge thickening area, location No. 7 Sludge

plant, location No.8 sludge drying beds. Figure (4.4) shows location of the measurements.



Figure (4.4)

Location of measurements taken inside Tubli STP facility

The measurements performed for each location are listed in Table (4.2), the monitor detected several odorous gases include: hydrogen sulphid (H_2S), ammonia (NH_3), sulfur dioxide (SO_2), methyl mercaptan, trimethyl amine and total volatile organic compounds (TVOC). These gases are common emissions in wastewater treatment works these gases are present at different concentration, the measuring unit use to represent the concentration level is part per million (ppm).

Table (4.2)

No.	Location Description	NH_3 (ppm)	SO_2 (ppm)	H_2S (ppm)	Methyl Mercaptan (ppm)	Trimethyl Amine (ppm)	TVOC (ppb)
1	Inlet Area	0.2	0.1	0.5	0.0032	0.0006	561.0
		0.5	0.4	0.7	0.0004	0.0005	414.0
		0.4	0.3	0.5	0.0009	0.0004	418.0
2	Inlet Area	1.4	0.2	8.6	0.0015	0.0047	5005.0
		1.4	0.2	8.0	0.0070	0.0035	3303.0
		1.3	0.2	7.8	0.0078	0.0028	3141.0
3	Tanker unloading area	0.5	0.2	0.6	0.0032	0.0005	492.0
		0.5	0.2	0.4	0.0015	0.0005	430.0
		0.4	0.1	0.3	0.0010	0.0005	328.0
4	Primary treatment area (HYBCS area)	0.5	0.1	0.6	0.0006	0.0003	317.0
		0.5	0.1	0.7	0.0005	0.0003	316.0
		0.5	0.1	0.7	0.0005	0.0003	245.0
5	Sludge Thickening	0.3	0.1	0.2	0.0005	0.0005	73.0
		0.4	0.1	0.2	0.0003	0.0004	75.0
		0.4	0.1	0.3	0.0003	0.0003	73.0
6	Sludge return area	0.6	0.1	1.0	0.0003	0.0003	152.0
		0.5	0.1	0.5	0.0003	0.0003	100.0
		0.4	0.1	0.3	0.0003	0.0003	84.0
7	Sludge plant	0.5	0	0	0	0	Not recorded
8	Sludge drying beds	0	0	0	0	0	Not recorded
Average temperature 25°; average humidity %65.							

Odorous gas measurement levels at the source, December 2016.

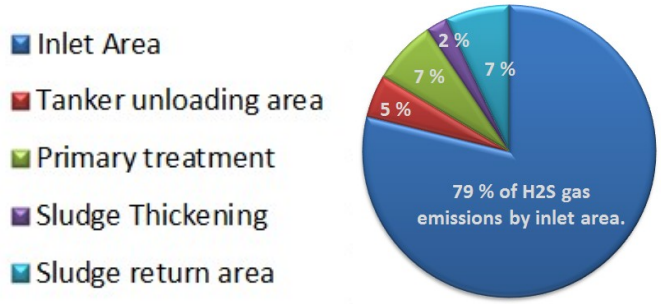
From Table (4.2) the average value of each gas in each treatment stage is estimated and listed in Table (4.3), also, the threshold value for each gas is listed for comparison purposes. In general the most concentration for the gases is measured in the inlet area (NH_3 = 1.4 ppm, SO_2=0.2 ppm, H_2S =6.2ppm, Methyl Mercaptan = 0.0059 ppm, Trimethyl Amine = 0.0039 ppm). Where sludge plant and sludge drying beds measurements are the lowest values.

Table (4.3)

Average measured value for the odorous gases.

No.	Location Description	NH_3 (ppm)	SO_2 (ppm)	H_2S (ppm)	Methyl Mercaptan (ppm)	Trimethyl Amine (ppm)
1	Inlet Area	0.4	0.2	0.6	0.0012	0.0003
2	Inlet Area	1.3	0.2	8.1	0.0059	0.0039
3	Tanker unloading area	0.4	0.1	0.4	0.0014	0.0005
4	Primary treatment	0.5	0.1	0.6	0.0005	0.0003
5	Sludge Thickening	0.4	0.1	0.2	0.0004	0.0004
6	Sludge return area	0.5	0.1	0.6	0.0003	0.0003
7	Sludge plant	0.5	0	0	0	0
8	Sludge drying beds	Not recorded	0	0	0	0
Odor threshold value[4] (ppm)		46.8	0.009	0.00047	0.0021	21.0

Tubli STP treatment stages contribution in H_2S gas emission



[4] Threshold values extracted from chapter 2, Table (2.1), (Tchobanoglous, G.; et al, 2003).

Following the review of the average values for the gases measurements shown in Table (4.3) and compare them with the threshold values, most of the detected gases concentration level are lower than the threshold values except for H_2S and SO2. The value of H_2S gas concentration is relatively high (6.2, 0.6, 0.5, 0.4 and 0.2 ppm) when compare it with the threshold value of (ppm= 0.00047). Therefore, H_2S gas will be selected to be the representative gas for Tubli STP odor. It worth to note that the inlet area, primary treatment and sludge return area are the most contributors for the H_2S gas emissions, where the H_2S gas was not detected in sludge plant and sludge drying beds areas. Similarly for odor source identification the locations where detection of H_2S gas was not achieved (sludge plant and sludge drying beds) will be eliminated. As result, odor source inside Tubli STP facility is limited to: Inlet area, primary treatment area, sludge return and sludge thickening areas. Figure (4.5) shows of odor source areas inside the STP facility.

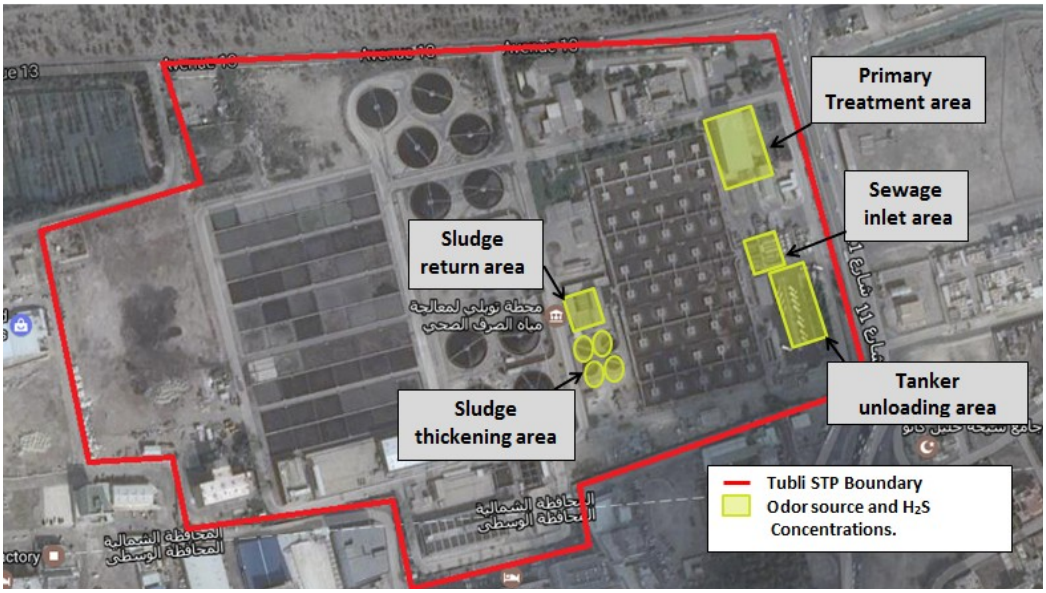


Figure (4.5)

Odor sources location inside Tubli STP.

H_2S concentration seasonal variation

The actual measurements for H_2S gas concentration were performed by the researcher in winter, the value of those emissions usually varied between winter and summer, the condition get worst in summer where the temperature and humidity accelerate the disintegration of the organic matter in return the release of the H_2S gas to the atmosphere will be increased as well. The summer value for H_2S gas concentration for this research will be extracted from previous gas measurements done by the STP operator at MOWMU. Using summer values for H_2S gas concentration will allow better understanding of the odor problem and how the gas dispersion is different all over the year. Table (4.4) shows the values of H_2S gas concentrations.

Table (4.4)
H_2S gas measurements performed by Tubli STP operator between the period of April and May 2012 (ppm).

Date	Inlet area	Tankers unloading area	Sludge Thickening
18.04.2012	13	30	13
19.04.2012	11	69	14
22.04.2012	6	18	12
23.04.2012	8	76	16
25.04.2012	12	44	16
26.04.2012	10	84	8
27.04.2012	8	12	4
29.04.2012	6	8	6
30.04.201	4	10	4

2			
02.05.2012	8	12	4
03.05.2012	6	8	4
13.05.2012	10	13	9
16.05.2012	8	12	7
21.05.2012	6	12	4
22.05.2012	7	60	3
26.05.2012	6	3	3
Average	**8**	**26**	**7**

As expected the values of H_2S gas concentration in summer is higher than values measured in winter, Table (4.5) shows the comparison between both values against each treatment stage. The increase in H_2S gas concentration from winter is varied for each stage; for example the inlet area is almost the same where the sludge thickening and tanker unloading area is about 98% higher.

Table (4.5)

Average value of H_2S gas concentration in summer and winter (ppm).

Season	Inlet area	Tankers unloading area	Sludge Thickening
Winter	6.2	0.6	0.5
Summer	8	26	7
% Increment *	23%	98%	93 %

*Increment percentage calculated using the following equation:
x 100 %

Discussion

The odor source identified as per Figure (4.5) is based on the H_2S gas concentration and it is in agreement with what is specified in the literature; where is the typical treatment units in wastewater treatment plant that produce odorous gases are the inlet (headworks), primary treatment, and sludge treatment plant. Also, the inlet unit is the main contributor to H_2S gas emissions (Talaiekhozani, A.; et al, 2015; Sengupta, A. 2014; Tchobanoglous, G.; et al ,2003).Also, using H_2S to represent the odor associated with the sewage treatment plants is very common in the previous studies, moreover H_2S has low perceivable threshold value (0.00047 ppm) and has relatively low molecular weight (34) comparing with other odorous gases like methyl mercaptan (48) and sulfar dioxide (64.07); low molecular weight is often related to the dispersion in the atmosphere, as such H_2S gas is considered the most responsible for odor complaints and usually selected for the odor dispersion modeling practices. In this research H_2S is selected to be modeled for dispersion. (Sengupta, A. (2014).For the seasonal variation, in some studies the assumption of double winter values are used to represent the H_2S gas concentration at summer, for this research the values provided at Table (4.5) will be used for the dispersion modelling purposes.

Use of dispersion Modelling

In order to have a better understanding for the dispersion of Tubli STP odor atmospheric dispersion model is used, the selected model is AERMOD and for the purpose of AERMOD use there are two input data processors that are regulatory components of the AERMOD modelling system: AERMET, a meteorological data pre-processor that incorporates air dispersion based on planetary boundary layer turbulence structure and

scaling concepts using details like location elevation reference to the sea level, meteorological station elevation, and AERMAP, a terrain data pre-processor that incorporates complex terrain (EPA, 2016). In this research only AERMET will be used, as the terrine in Tubli STP area is considered simple and flat. Based on EPA recommendation the meteorological data used in AERMET must be for one year minimum and preferable for three years, the same guideline is used in the Kingdom of Bahrain by Supreme Council of Environment (SCE).The meteorology have wide impact on the dispersion of the odors, meteorological data like wind speed, wind direction, temperature, humidity, solar radiation, and atmospheric stability influence the dispersion of the suspended particles in air which in our case H_2S, also, it gives certain results whether the particles will be diluted in to atmosphere and transfer or simply will tend to concentrate on to the ground and stationed around the emission source. In simulation the dispersion the metrological data plays major role along with particle molecular weight and emission rate. The metrological data can be obtained from Civil Aviation Affairs (CAA) in the Kingdom of Bahrain or it purchased from EPA website for the specific location. It should be noted that the data file needs to be set in certain arrangement in order to be read and processed by AERMET these data include average hourly recorded data for the following parameters: temperature, humidity, wind direction, wind speed, metrological station pressure, solar radiation, cloud cover, and sea level pressure (Capelli, L.; et al, 2013). Step by Step procedure for using AERMET is showing in Appendix 3. The outcome of AERMET is two files called SAMSON and SCARM files, these files provide processed information compatible with AERMOD for surface reference details include the growth and structure of the atmospheric boundary layer where the dispersion of pollutant is carried out as well as

the factors influence this atmospheric layer locally. In addition, AERMET passes all measurements of wind, temperature, and turbulence in a form AERMOD needs (EPA, 2004), also the wind rose can be extracted from AERMET processor as separate graph; wind rose gives a concise view of how wind speed and direction are typically distributed at a particular location. Presented in a circular format, the wind rose shows the frequency of winds blowing from particular directions. The length of each spoke around the circle is related to the frequency of time that the wind blows from a particular direction. Each concentric circle represents a different frequency stemming from zero at the center to increasing frequencies at the outer circle, also, the wind rose contain information that each spoke is broken down into discrete frequency categories that show the percentage of time that winds blow from a particular direction and at certain speed ranges. Wind rose is used typically to identify the prevailing wind for particular period of time also it is commonly associated with the air quality monitor and dispersion model, where the pollutant dispersion is examined. For this research the metrological data for three years is used 2014, 2015 and 2016 for comparison purposes graphical representation for the wind rose extracted from the AERMET processor is shown in Figure (4.6), Figure (4.7) and Figure (4.8)

respectively.

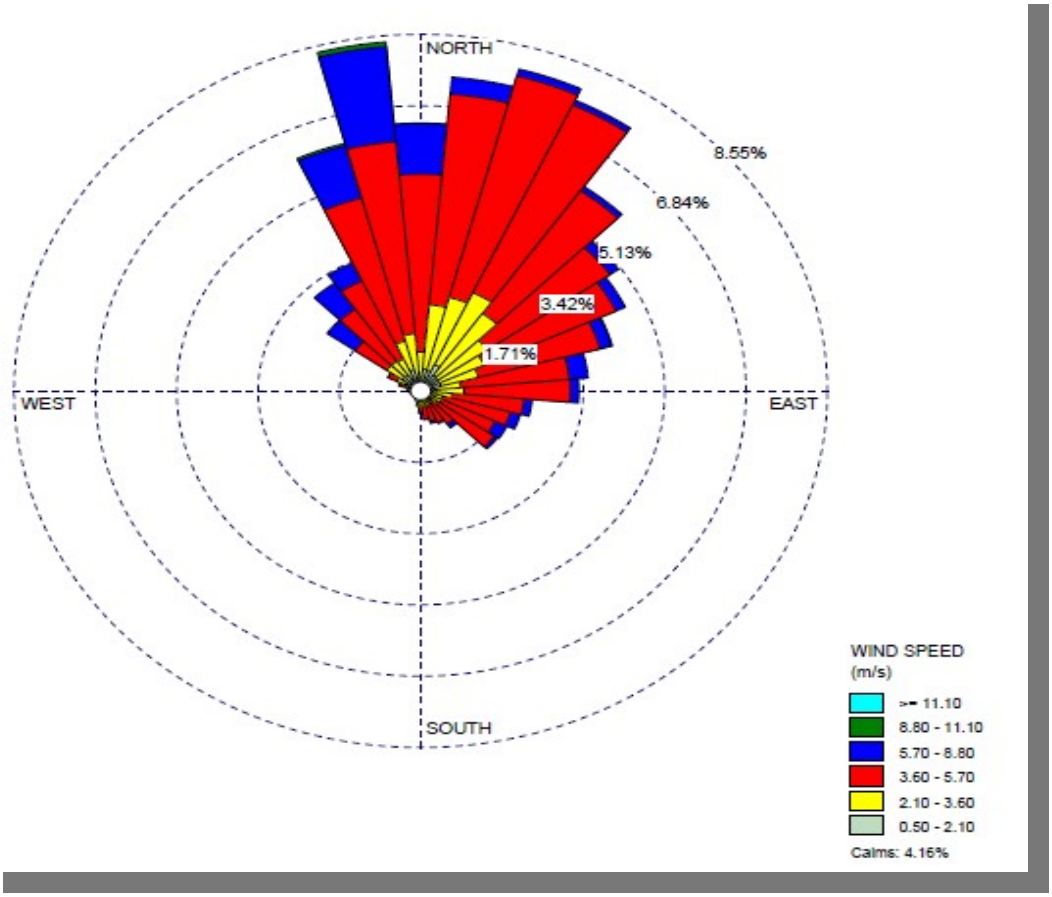


Figure (4.6)

Wind rose for Tubli STP year 2014.

The wind rose Figure (4.5) shows that the prevailing wind is north (N), north west (NW) and north east (NE), total of 54% of all hourly winds direction. This can be calculated by adding the spokes percentages (8.5+7.7+7.7+7.7+6+8+3.4+5.1= 54%), it also shows that the wind rarely blow from the south west (SW) direction. The wind rose also provides details on speed from each direction. Examining the spoke from north west (NW), the longest spoke, it is approximately 0.5 % of the time at year 2014 the wind blow from the north west direction at speeds between 8.8 to 11.1 meters per seconds. Similarly it is 2.6% of the time at year 2014 the wind blows form the north west (NW) direction at speeds between 5.7 to 8.8 meters per seconds. In addition, the wind rose legend shows that 4.16 % of the time at year 2014 the wind was calm.

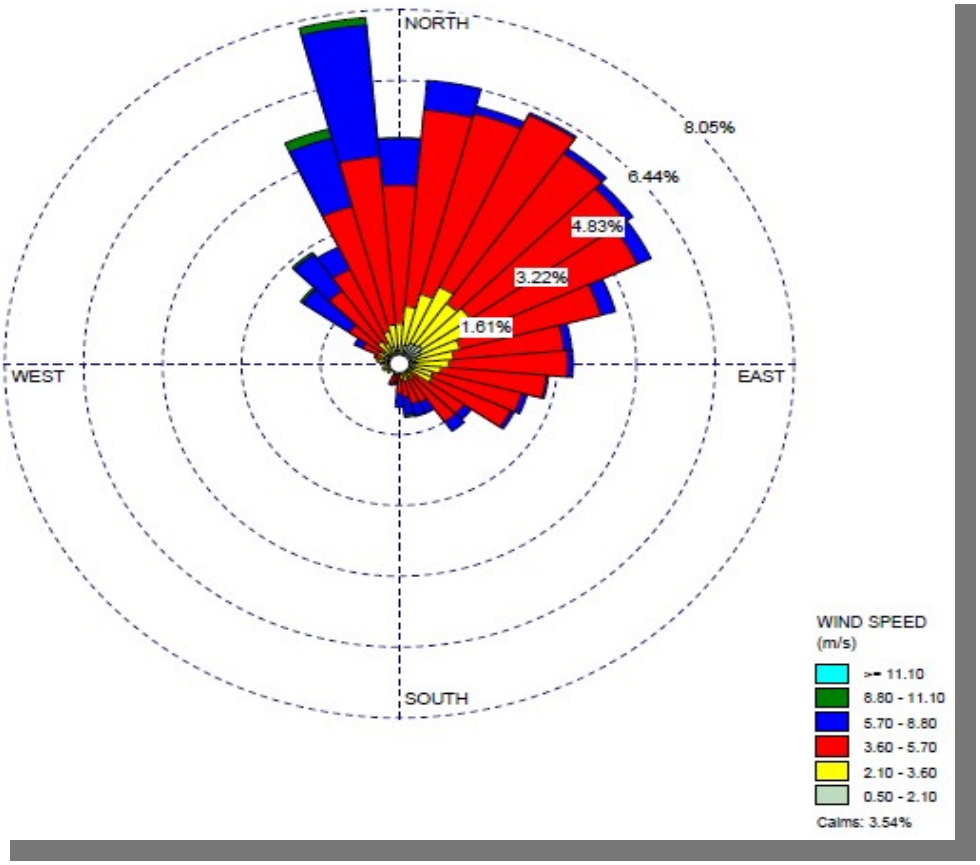


Figure (4.7)

Wind rose for Tubli STP year 2015.

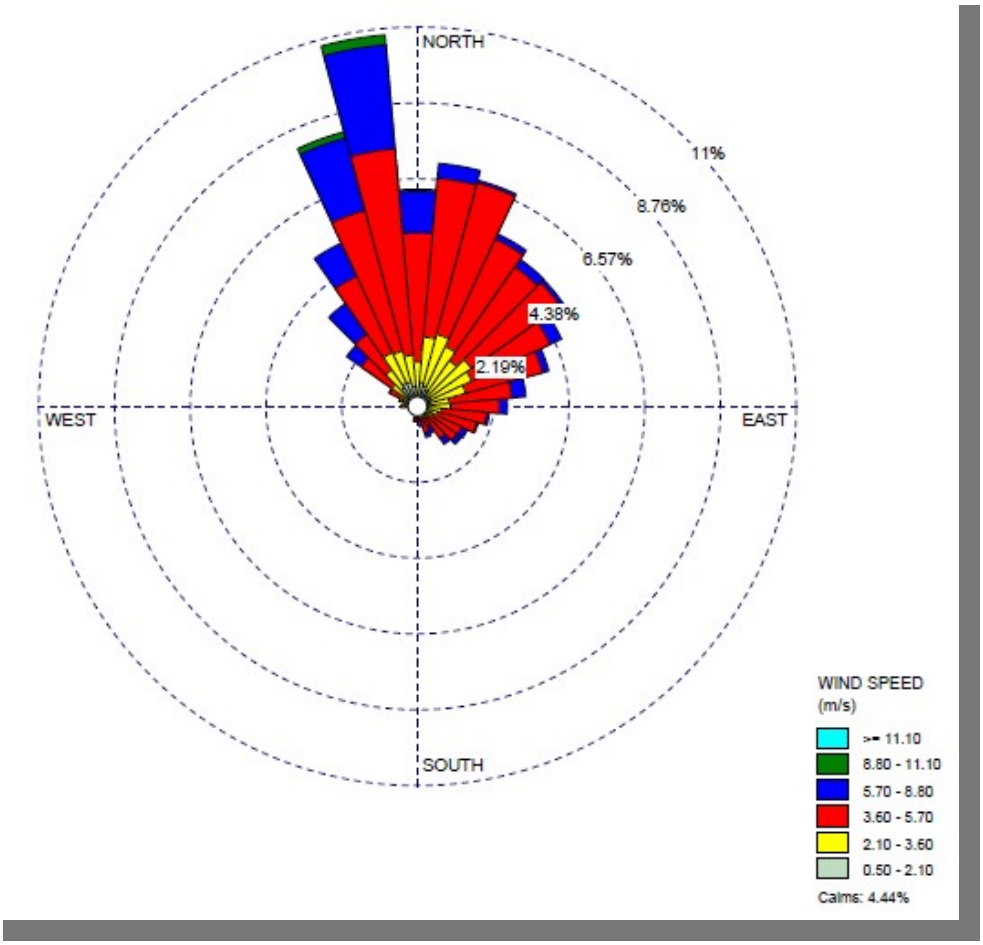


Figure (4.8)

Wind rose for Tubli STP year 2016.

Following the review of the wind roses for year 2014, 2015, and 2016; there is light difference in the frequency of the wind blows for example when comparing the wind blows at direction between north (N) and north west (NW) direction it is found that at year 2016 the wind blows more frequent in this direction (28%) in relative to year 2015 (19.5 %) and year

2014 (21%). These differences in frequency for wind speed and direction will be reflected in dispersion model for these years.

Moreover, for the modeling purposes it is very crucial to identify the odor sources and emission rates at which these odors are emitted to the atmosphere. At Tubli STP the odor sources were identified based on field measurements, where it is evident that the sewage inlet, tankers unloading areas in addition to the primary treatment and sludge return and thickening basins are the odor sources at the plant, Figure (4.7) shows actual source location at the plant with H_2S gas concentrations, the coordinates of each source and dimensions will be entered in AERMOD for modeling purposes. It must be noted that the inlet area is represented by one area for the simplicity of the modeling.

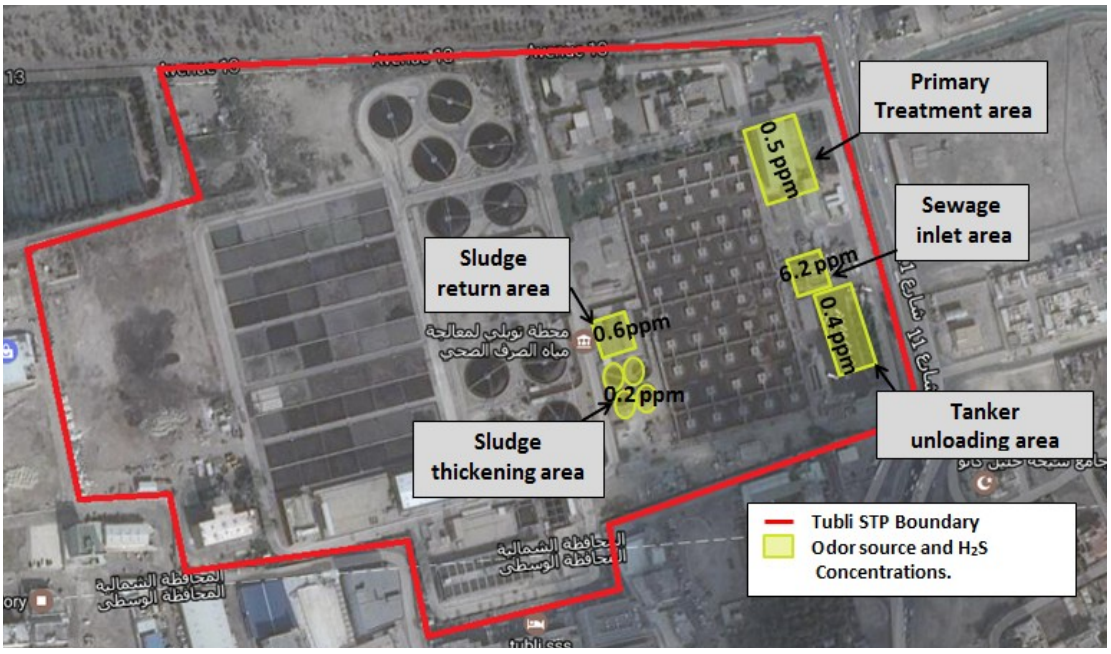


Figure (4.9)

Odor sources location at Tubli STP with H_2S gas concentration level.

Moreover, the odor emission rate is required for the modeling purposes, the emission rate is defined as the quantity (mass) of odor emitted per unit time from a unit surface area (Jaing, J.2000). Usually, the emission estimates are important for developing emission control strategies, determining applicability of permitting and control programs, evaluating the feasibility and the effects of appropriate mitigation strategies (Capelli, L.; et al, 2014). There are several established methods to estimate the emission rate at the source like: flux chamber test, emission factors, mass transfer and continuous emission monitoring systems. The most common recommended method is flux chamber method where gaseous emissions are collected from an isolated surface area with an enclosure device in order to collect the gas and then measure its concentration usually the flux chamber test is combined by pump test in order to measure the air flow and accordingly compute the emission rate. Estimating the emission rate using the flux chamber method is approved by the EPA and provide accurate results, (EPA, 2004) however the pump test is usually expansive and the setting of flux chamber required effort especially for the sewage inlet and the primary treatment basins. The second common method to estimate the emission rate require continuous monitoring devices and the testing period would last over long period of time. Due to the unavailability of the continuous monitoring devices and the difficulty of performing the flux chamber test at various treatment stages, an alternative method is used for this study where the mass transfer equations are used to provide an approximate estimation for the emission rate. In order to compute the emission rate from the available information about the flow rate and the gas concentration measured on site for each source the average concentration level is multiplied by the flow received by the STP assuming constant continuous

emission rate. The concentration level of the gas must be represented in mass per unit volume, in order to estimate the mass per volume rate for H_2S the ideal gas law equation is used, the theory behind this is that the volumetric rates measured at actual conditions can be converted to reference or standard conditions using the universal gas laws. The monitoring devices and instrumental analyzers typically report pollutant concentrations on a part per million volume basis (ppmv). This unit needs to be converted to a mass per unit volume basis (mg/m^3) in order to determine the mass rate of the pollutant using the following equation:

Intensity = (4.1)

Modeling Scenario

The emission rate calculation is based on the sewage flow received by the STP, in order to account for the flow fluctuation two modeling scenarios will be adopted in this research is for two cases: normal operation with average flow received and worst case scenario, both scenarios will be modeled for H_2S dispersion using AERMOD. The normal case scenario is assumed when the STP received average flow and the existing field condition when measurements performed December the average values are shown in Table (4.5). In the other hand, the worst case scenario will be developed at the summer season where the potential of the H_2S emissions are increased (Witherspoon, J.). The emission rate is coupled with the maximum flow rate received by the STP ($310{,}000 m^3$/day).

Sample of calculations

Molecular weight of H_2S = 34.076 kg/ mole

Concentration of H_2S = average measured levels provided in Table (4.5)

12.187 conversion factor for the units

Flow rate = 280,000 m^3/day[5]

For location No. 2 = Inlet Area

H_2S = 8.1 ppm

C° = 25°

Intensity (mg/m^3) = = 9.2 mg/m^3

Emission rate = 9.2x 10^{-3} x 280,000 = 2,576 g/day

Table (4.6) represent the tabulated emission estimation for each odor source.

Table (4.6)

Emission rate for each source location

for normal scenario.

No.	Location description	H_2S (ppm)	Mass intensity (mg/m3)	Emission rate (g/day)
1	Inlet Area	6.2	9.2	2,576.0
2	Tankers unloading area	0.4	0.6	168.0
3	Primary treatment	0.6	0.9	252.0
4	Sludge Thickening	0.2	0.3	84.0
5	Sludge return area	0.6	0.9	252.0

Sample of calculations

Molecular weight of H_2S = 34.076 kg/mole

Concentration of H_2S = Table (4.5)

12.187 conversion factor for the units

Flow rate = 310,000 m^3/day[6]

For location No. 1 = Inlet Area

H_2S = 8 ppm

C° = 35°

Intensity (mg/m^3) = = 35.0 mg/m^3

[5] Average flow information estimated from the annual reports obtained from the STP operators.

[6] Maximum flow information obtained from the STP operators.

Emission rate = 35.0 x 10^{-3} x 310,000 = 10,850 g/day

Table (4.7) represent the tabulated emission estimation for each odor source. For the sources that have no summer values the normal scenario values are used.

Table (4.7)

Emission rate for each source location

in summer (worst scenario).

No.	Location description	H_2S (ppm)	Mass intensity (mg/m3)	Emission rate (g/day)
1	Inlet Area	8	10.78	3,342.219
2	Tankers unloading area	26	35.0	10,850
3	Sludge Thickening	7	9.43	2,923.3

The values of the emission rates is increased dramatically, especially in tankers unloading area, this increment is expected due to the increase of the temperature at summer which lead to accelerate the specify of the sewage and eventually increase H_2S generation, however, although this increase of H_2S concentration level at summer the weather and wind condition does not support the dispersion and gas transfer as the wind is in general blow lesser and in slower rate at summer (Witherspoon, J.), therefore, it is expected that the odorous gases have a more tendency to be stationed inside the STP facility. Nerveless, for the modeling both scenarios the emission rates shown in Table (4.6) and Table (4.7) for the odor sources shown in Figure (4.8), Step by step procedure for using the AERMOD is shown in Appendix 4. SCE guideline require minimum of one kilometer diameter receptor area to be modeled for this research area of five kilometers are modeled in order to have better understanding of the impacted area surrounding the STP. In addition, SCE guideline call for 1 hour average modeling then the

dispersion values is compared with the maximum average H_2S concentration level, 30 ppm, (Bu Hassin, E.; et al, 2011). In the other hand, AERMOD will process the data for the entire period in which the metrological information is provided and then select the condition where the pollutant is at highest concentration to provide the odor contour map. Moreover, based on AERMOD user manual (EPA, 2004) the user may alter and select the data and range of period for the modeling scenario. For this research the odor contour maps for years 2014, 2015, and 2016 is modeled for both normal and worst case emissions. These contour maps are shown in Figures (4.10) to (4.15).



Figure (4.10)

H_2S gas dispersion 1 hour average, normal case scenario year 2014.

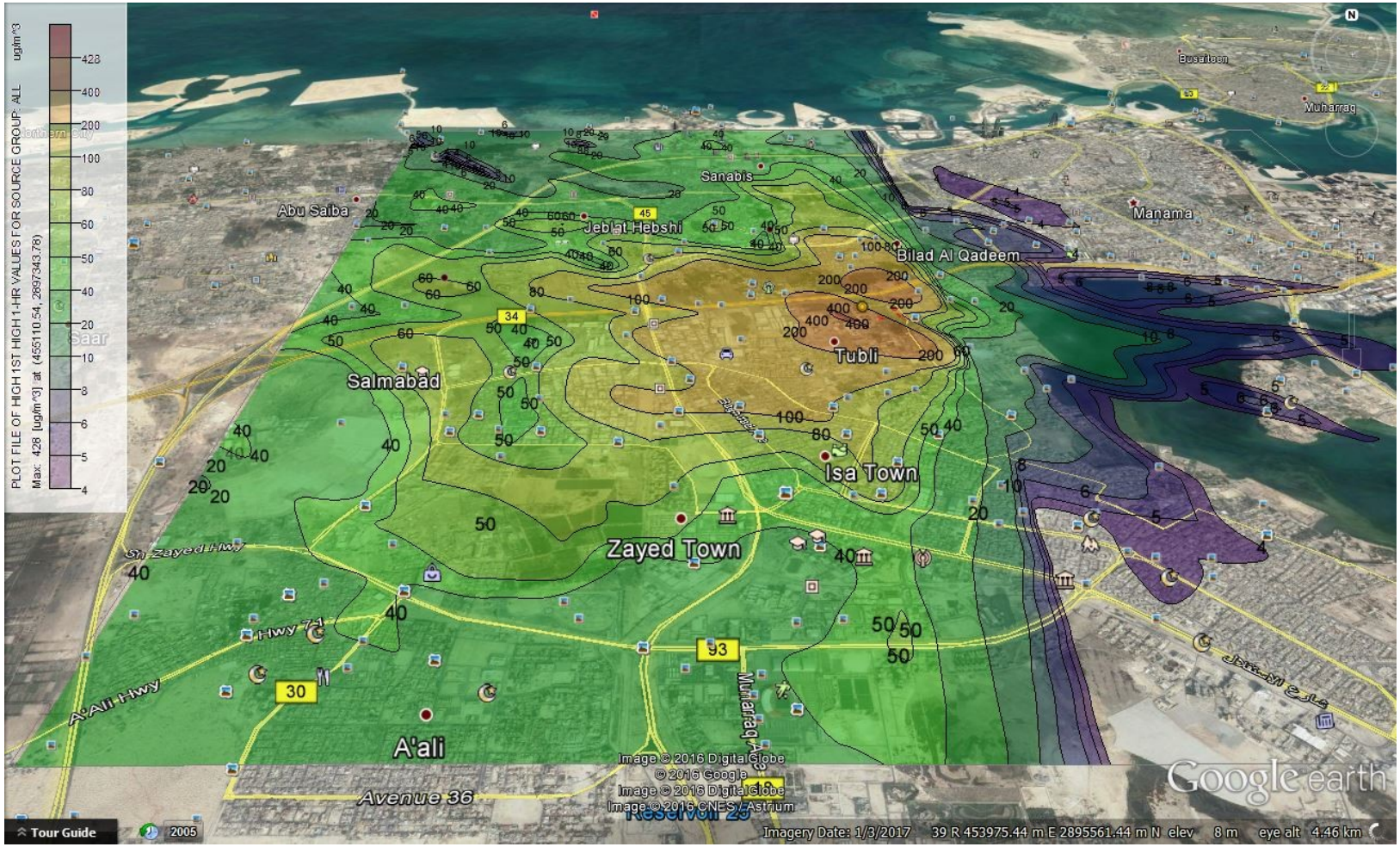


Figure (4.11)

H_2S gas dispersion for average 1 hour, normal case scenario year 2015.

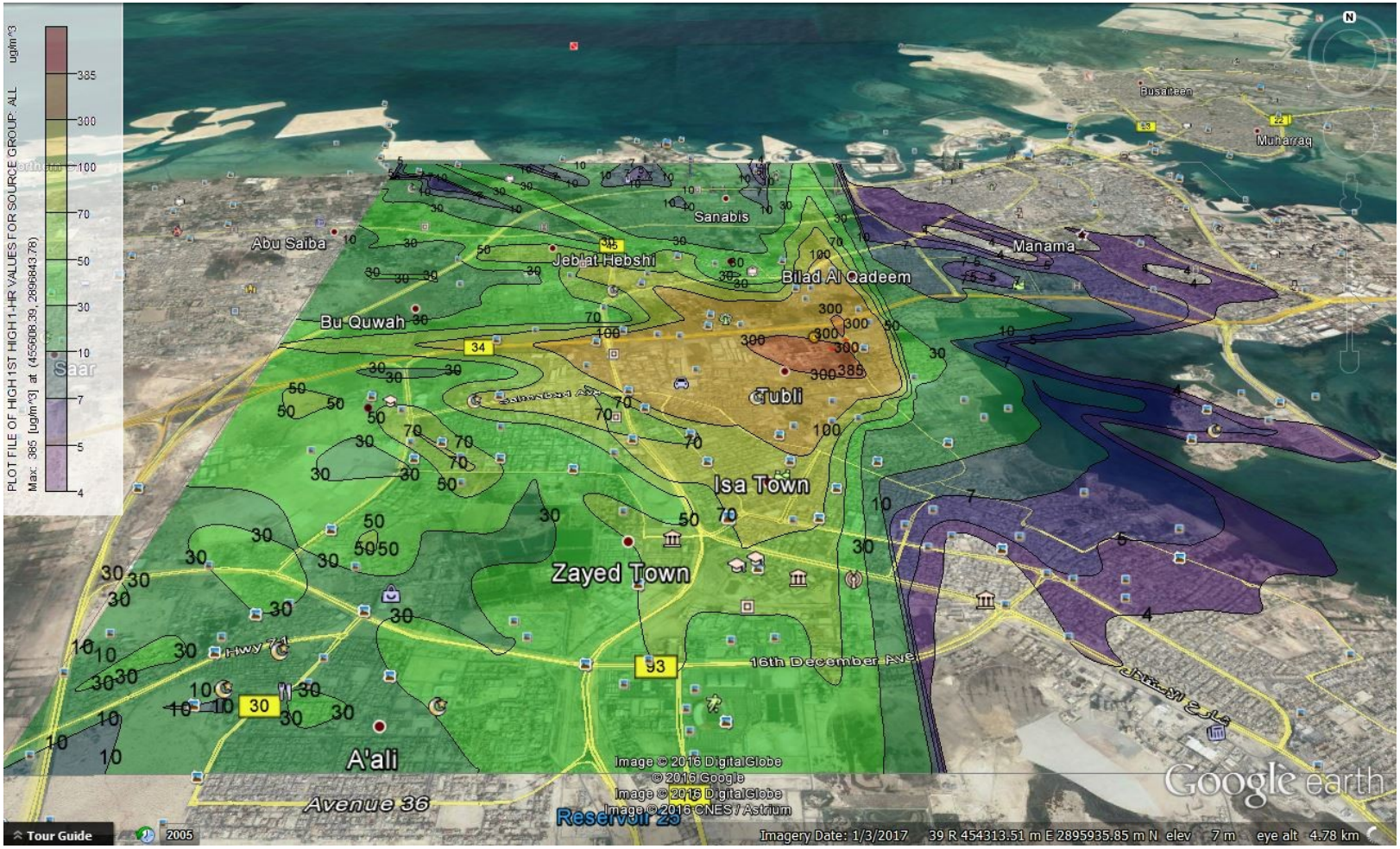


Figure (4.12)

H_2S gas dispersion 1 hour average, normal case scenario year 2016.

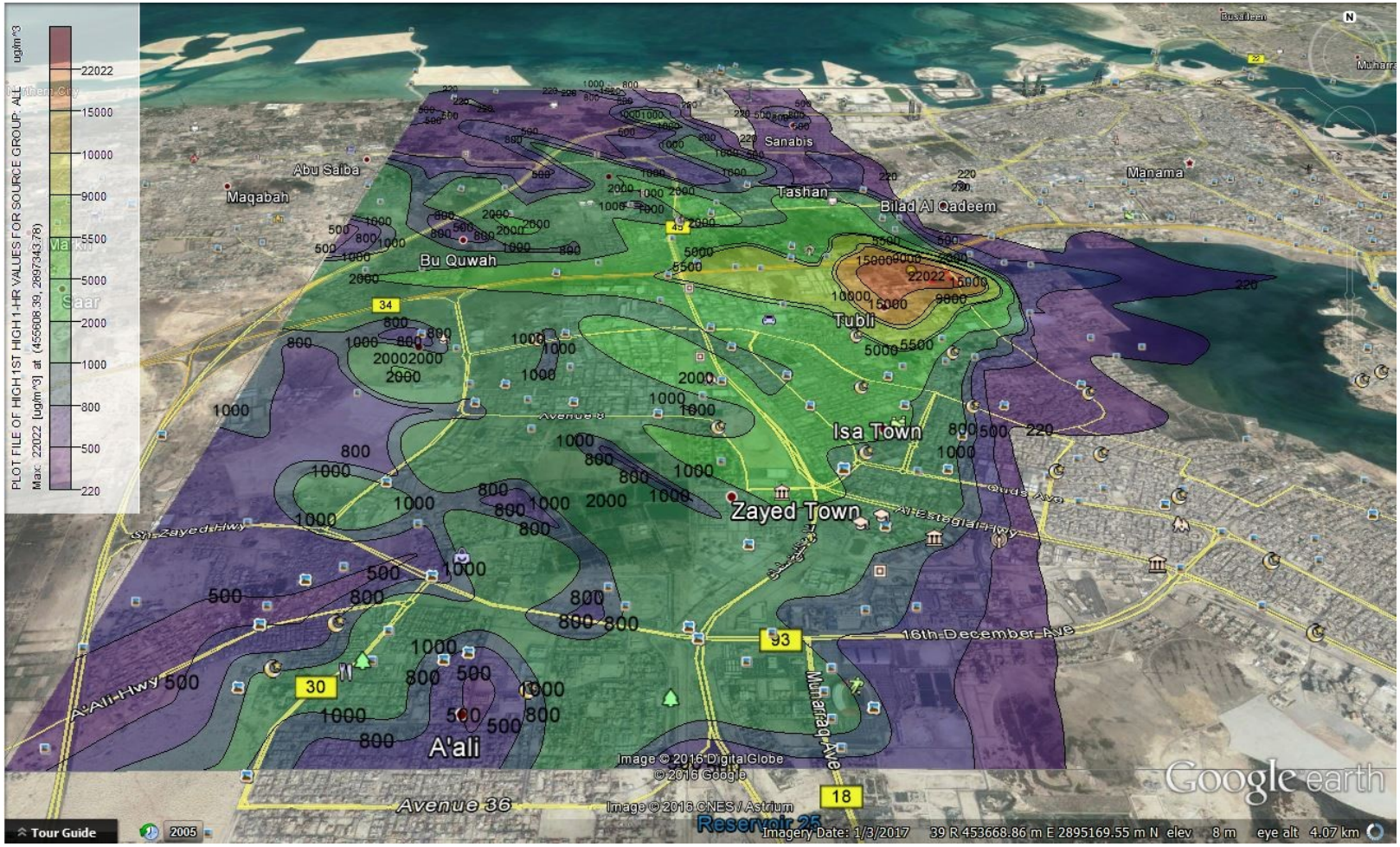


Figure (4.13)

H_2S gas dispersion for average of 1 hour, worst case scenario year 2014.

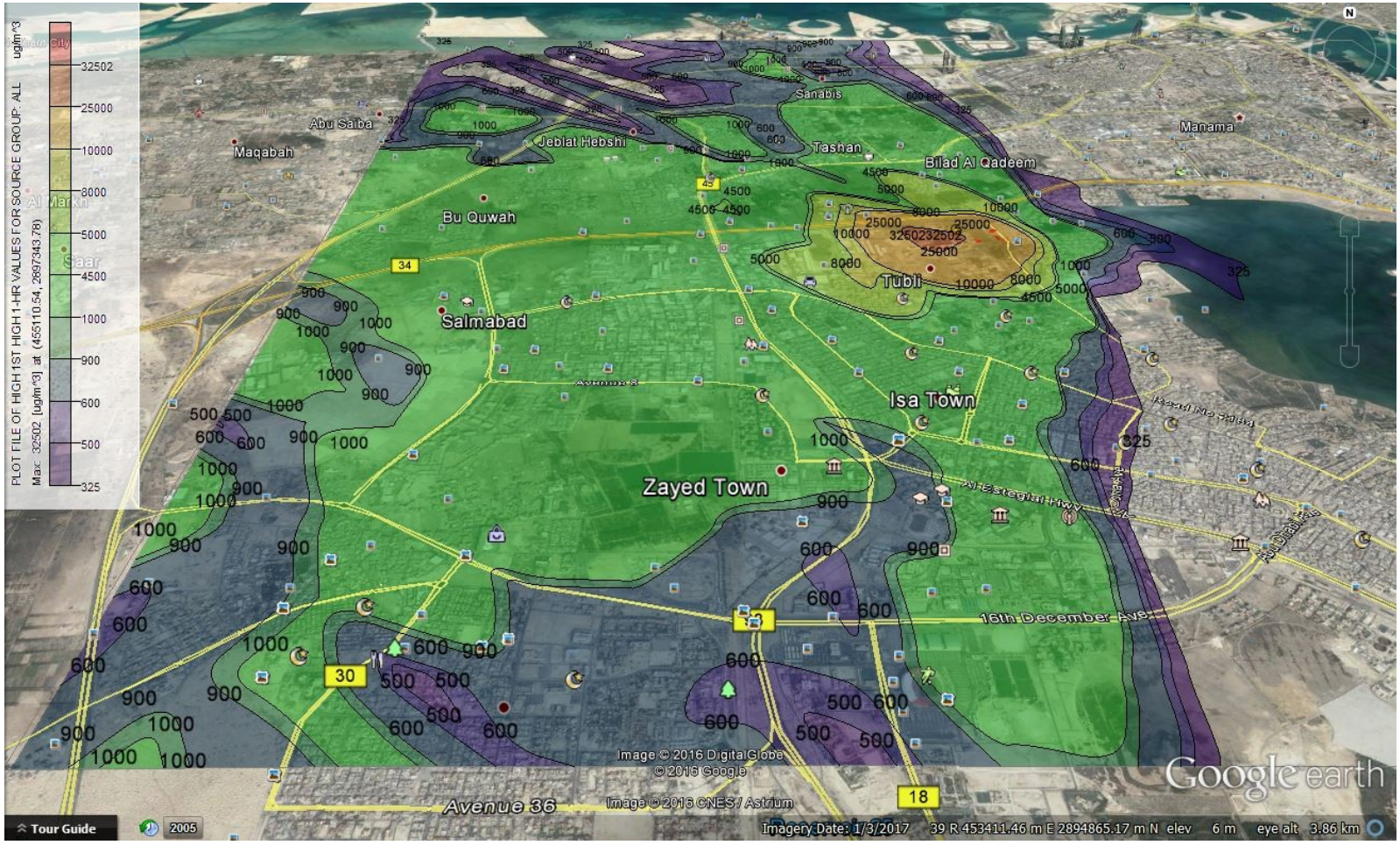


Figure (4.14)

H_2S gas dispersion 1 hour average, worst case scenario year 2015.

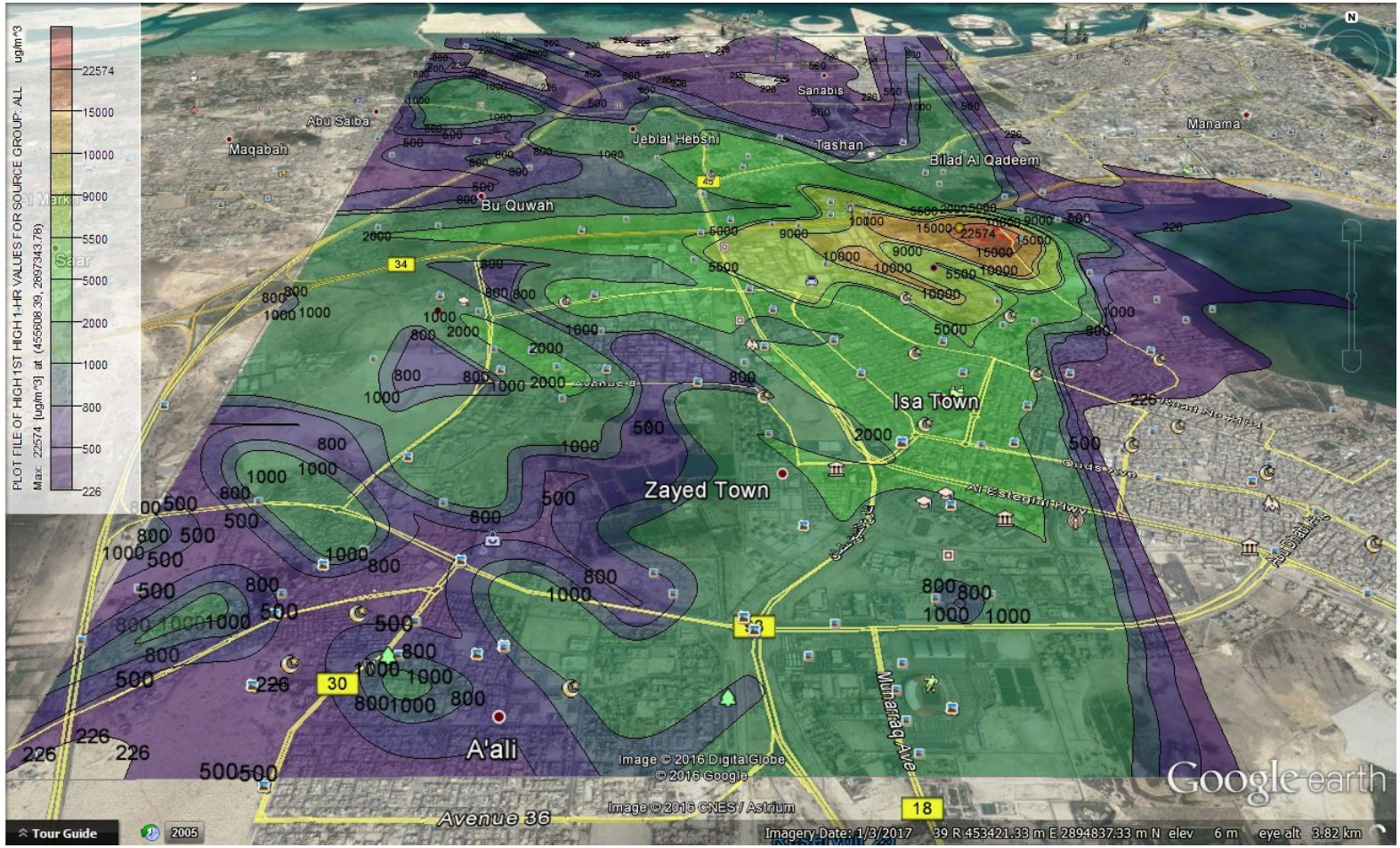


Figure (4.15)

H_2S gas dispersion for average 1 hour, worst case scenario year 2016.

The graphical representation for the odor contour maps shows the concentration in µg/m^3, the scale located in the left side of the graphs represent the level of H_2S concentration as per the color coding, the maximum concentration showed in red. The red area concentrated at the source location inside the STP facility. In order to compare the values with the threshold value for SCE guideline the contour lines value is converted to the ppb unit using the same equation (Felder, R., et al, 2011):

Concentration in ppb = (4.2)

Sample of calculations (normal scenario, year 2016)

Molecular weight of H_2S = 34.076 kg/ mole

Molar volume of H_2S = 24.45

For contour line = 385 µg/m^3

Concentration in ppb = = 276 ppb

Table (4.8) and Table (4.9) show the concentration level in ppb for year 2016 for normal and worst case scenarios respectively.

Table (4.8)

Concentration levels of H_2S gas as per the dispersion model, 1hour average for normal case scenario year 2016.

Concentration (µg/m^3)	Concentration (ppb)
385	276
300	215
100	72
70	50
50	36
30	22

Table (4.9)

Concentration levels of H_2S gas as per the dispersion model, 1hour average for worst case scenario year 2016.

Concentration (µg/m³)	Concentration (ppb)
22574	16197
15000	10763
10000	7175
5500	3946
2000	1435
1000	718
500	359
226	162

The results shown in the normal case scenario indicate high H_2S concentration which exceed SCE guideline value for 30 ppb in 1 hour, the area represented in yellow, orange and red color in Figure (4.14) however, the worst case scenario model shows that the entire receptor area is at danger. There are many factors influencing the dispersion of the gas, the fluctuation of the flow, the meteorological condition and the downwash effect.

Discussion

1. The values of the predicted H_2S concentration are much higher than the allowable limits by SCE 30 ppb.
2. The predicted values for worst case scenario are ten times higher than the normal case scenario.

3. When comparing the results for the consecutive years 2014, 2015, 2016 for each scenario it shows that the highest concentration recorded in 2015.
4. The modeled values for normal case scenario for year 2016 varied between maximum 276 ppb and 215 ppb inside the STP, Figure (4.12), when these values are compared with the actual measurements taken in December 2016 inside the STP the values varies from 1600 ppb (at inlet area) to 200 ppb (sludge thinking basins), Table (4.8), the modelled values are close to the lowest measured concentration.
5. For Summer model the resulted values are very high and unrealistic and cannot be accepted.
6. Similarly, for worst case scenario the modeled value for year 2016 is maximum of 16197ppb and 10763 ppb inside the STP, Figure (4.15), against the measurement values between 68,000 ppb (at tankers unloading area) and 19,000 ppb (at inlet area), Table (4.9), the modelled values are close to the lowest measured concentration.
7. Based on the modelling outcome areas surrounding the STP have similar H_2S concentration, for normal case scenario 215 ppb and for worst case scenario 10763 ppb, it assumed that the residents would complain about the odor is similar proportions in these areas, however, the complaints record received form MOWMU shows that complaints received only from block 711 residents.

8. The observation of Figures (4.10) to Figure (4.15) shows that large area impacted by the relatively high concentration (the recommended limits based on SCE for average of one hour is 30

ppb), this is not reflected on the complaints registered where the residents of block 711 at Tubli area are frequently complaining (total of six complaints in six years), based on this observation the following question is raised: provided that there are no reflecting[7] reasons do other areas residents perceived lower concentrations? Do the model values are realistic?

Therefore, in order to have a more realistic overview for H_2S dispersion in the atmosphere; it was decided that random field measurements to be performed. Therefore, H_2S gas concentration level was measured in different locations using the same air quality monitor. These measurements will be used to validate the model for normal condition. Figure (4.16) indicates location of H_2S measurements, where Table (4.10) shows that tabulated Figures of the actual measurements. It must be noted that the locations selected randomly and that around three measurements are taken for each location. Moreover, the measurements taken are located in different contours. Table (4.10) shows the measurements taken in comparison to the modeled value of the normal case scenario year 2016, Figure (4.12).

[7] Reflecting reason is based on the British standard terminology, to describe why residents who suffer from STP associated odor don't raise complaints, DEFRA 2006.

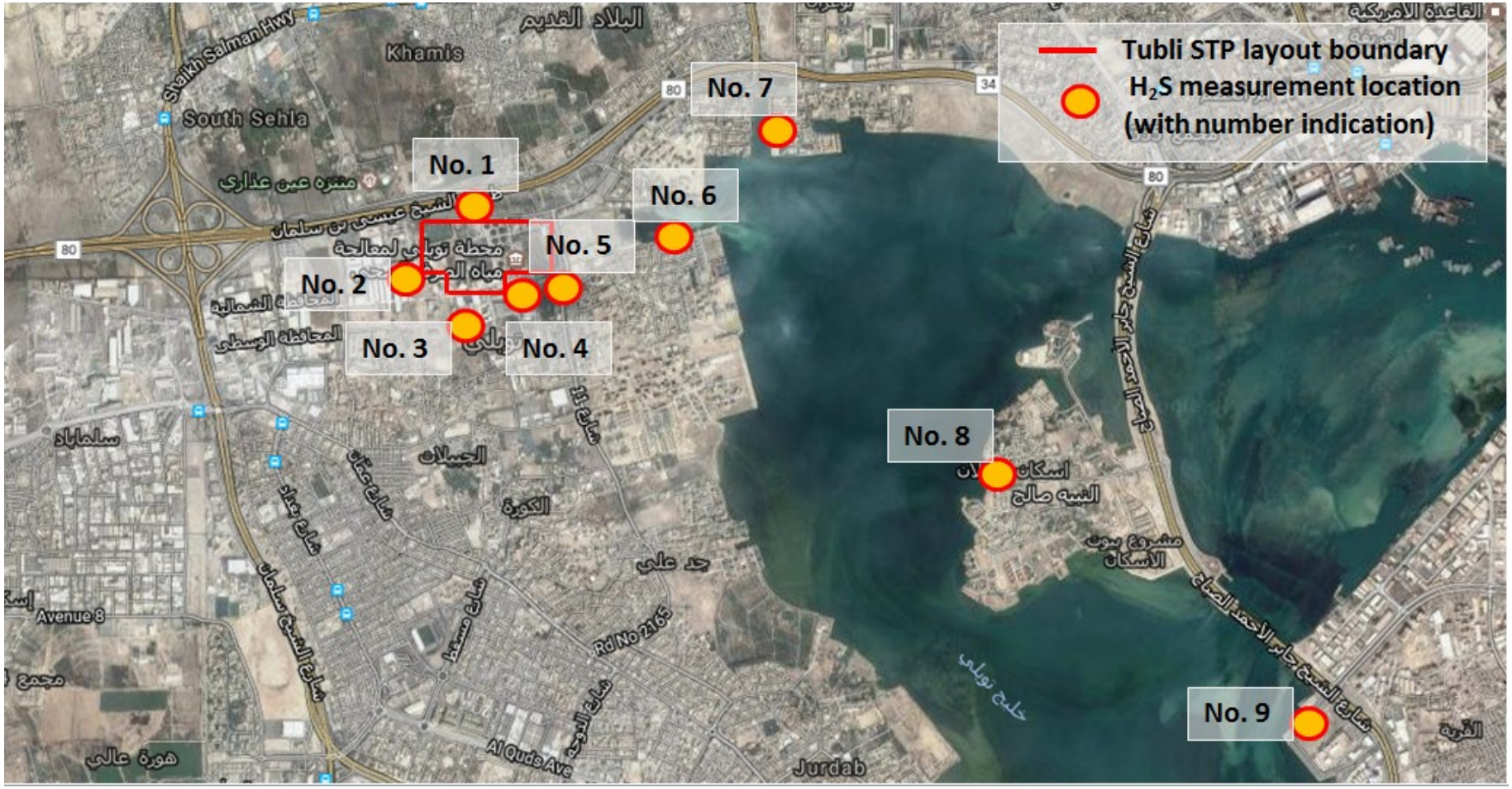


Figure (4.16)

H_2S measurement locations, January 2017

Table (4.10)

Field measurements for 9 locations in area surrounding the STP, January 2017.

Measurement location		Field measurements* (ppb)				Modeled** value (ppb)	Difference %
No.	Description	Recorded readings			Max reading		
1	North side of the STP	0	0	0	0	213	100
2	Back side of the STP - east side	400	500	200	500	213	135
3	Residential area back of the STP	0	0	80	80	213	62
4	Back side of the STP - west side	0	0	0	0	72	100
5	Adjacent to avenue 11	0	190	60	190	72	164
6	Adjacent to Tubli bay	0	10	20	20	22	9
7	Opposite to Tubli bay	10	40	30	40	7.2	456
8	Nabih Saleh island	10	10	10	10	5	100
9	Near Sitra mall	100	80	40	100	2.9	3348

Difference % calculated using the following equation = x 100%

*Measurements done in January 2017, average temperature 25° C, average humidity: 45 %.
**Values extracted from year 2016 dispersion model (normal case scenario) shown Figure (4.11) and Table (4.8).

Discussion

1. H_2S measurements values at the measurements locations exceeded the allowable limits of 30 ppb in one hour average as per SCE. (Bu Hassin, E.; et al, 2011).
2. Values from field measurements are in general less than the values predicted by the dispersion model.
3. The variation of the field measurements against the modeled values can be justified by the following:
   a) The dispersion of the gas is related to the metrological condition, local condition at the time of the measurement may contribute in values variation.
   b) Level of H_2S concentration depends on many factors related to the operation of Tubli STP, alteration of any of these factors may lead for the changing the values at the receptor, these factors are: flow received by the STP, the actual H_2S gas generated from different stages, and how smooth the process at the STP.
   c) Downwash affect, which typical condition occurred in conjected area where the presence of the buildings lead to dilute the odor locally and prevent the natural (predicted) path of pollutant dispersion.
4. H_2S concentration measurements agreed in principle with the model that the area impacted by the odor is large and not limited to block 711.

The modeling outcome exceed the allowable value by SCE for 30 ppb in one hour average, the odor contour maps shown in Figures (4.9) to (4.14) reflect large area impacted by the H_2S gas dispersion; where the actual field measurements indicate lower H_2S values (average of 80%

differences between the modelled and the field gas concentrations) therefore, using alternative method to validate the model result would provide a comprehensive understanding to the odor dispersion. The sensory measurement approach is selected and will be implemented through the community questionnaire according to the following reasons:

1) Odor is subjective quality and it is dependent on how people usually perceive it. Therefore, taking the residents feedback would provide better understanding for the odor dispersion limits.
2)The questionnaire is a common tool to identify the odor dispersion extension and there are many previous studies used it.
3)Employing the human nose of the residents to identify the odor is good indicator for the actual severity of the problem.
4)The results from the questionnaire will be compared with the complaints register this will support the first objective of the research.
5)Regulating authority commonly use the residents response 9through complaints) as indicator of odor problem.

It must be noted that the questionnaire is a qualitative assessment tool and it is difficult to compare the questionnaire outcome with the modelling (quantitative method) results, however the questionnaire would provide the actual residents perception for the odor.

Using the questionnaire

In order to have a more realistic overview of the actual perceiving range to Tubli STP odor emissions, the community questionnaire is used; the questionnaire is designed to identify the area in which the odor associated from Tubli STP is perceived, also it is requested from the

respondents to identify the level of the odor perceiving in normal case scenario and summer as the worst case scenario. Odor identifying scale used six categories:1) no odor is perceived, 2) odor is barely perceivable, 3) odor is faintly perceivable, 4) odor is clearly perceivable, 5) odor is strongly perceivable and 6) odor is very strongly perceivable. The questionnaire's model is of closed type with multiple choice questions. The pol is based on the general olfactory memory (past experiences) of the residents reflecting their experience with respect to the odor perceived in area surrounding the STP facility. Moreover, completed questionnaire is used regardless of the respondent condition as there is no exclusion mechanism applied for the responses which includes the smoking, age, ext). Appendix 1 shows the questionnaire model distributed to the residents in areas surrounding the STP, located within 2.5 km in radius where the STP is centre, these areas are identified as follow: Tubli, Zinj, Bilad Alqadim, Um Al Hassam, Alkawara, Adari, Isa Town and Nabih Saleh.

Sample Population

The identified areas surrounding the STP in the study area, 2.5 km in radius, has population size of around 150,000 per capita, 6.25 km^2 in order to have representative sample size the general statistic formula is used:

Sample size = (4.3)

Where,

Z =1.96 for confidence level of 95%,

σ = standard deviation, normal value =0.5 is used,

margin of error = 5% (100- confidence level)

Sample size = = 384.16 ≈ 385

Therefore, the minimum sample size is 385, the questionnaire is distributed to the residents though personal visits and electronically through online survey website. The total number of the completed questionnaire is 410, list of the responses is shown in Appendix 2, of this 56% of the respondents were male and 44 % were female. Where 77% of the total had age between 20-49 years old, and 20% were smokers. The characteristics of the population sample is represented graphically in Figures (4.16), (4.17) and (4.18).

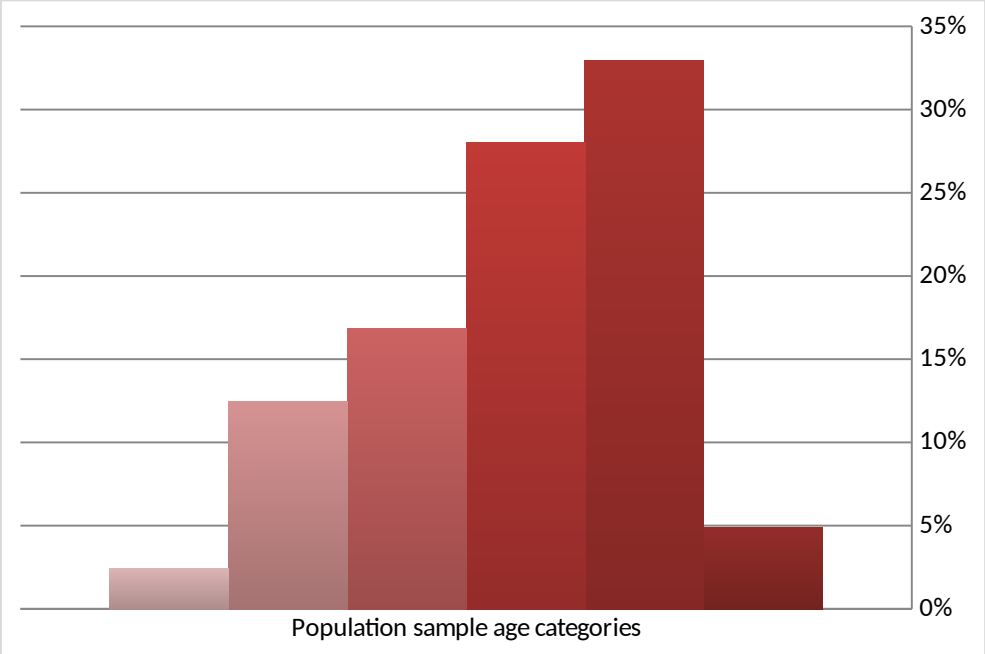


Figure (4.17)

Population sample age groups.

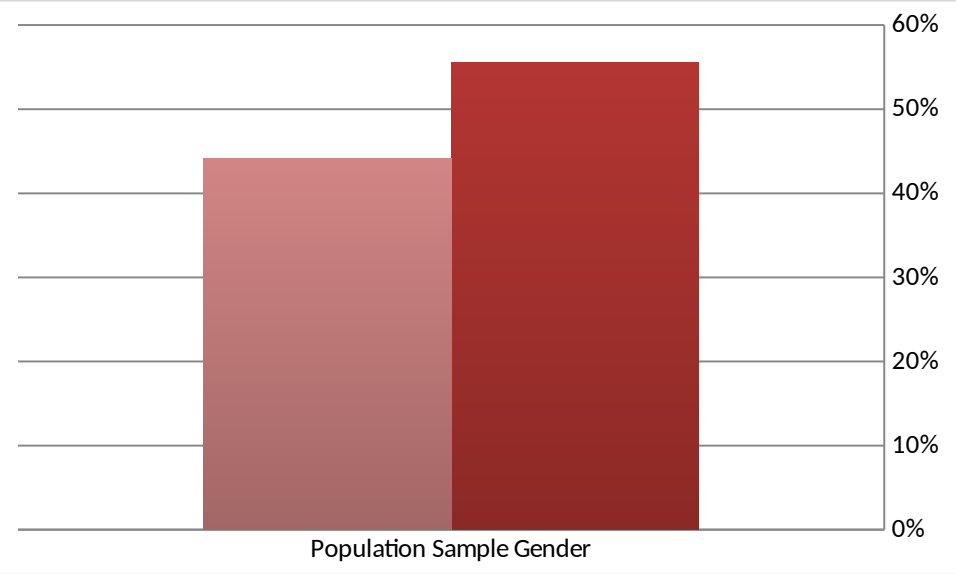


Figure (4.18)

Population sample gender groups.

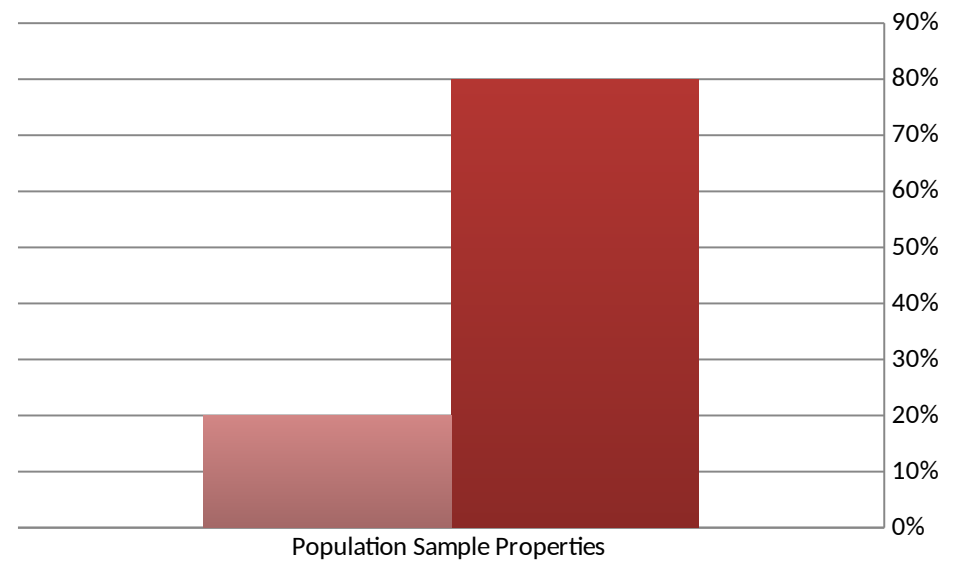


Figure (4.19)

Population sample smoking category

Questionnaire questions

The questionnaire is designed to collect information from the residents of areas surrounding the STP in order to measure their perception level of the odor associated with the STP in normal case condition as well as the summer time. Furthermore, information about the time period were the most odor perceived was required at the end of the questionnaire in order to identify the most dispersion time of the odor as perceived by the residents. Each respondent identify the location in question, and then the odor perceiving level was identified on scale of six in the time of the questionnaire which is between March and April and in summer time to identify the worst case scenario. At the end of the questionnaire the respondents were asked to identify at what period of the day the odor is perceived the most. Figure (4.19) and Figure (4.20) shows the graphical representation for the responses.

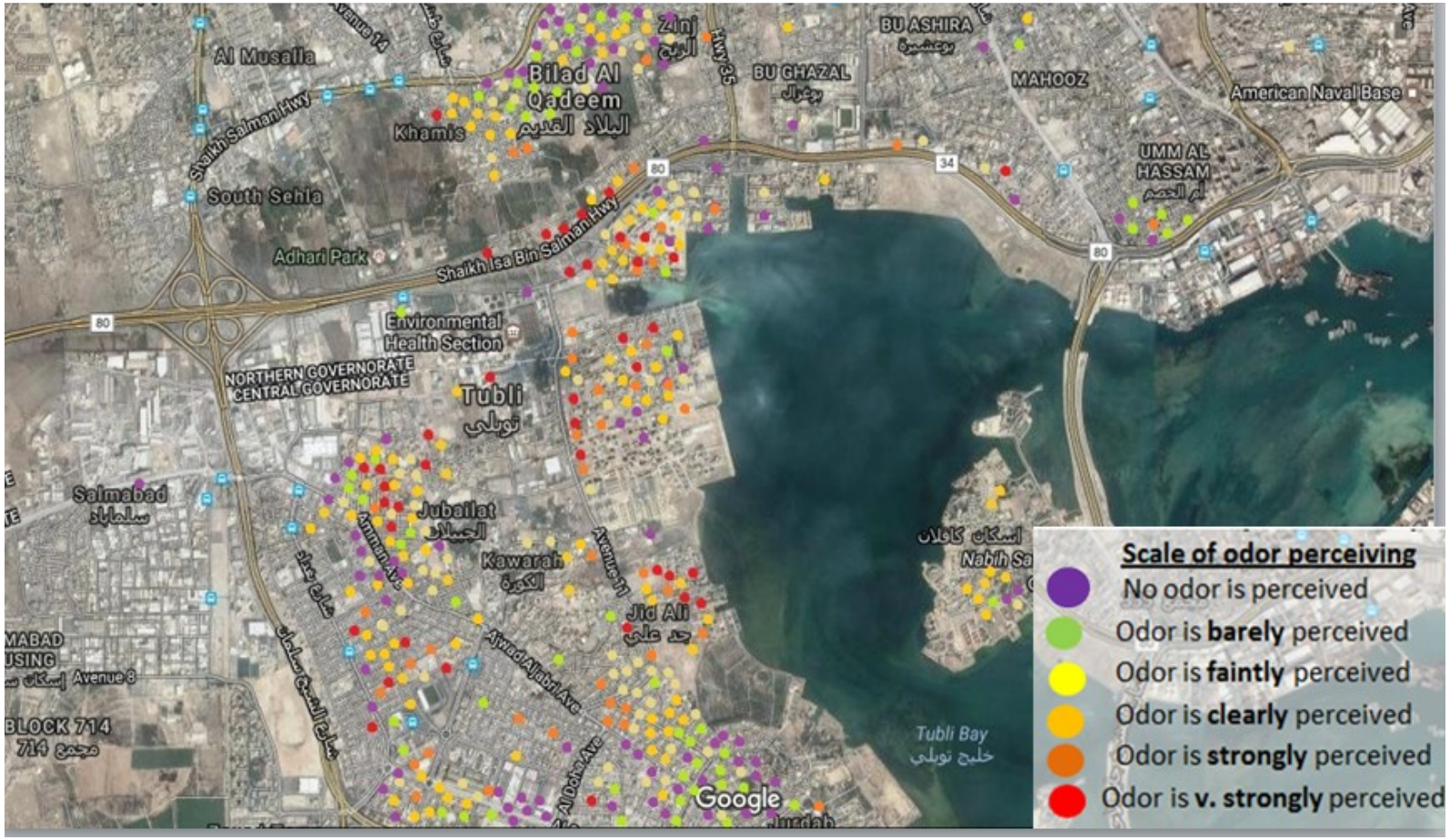


Figure (4.20)

Representation of the odor perceived areas as per the questionnaire

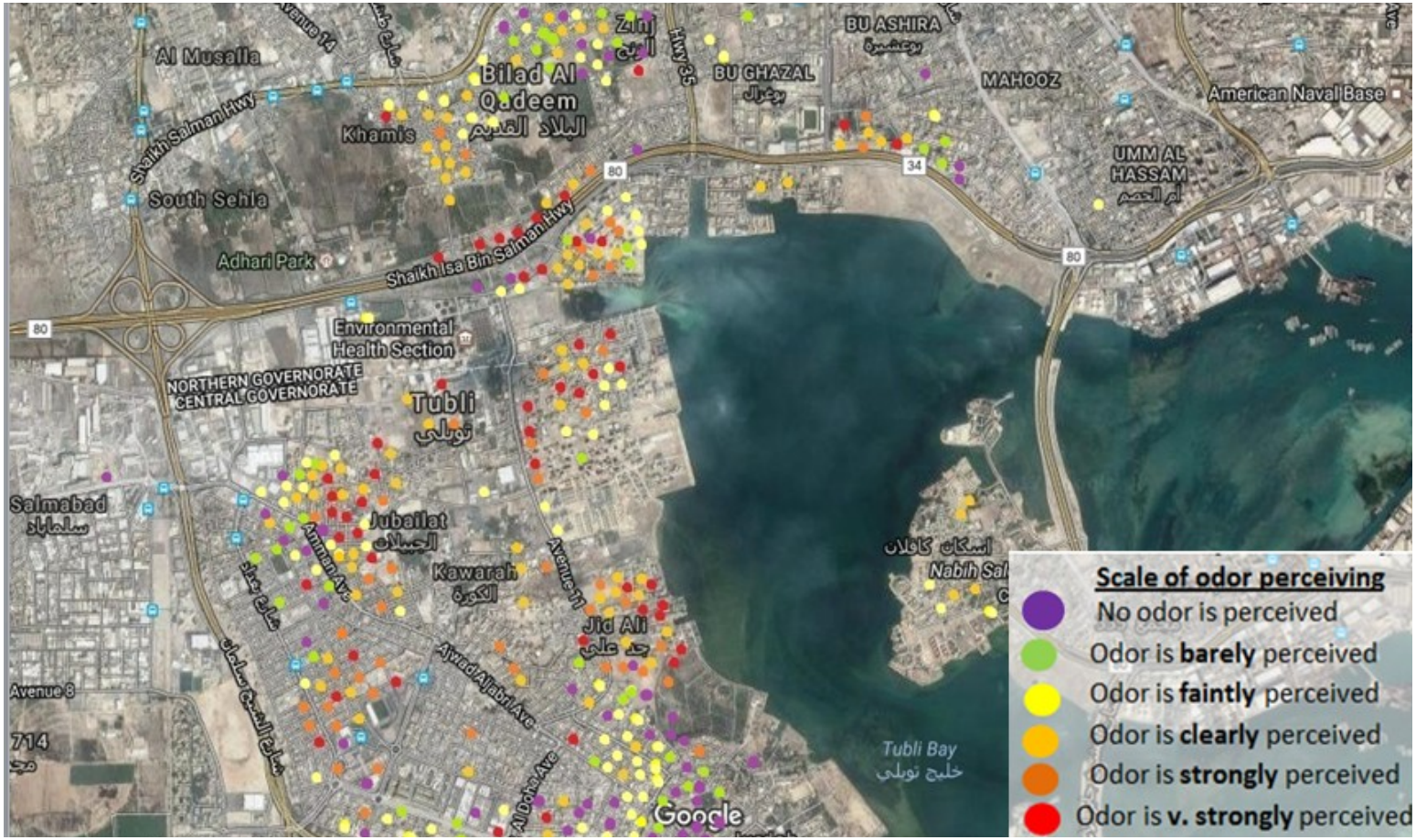


Figure (4.21)

Representation of the odor perceived areas as per the questionnaire in summer

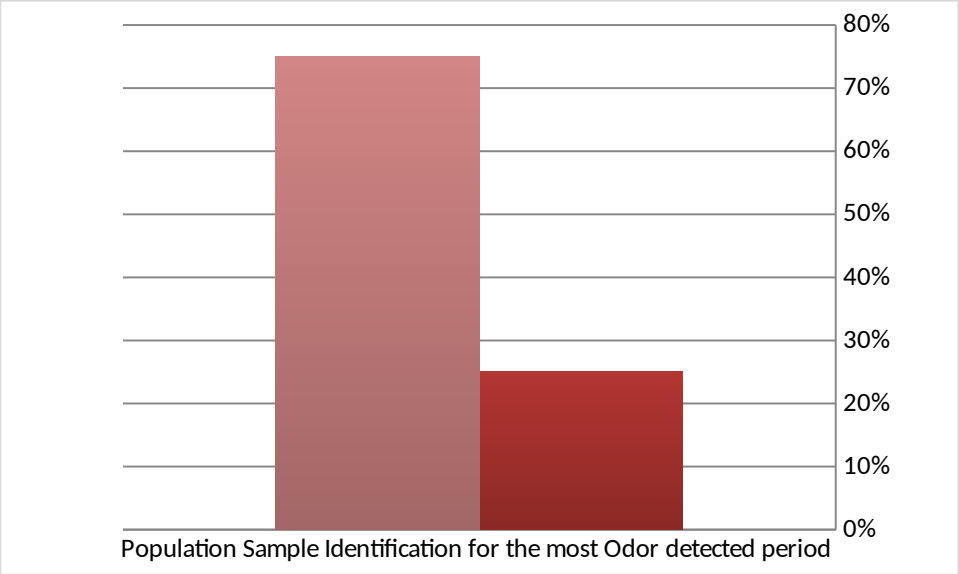


Figure (4.22)

Bar chart represents the total responses percentage for question number three.

General observation upon the questionnaire results

Based on the responses received the following observation is made:

1. Figure (4.20) and figure (4.21) shows that most respondents agreed that the very strong odor is perceived in the areas adjacent to the STP where dark red spot represents " very strong" and red spot represents " strong" odor perceiving level, this is similar to the location of the most frequent complaints located at Block 711.

2. About (66% - 271 out of 410) of the respondents agreed that same odor level is perceived during the entire year, against (34% - 139 out of 410) stated that in summer the odor perceiving level is stronger and about of (77%) stated that the odor level is perceived stronger by only one scale level higher.

3. Majority of the respondents (75%) stated that the odor is detected more in night time this results matches what is commonly illustrated in previous studies, the reason for this was referred to atmospheric layer condition at night, this phenomenon was not fully addressed in the previous studies reviewed and many due to the involvement of other uncontrolled factors it is difficult to identify the exact reason.

4. There is variation between the responses in same areas, where some may rank the odor perceiving level "very strong" other would state "no odor" for the same location.

5. Most responses (72%), in normal condition and (82%) in summer (worst case scenario) stated that Tubli STP odor is detected, responses for scale between barely and very strong odor perceiving, within the surveyed area of 2.5 kilometres radius circle.

6. There were some of the responses of strong odor perceiving level recorded close to the no odor and barely odor perceiving level responses this might be due to a local foul odor source rather than the STP, further investigation for these cases might provide better understanding.

Questionnaire responses analysis

The questionnaire responses of 410 respondents are collected and represented in figure (4.23) which shows the odor level perceiving in both season.

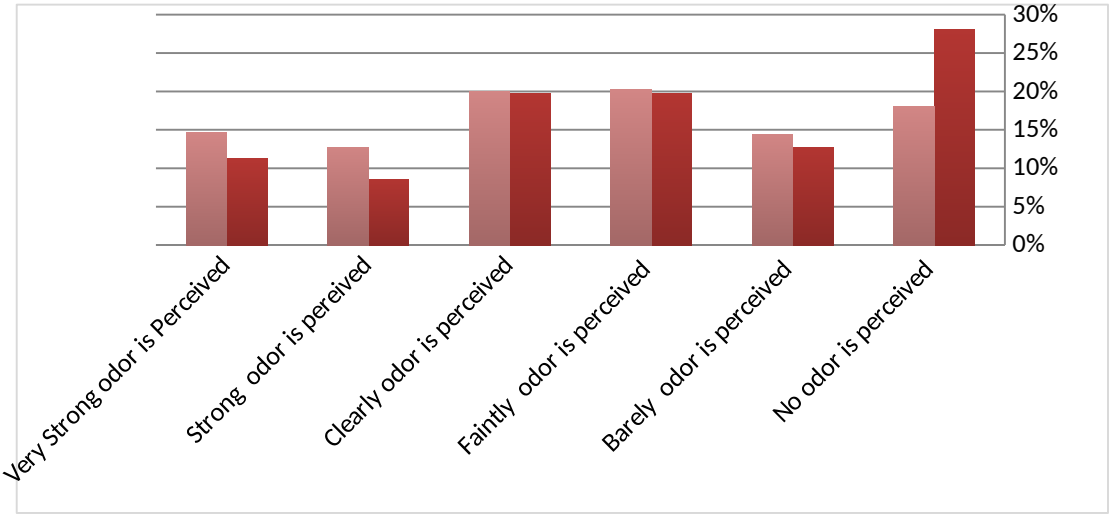


Figure (4.23)

Total population sample responses percentage.

Based on the sample responses shown in Figure (4.22), among the 410 respondents sample it is estimated that over 28% do not perceive any odor in normal condition against 72% that confirmed that odor is perceived in some level, similarly in summer season, worst cases scenario, only 18% of the respondents stated that they can't perceived the odor against 82% who stated that odor associated with Tubli STP is detected. When compare both scenarios it shows that there is no significant differences between the overall perception, based on the results it is 10% of the respondents admitted that odor can be perceived for some level only in summer. In the other hand, if the assumption is made that the level of annoying is considered to be equivalent to the "strong odor level perceiving" on the questionnaire scale, the total annoyed respondents form the odor in normal condition is 20% and 28% in summer season. Furthermore, the responses recorded for very strong, strong and clear odor perceiving level are considered as annoyance zone, when the responses of these category is plotted against the distance from the STP as shown in Figure (4.24).

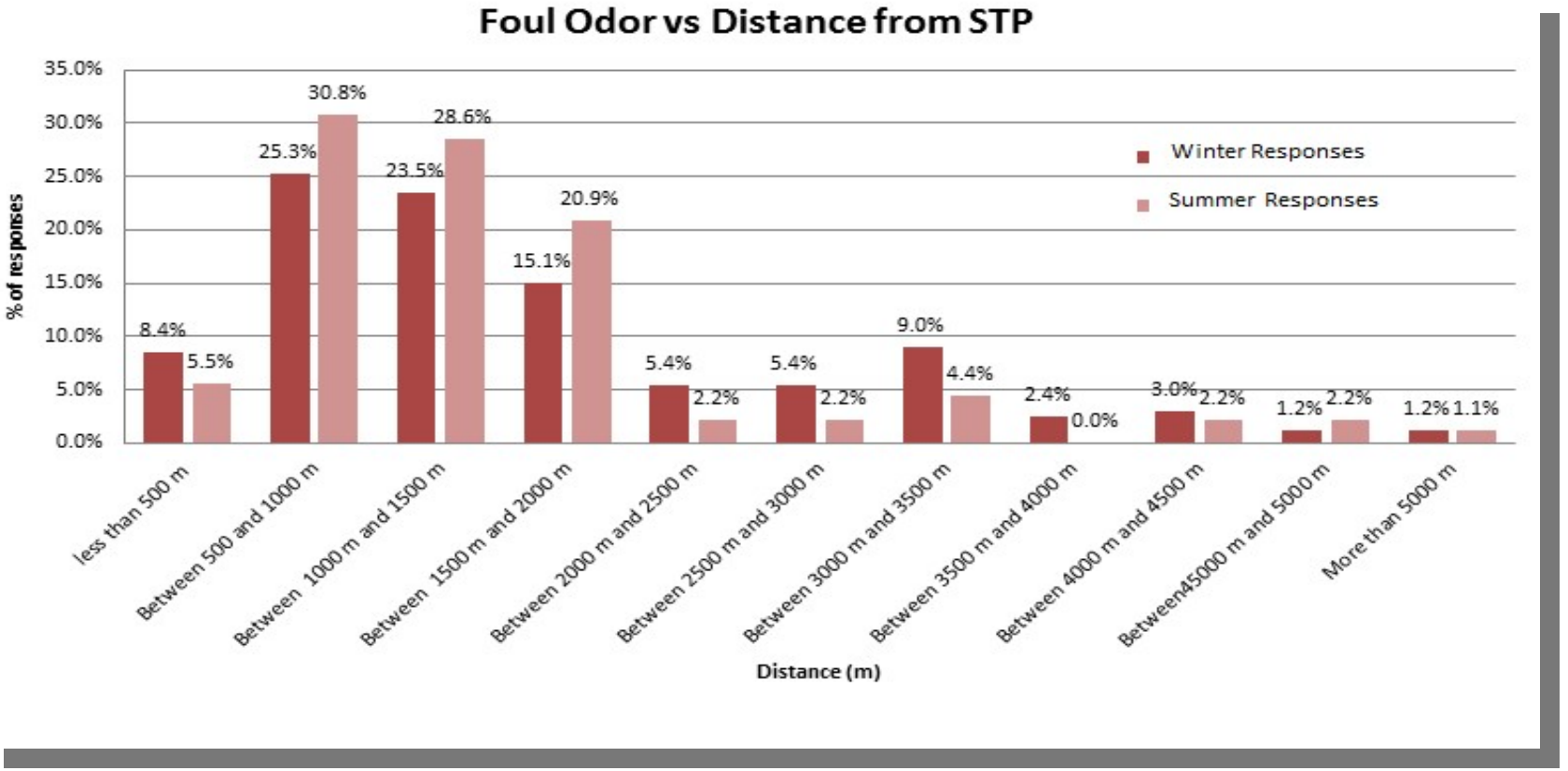


Figure (4.24)

Responses of the questionnaire based on the distance from the Tubli STP

As shown in Figure (4.24) the results indicated that the odor is most sensed within the first 1.5 km from the STP and faded away as the receptor is distanced from plant. In other words, the areas located away from the STP are less likely to complain about the foul odor emitted from the STP. In addition, the comparison between the despondences in summer and other months are almost similar Figure (4.24) shows the difference between both seasons odor emissions is minimum, this might be referred to the fact that in summer season there is almost no wind to transmit the odor. The data presented in pervious figure shows that the major influence odor annoyance is the distance close to the STP this indicate that the STP odor is causing nuisance in cases where the STP is located in residential areas or for the older STPs like Tubli, when the area surrounding the STP is occupied. In the other hand the responses gathered from the residents less than 500 meters are lesser compared to the other categories (500 to 1000 meters) and (1000 to 500) this may be due to the land uses and existing developments for the areas adjacent to Tubli STP is commercial and light industry and accordingly semi – skilled labors might not be able to respond to the survey.

Odor dispersion area (Model versus Questionnaire)

The resulted graphs from the questionnaire to be compared to the results from the dispersion modelling in terms of the area impacted by the odor nuisance, it is assumed that for the annoyance odor level, responds reply with : very strong, strong and clear odor level is perceiving, where for the modelling results SCE guideline for 30 ppb is used as the minimum level of annoyance in other words odor contours represent 30 ppb and more are within the impacted area. Although, the threshold value for H_2S is very low (0.00047) and using 30 ppb would be

conservative as value of annoyance. Moreover, the dispersion modelling for normal case scenario will be used for comparison purposes only since the worst case scenario modelling results are unrealistic and cannot be exist in the atmosphere. Figure (4.25) shows the dispersion model odor contour for year 2016 with the odor contour = 30 ppb (contour 50 μg/ m^3 = 36 ppb), similarly Figure (4.26) shows the (normal case) winter scenario for the questionnaire results. The highlighted area in the figures represent the approximate distance of the odor limit extension, by comparison the area impacted as per the respondents is less than the area simulated by the model, the reason for this variation could be the down wash effect of the building located around the STP . By comparing both figures the suggested area impacted by the STP odor is limited to a maximum of two kilometers away from the STP, however, this area needs to be further studied and validated by continuous measurements monitors. These monitors would be placed in identified receptors at fix intervals, following receiving the gas concentration at these points odor contour map needs to be drawn and further compared to the questionnaire and model produced maps. The area impacted can be monitored and further controlled.



Figure (4.25)

Modelled normal case scenario (2016) showing the around 5.5 km circle of more than 30 ppb.

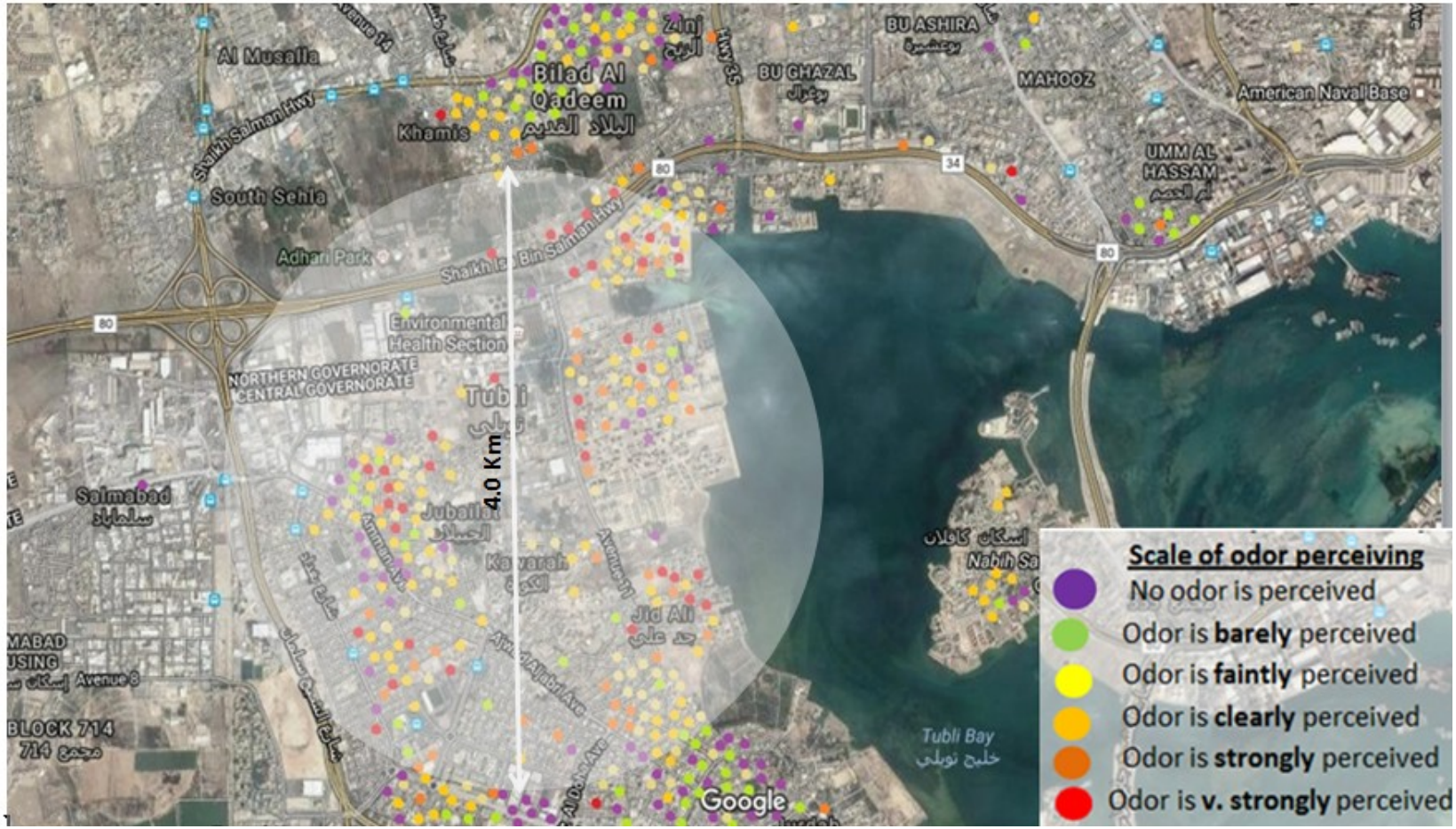


Figure (4.26)

Questionnaire results for (normal case) winter scenario showing the around 4.0 km Circle of odor dedetcted.

H_2S Concentration Scale

The results of the questionnaire provide a qualitative way to identify the odor perceiving level, in order to covert the level of the odor perceiving into a quantify value the odor index concept is used. Odor index is a representative value for how much of a particular chemical it takes for the average citizen to notice the odor. The purpose of this index is to provide a standard method to measure and quantify the odor internationally, similar to the sound unit decibel (Shih, Li, Chan, & Syu, 2007). Similarly, a scale is used in logarithm to identify the level of the perceiving the odor against the actual measurements. In attempt to compare between the results obtained by the field measurements and the questionnaire respondents, the limits would be drawn in the logarithm scale and further be correlated to the responses. Based on the field measurements performed in September 2016 showing in Figure (3.5), the H_2S measurement value outside the STP boundary is less than 1ppm, therefore, it is assumed that this value will represent the highest value in the odor perceiving scale used in the questionnaire "very strong", where the minimum value in the scale is set at the threshold value of 0.0047 ppm, any concentration less than this value will be set as "no odor is perceived". In addition, the clear odor perceiving value would be set as 30 ppb. The logarithm scale between these three identified values will be divided equally to set the remaining levels in the scale. As shown in Figure (4.27). Moreover, the values estimated are shown in Table (4.11) for each odor perceiving level used in the questionnaire.

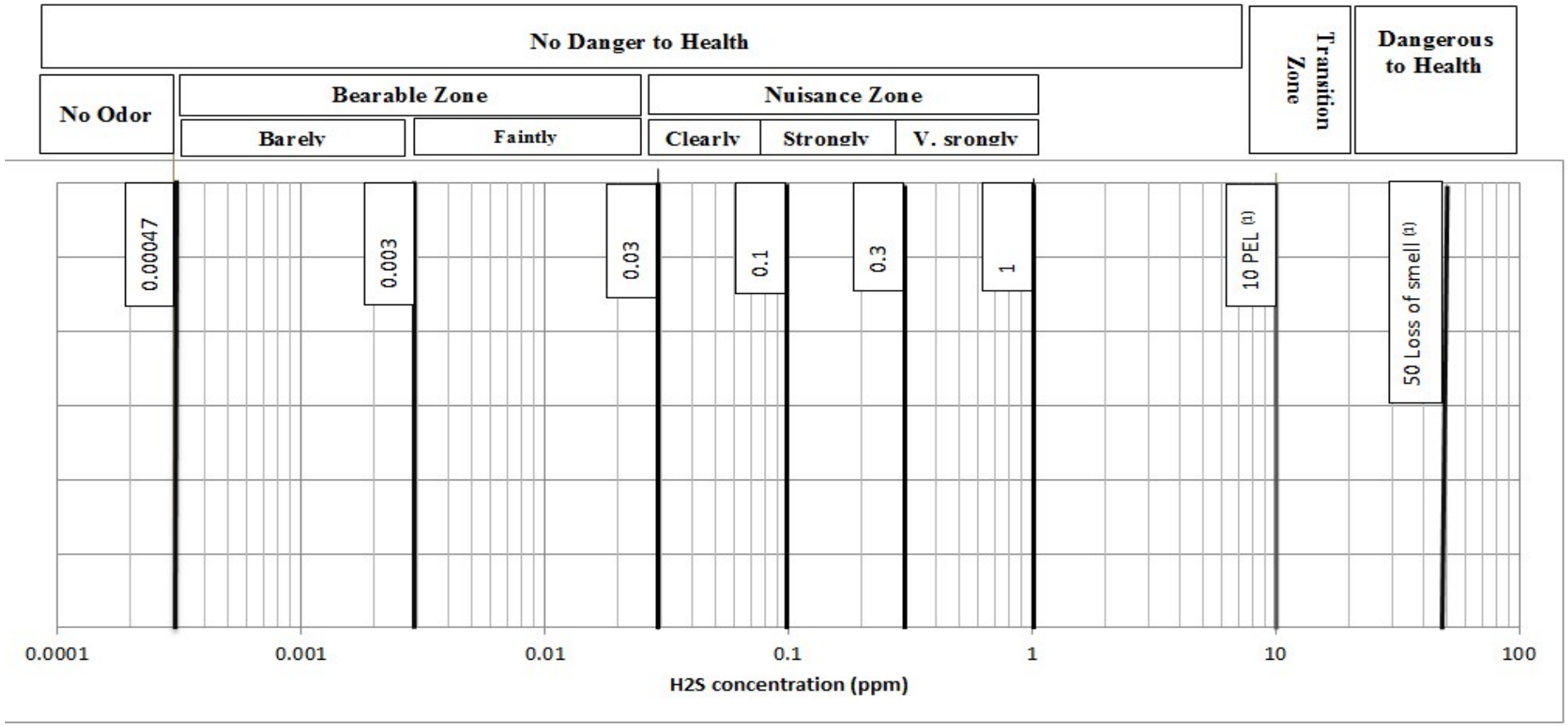


Figure (4.27)

Relating the questionnaire responses scale with the field measurements using logarithm scale. ([1] OSHA(2017). *Saftey and Health Topics – Hydrogen Sulfide- Hazards. Retrieved 2017, from www.osha.gov.* PEL: permissible exposure limit - enforceable)

Table (4.11)

H_2S gas concentration and the relative odor perceiving level as specified in the community survey.

H_2S concentration (ppm)	odor perceiving level
0.3 - 1	Very strongly perceived
0.1 - 0.3	Strong perceived
0.03 - 0.1	Clearly perceived
0.003 - 0.03	Faintly perceived
0.00047 - 0.003	Barely perceived
Less than 0.00047	No odor is perceived

The values shown in the table above showing that the H_2S gas concentration has wide range from the minimum perceived value at 0.00047ppm to the 1 ppm this would be reflected in the variation of the responses of the questionnaire, each individual would response to the same concentration of the gas differently which make the criteria to control the odor complaint is also difficult, the British regulation agency DEFRA suggested that limit the H_2S gas concentration to 5 ppb (DEFRA, 2006) which represent the no odor category, in order to maintain this value management plan for monitoring the odor emissions in addition to odor control measures must be implemented.

Tubli STP Odor Management and Control

The odor assessment for Tubli STP confirmed that residents of the area adjacent of the STP can perceived the odorous emissions that were confirmed by the community questionnaire and simulation model. Also, the resulted odor impacted area from the community survey and the dispersion model are the same in common area of 2 kilometer radius circle which the H_2S gas concentration is varied in range less than 1 ppm which is safe gas concentration. The low gas concentration of H_2S

however, still causing public nuisance. Alternatively, this situation would be worsening due to the location of the residential buildings in close proximately to the STP, therefore, odor management and control measures must be implemented.

Odor management at Tubli STP

Management of the odor emissions in Tubli STP consist of two parts: implementing the good practice and odor monitoring. The good practice includes that the STP operator must implement appropriate measures to manage and control the odorous emissions from the STP, the good practices include:

1. The overall sewage treatment works management.
2. Design, construct, and maintenance overall STP facility.
3. Operation of the STP at the designed condition.
4. Maintained the STP facility and treatment process at the designed condition.
5. Provide sustainable and maintainable measures to control or ventilate the odors from different part of the STP.

The involvement of the climate conditions and the surrounding local developments are important factors that the STP operator must take into consideration. The awareness of the receptor sensitivity would control the overall required STP performance. In other words, the STP is normally emitting odorous emissions however; the level of receptor sensitivity is playing the major role. Similarly, for sensitive receptors more conservative approaches for the odor control measures. In the other hand, odor monitoring include all the activities that the STP operator would implement in order to detect, verified or/and predict odor existing or concentration outside sand inside the STP boundary limit. There are

several means to identify the level of odor significance or level outside the STP such as:

1. Complaints monitoring: this is a qualitative approach and there are several factors involved in the complaints evaluation like: volume of the complaints against the nuisance of the odor, complaint frequency, repeated complaints against odor.

2. Population survey: this is a qualitative approach, survey to cover the population surrounding the STP and collect the feedback on the effectiveness of STP odor control. These surveys may be conducted by external party. Also, odor logs and diaries can be used to verify the odor existing in areas adjacent to the STP.

3. Field assessment: this include the "sniff test" in which the odor intensity is recorded on the VDI scale ranging from (0= no odor to 6= extremely strong) every 10 seconds over minimum 30 minute period at each location. (DEFRA, 2006) or installing ambient air quality monitors in the sensitive receptors that measure concentrations of odorous gases.

4. Dispersion modelling: a quantitative approach to predict the gas concentration at on location based on the operation data of the emission rate and metrology. This data might not be available.

Complaints Management

The complaint is a useful indication for the existing of the odor, therefore, the operator must develop a strategy to optimize the quality of data of each complaint and keep an updated register for the most frequent complaints over the years. Also, it is important to decide how the complaints data will be used and interpreted there are several factors involved in complaint receiving like the complaint volume where the number of complaints should not be the only factor for example several complaints from the same individual does not mean the same as several complaints from several locations. Also, the investigation for any complaint must include other factors, like the FIDOL: frequency, intensity (concentration), duration, relative offensiveness and the location (DEFRA, 2006). Moreover, there are factors that influence the human responses for any odor, there are more sensitive people for the odor then others. Complaint evaluation sometimes does not count for the very sensitive individuals. In addition, adaptation factor plays major role, for example people who used to the odor won't raise complaint, for Tubli STP odor assessment the number of the respondents who reported that the odor is very strong is not reflected in the complaints register, as well as the location of the complaint. Therefore, absence of the complaint does not necessary mean that there is no odor. In other words, compliant management and monitoring should not be the only approach for odor management of the STP.

Odor Management Plan (OMP)

Odor management plan is a formal document developed usually and used by the STP operator the main purpose of this document is maintain consistent and effective procedure in dealing with the STP's odor, the

document give detailed description of the STP operation, process, plant performance checks as well as introduce the operator for the action and type of data to be gathered when odor complaint incident is occurred. Moreover, the plan must contain detail information about the procedure to allow the STP operator and maintenance staff to understand exactly the operational and abnormal. This plan would describe the protocol in dealing with complaint. OMP normally includes the following:

1. All potential odor sources on the site,
2. Identification of the odor sources that most likely to cause the annoyance and probably raise complaints.
3. Identification of the odor control strategies for each significant odor source.
4. Development of practical protocol to respond to odor complaint.

The description of odor source includes details about the size, dimension, type of source, emission rate, time of operation, distance to property line, distance to neighbor and public areas, topographic, and ventilation system. This plan should be reviewed and modified as needed or in annual basis, where any changes in the STP facility, operation or the outside community or adjacent building must be recorded and reflected in the OMP. This plan would reflect the overall performance of the plant and must promote for healthy communication between the STP operator and the surrounding community.

Tubli STP odor management proposal

In order to improve the odor management of Tubli STP it is suggested the installation of the monitors at the fence – line to dictate the gas concentration outside the STP. Based on 2016 wind rose showing in Figure (4.8) that represents high and low wind direction in addition to the neighbor developments that located in close proximity three air monitors is proposed, installation of two monitors in the high wind direction and in the low wind would provide good information for the STP performance. Figure (4.28) shows the suggested location for the monitors. In addition installation of four off-site monitors at selected sensitive receptors. In other hand, population survey may be conducted as part of the general Sanitary Services customer surveys, these surveys might be conducted annually or every two years.



Figure (4.28)

Location of the proposed gas monitors at Tubli STP

Moreover, it is suggested that the STP operator develop an odor management plan and make it part of the work procedure, OMP implementation in this case would be part of the good practices. The

operator would keep checks of the odor control and management effectiveness inside and outside the STP facility at regular basis and report the performance in the management meetings. Finally, STP operator is strongly suggested to maintained effective and updated compliant monitoring register.

Odor control for Tubli STP

Tubli STP odor problem origin is directly based on the location of the development in close proximity to the STP. Tubli area which once was remotely from the population is considered now populated and popular area; accordingly, additional measures for odor control and abatement are needed. It is suggested to concentrate on the most odor source(s) inside the facility. Based on the field measurements inlet, and sludge thickening areas inside the STP contribute mostly in the overall odorous emissions. Odorous emissions are preferred to be prevented rather than to be contained and treated however, where cases it is not practical to prevent the odor then odor control measures need to be implemented to the level prevent annoyance to the public. The main factor for selecting the odor control is life cycle cost. The STP operator would perform a total life cycle cost evaluation for each alternative with the correspondence odor abatement degree. Following the assessment the most effective solution would be selected among other. Life cycle cost assessment would include the initial installation, operation and maintenance cost during the full life cycle. In general, the good practices measures would be more cost effective than the odor control installation. There are two approaches for the odor control one promotes the reduction of the odor emissions and the other promotes the odor dilution and dispersion.

Odor Reduction Methods

Odor reduction techniques depend on collecting the odor and treat it before they leave the site. Usually this process is involved biological, physical or chemical processes, one of the most common techniques are:

1. Biofilters:

   A biofilter treats the odorous gases using microorganisms exist in the biofilter media which oxidize the gases into simpler odorless compounds. The installation of the biofilters and use is simple and they reported effective if properly designed and maintain. However, disadvantages of these filters are the large area required for treatment which is directly relation with the inflow to be treated. The biofilter normally need a retention time between 40 – 60 seconds before the treatment. Poor performance of the biofilter is due to: lack of moisture, pH depression, and high temperature. In addition, high concentration of ammonia (more than 35 ppm) in the media would reduce the ammonia removal deficiency. The need to keep the media moist needs considerable amount of water and the used water (leachate) need to be dealt with. The use of the biofilters in Tubli STP is not suitable due to the following reasons: high temperature, where there is limited area inside the STP and the filters needs considerable area. This would alternatively promote the use of the chemical scrubber.

2. Chemical scrubber:

   The basic principle of the scrubber is to provide contact between odorous air and chemicals to enable the oxidation of the odorous compounds into simpler odorless compounds. The multiple scrubbing is suitable for removal of mix odors, the basic elements consist the scrubber is the vessel, packing material liquid recirculation system with spray nozzles, recirculation pump, a sump and mist eliminator. A fan is used to push the odorous air into the scrubber where the solution is sprayed by the nozzles; the liquid solution is then fall into the sump where it is recirculated and the air then exits through the mist eliminator to avoid the droplets from exiting the scrubber. The common chemicals used in the scrubbers are: oxidize hydrogen sulfide and other reduced sulfer compounds include sodium hypochlorite (bleach) and sodium and sodium hydroxide. Chemical scrubber is proven technology which removes 99.5% of the hydrogen sulfide and ammonia even at high concentrations (Tchobanoglous, G.et al, 2003). Although, the chemical scrubber required less area than the biofilters however, the scrubers required a lot of maintenance and continuous chemical supply alternatively it is a long investment which needs a management make decision. For Tubli STP there is an existing odor control unit which is also chemical scrubber this unit is installed for the tankers discharge channel. For the inlet area which is the main odor source a chemical scrubber would be suitable.

Odor Dilution Methods

The dilution of odor in the air is a function of distance, topography, and meteorological condition. Techniques to increase the odor dispersion and dilution before reaching the sensitive receptors include: shelterbelts, windbreak walls, and setback distance. The most cost effective approach would be the setback distance, however, for Tubli STP this option would be challenging as all area surrounding the STP facility is privately owned. The most attractive techniques alternatively would maintain tree lines inside or just outside the facility boundary the location of the tree line is most favorite to be close to the odor source where the turbulence caused by the trees would increase the dilution of the odor and alternatively reduce the odor strength. Normally three tree lines are recommended (NRCS, 2007). The STP operator would easily maintain these trees since that irrigation water is available from the treated sewage effluent produced by the treatment process. There are several tree types that would promote purifying the air; normally combination of the trees is recommended as per the US department of agriculture: one line of low-growing shrub to provide vegetation down to ground level, second, an evergreen species in order to provide year round vegetation and odor control, third of deciduous trees. The general guideline for the buffer zone is depended on the area available on site and the type of trees selected, however, the US general guideline for the spacing between the rows is from 16 to 20 feet (4.9 – 6 meters) these distance is maintainable. Table (4.12) shows general guidelines for the spacing between trees. Also, the trees should be more than 3 meters height because that the inlet chamber opening is located 3 meters above the ground.

Table (4.12)

Spacing between the trees in buffer zone vegetative, (NRCS, 2007)

Type of tree	Spacing
Small shrubs (4 – 12 feet tall)	4-6 feet apart
Large shrubs and small trees (12-30 feet tall)	6-10 feet apart
Large trees (over 30 feet tall)	10 – 14 feet apart
Evergreen trees (depending on the species)	8-14 feet apart

As per the American standard it is recommended that three tree lines to be provided and each tree line is 6 meter apart (20 feet), the required area for the buffer zone is minimum of 18 meters, the guideline also specify that for the location adjacent to the building ventilation fan the first tree line must located at distance at least 6 times the diameter of the fan apart. To identify the area available in Tubli STP measurements using google map is taken, Figure (4.29) shows the area available for the buffer zone approximately.



Figure (4.29)

Available area for buffer zone at Tubli STP

Tubli STP Odor control proposal

The most suitable selection of the odor control measures depends on several factors like: cost effectiveness, area available, operation and maintenance team availability and commitment, and the degree of odor abatement. STP operator must perform life cycle cost assessment for the feasible alternatives and select most effective option accordingly. The selected control measure might be a compensation of more than one option that would result in an effective control procedure. The operator must also take consideration that when design, install and operate the control measure all safety requirements and met, due to the potential of unsafe environment to occur when gases is collected and contained for high concentrations. For Tubli STP it is suggested to have the following measures:

1. Installation of chemical scrubber at the inlet chamber.
2. Provide dense vegetative buffer zones around the entire STP parameter wherever possible.

Alternatively, the installation of the chemical scrubber as mentioned earlier needs management involvement and agreement of the investment cost. Other approaches which was not covered in this study call the possibility of capturing the odor prior to the STP inlet, possibility of designing collection system that minimize the odor formation as well as installation odor control units in the major pump stations prior to STP.

4.2 Discussion of results

In this research odor associated with Tubli STP is studied and assessed, the assessment includes reviewing the complaints register and using two assessment approaches: atmospheric dispersion modelling, (quantitative approach) and community questionnaire (quantitative approach), in order to fulfill the research objectives. In addition, analytical measurement is used to measure the concentration of odorous gases inside Tubli STP facility and areas surrounding, all measurements performed using air quality monitor with low threshold value.

The review of the complaints register shows that the number of the complaints over the past six years is relatively small, total of 7 complaints this small number does not reflect critical problem. In addition, most of these complaints location are identified as block 711; this block is where the STP located. It was also noted that the number of complaints raised in summer time (June, - August) is almost the same as the winter time (October- December). The first objective of the research is to identify the impacted area by Tubli STP odor based on the residents' complaints and based on the complaints register review it is evident that the area impacted is limited to block 711.

The identification of the odor problem calls for identifying the odor source inside the STP as well as identifying the odorous gases mix. The air quality monitor used to identify the gases type and their concentration inside the STP facility, accordingly the odor source location is identified as follow: inlet area, primary treatment area, tankers unloading area, sludge return area and thickening basins, similarly the gases contribute in the odor mix are identified as follow: H_2S, NH_3, SO_2, Methyl Mercaptan,

and Trimethyl Aimne, in addition to the TVOC, these results is in agreement with what was mentioned in the theory. In the other hand, for Tubli STP, the main contributor for the odorous gas emissions is identified as the inlet area this information is critical for the assessment of the odor control measures. For the purpose of the modelling H_2S gas is selected, based on the low threshold value and lower molecular weight comparing with other detected odorous gases. The measured concentration values is set for the winter and cannot be representing the entire year condition therefore, archived gas concentration is obtained from MOWMUP, these readings in some locations are10 times higher than the values of the H_2S gas measured in winter, this increment might be justified by the high temperature and the increase in humidity. The measurements values received from MOWMUP is assumed to be accurate and used for the model without alteration. As result, it is expected that the dispersion modelling outcome is differ massively between both season. For the modelling two scenarios are selected: normal case represents the winter and worst case represents the summer.

For the dispersion model AERMOD 8.8.2 is used, this model is approved by EPA and it is commonly used in the odor assessment studies, the outcome of the model shows high H_2S gas concentration when compare it with the allowable limits of 30 ppb set by SCE, and the impacted area by the H_2S dispersion is quite large around two kilometers around the STP, when this area is compared with the area limited by the complaint it is evident that block 711 perceived H_2S concentration similar to the nearby areas like Table block 702, and Bilad Al Qadim block 364, however, there is no complaints raised by these blocks residents. Based on this resolution it is concluded that there is might be other factors that

involve in complaint raising process and need to be investigated in separate study. In the other hand in order to validate the model results field measurements are performed in nine different locations, the comparison of these measurements with the modelled values show that in general the model values are higher than the field measurements, however the measurements reading become gradually lesser when distanced from the STP. The differences in values can be justified by the metrological condition and the down wash effect. The simulation of the odor dispersion is performed using the atmospheric dispersion model as per the research objective and the outcomes of the modelling provide answer for the research question to identify the impacted area by the STP odor as well as showing how the odor is disperse in the atmosphere, this is also reflected in three consecutive years 2014, 2015, and 2016.

The second approach of the assessment is to use the community questionnaire in validating the model results, the population sample for this survey is estimated as minimum 385 respondents from the residents of the areas surrounding the STP, for this assessment 410 respondents completed the questionnaire and identified the level of odor perceiving in the area of their residence area. The outcome of the questionnaire confirmed that the area impacted by the odor is larger than the one set by the complaints analysis, however, is lesser than the modelled area. Based on the questionnaire results 72% of the respondents stated that the odor is detectable where this percentage is increased in summer to 82%, it is proven that H_2S gas emissions increased in summer due to the high temperature. Moreover, it must be noted that the questionnaire is a qualitative assessment tool and it is difficult to compare the questionnaire outcome with the modelling (quantitative method) results, and in order to

identify a quantified value for the questionnaire the odor index concept is used. The values computed by the adopted logarithm scale validated the modelled values in low concentrations, however, the most critical area where H_2S gas emissions is expected to be high the modelled values show much lower values than the one computed by the logarithm scale.

For odor management at Tubli STP the good practices must be followed by the STP operator, the good practices are proven to increase the performance of treatment operation and alternatively decrease the odorous emissions. In addition odor monitoring measures must be adopted; the installation of the odor monitors at the facility boundary would provide ideal monitoring system. Also, the odor management plan implementation would increase the awareness of the actual sensitive receptor and promote for addressing the complaints effectively. Maintaining comprehensive records of the complaints history would help tracking the overall performance of the odor control measures. Finally it is recommended to provide efficient vegetative buffer zone as immediate measures it would be cost effective and would enhance the overall perception of the public. Moreover, installation of the chemical scrubber at the inlet chamber would reduce significantly the odorous emissions however, this solution might be not be economic and required management commitment. The STP operators may study other alternatives involving capturing the odorous emissions in collecting system prior to the STP.

Results Summary & Conclusion

1. The reason behind the odor problem at Tubli STP is due to the location of the development close to the STP.

2. Odor associated with treatment works in Tubli STP consisted of mix of gases like: mercaptans, ammonia, TVOC, and Trimethyl Aimne.

3. The threshold for detecting the odors (H_2S gas) is very small at (0.00047 ppm) this make the odor detectable in wide range around the STP.

4. The complaints register from 2010 to 2016 shows that complaints are concentrated in block 711 only.

5. H_2S concentration outside the STP boundary is less than 1 ppm.

6. Inlet chamber, primary treatment and sludge returned and thickening areas are the most contributors in H_2S gas emissions

7. Based on the questionnaire results around 72% of the respondents confirmed that odor is detected at some level.

8. Area influence by the odor as per the community survey is estimated within circle of 2 km radius which is less than the odor contour map resulted by the dispersion model about 2.5 km.

9. The result produced by worst case scenario simulation model of Tubli STP odor is exaggerated and unrealistic.

10. Odor management for Tubli STP call for: good practices and odor monitoring measures.

11. Improved complaints management system is suggested to be adopted for Tubli STP.

12. It is suggested to install three odor monitors in the faceline perimeter of the Facility to monitor the odorous emissions.

13. Odor management plan to be adopted and implemented for Tubli STP.

14. Vegetative buffer zone to be provided around the STP perimeter wherever possible.

15. Chemical scrubber unit to be installed for the inlet chamber.

16. Further study and consideration for sewer collection system to investigate the possibility of reducing odorous emission prior to reach to STP.

4.3 Study's Recommendations

Following the assessment of the odor problem associated with Tubli STP, the following recommendations are suggested:

1. Considering covering of the inlet chamber in Tubli STP and other emission source as an immediate of odor control measure.

2. Review MOWMU standards to include installation of odor control measures in new STP.

3. Odor impact assessments to be part of the new STP, assessment report must be review and approved by the ministry before approving any new STP design.

4. Vegetative buffer zones must be mandatory in STP, as such buffer zone must be registered under the STP property and protected.

5. Considering the revision of building permit regulations in order to include percussion for the areas close to STPs and other emissions plants.

6. Further consideration for odor control measures in collection system in order to capture the odors before reaching the STP.

4.4 Future Work

This study profound a good basis for further studies in odor assessment area, the following are some suggestions for future research topics:

1. Feasibility study for odor mitigation and control measures for Tubli STP.

2. Preform odor dispersion modelling for Tubli STP following completion of the new expansion.

3. Carry out buffer zone assessment for Tubli STP or one of the Bahrain's existing STP.

4. Studying methods and approaches to minimize the odors in collection system.

References

Brancher, M., & Lisboa, H. (2014). Odour Impact Assessment by Community Survey. *Chemical Engineering Transactions*, 139-144.

Bu Hassien , E., & Humadan, H. (2011). *Report about hydrogen sulfide in Nabih Saleh Island for the period between September 2008 - July 2011.* Manama: Authority of Marine, Environmenbt and Wildlife Protection.

Capelli, L., Sironi, S., Rosso, R., & Guillot, J.-M. (2013). Measuring odours in the environment vs. dispersion modelling: A review. *Atmospheric Environment*(79), 731-743.

Capelli, L., Sironi, S., & Del Rosso, R. (2014). Odour Emission Factors: Fundamental Tools for Air Quality Management. *Chemical Engineering Transactions, 40*, 193-198.

Churchill, P., & Elmer , D. (1999). *Hydrogen Sulfide odor control in wastewater collection systems.*

DEFRA. (2006). *Code of Practice on Odour Nuisance from Sewage Treatment Works.* London: Department for Environment, Food and Rural Affairs (DEFRA).

EPA. (2004). *User's Guide for the AMS/EPA regulatory model - AERMOD.* EPA.

Felder, R. & Rousseau, R.(2011) *Elementary Principles of Chemical Processes* 4th edition). John Wiley & Sons.)

Gostelow, P., Parsons, S., & Stuetz, R. (2000). Odour measurements for sewage treatement works. *Elsevier Science, 35*(3), 579-597.

Jeon, E.-C., Son, H.-K., & Sa, J.-H. (2009). Emission Characteristics and Factors of Selected Odorous. *Sensors*(9), 311-326.

Maine Department of Health & Human Services. (2006). *Ambient Air Guidelines for Hydrogen Sulfide* . Maine: Maine Department of Health & Human Services.

NRCS. (2007). Windbreak plant Species for Odor Management around Poutry Production Facilities . United States : Natural Resources Conservation Service, United States Departement of Agriculture.

OSHA. (2017). *https:www.osha.gov*. Retrieved January 2017, from OSHA .

Sengupta, A. (2014). *Preliminary Hydrogen Sulfide Emission Factors and Emission models for wastewater treatment plant headworks.* New Orleans: University of New Orleans.

Shafibeik, O. (2015). *Odour Assessment.* Anglian water services Ltd.

Shih, C.-J., Li, C.-N., Chan, J.-K., & Syu, C.-Y. (2007). A Practical Odor Index for Evaluating De-odorant performance for MSWI Bottom Ashes. *J.Environ.Eng.Manage.*

Simms, K., Wilkinson, S., & Bethan, S. (1999). *Odour nuisance and dispersion modelling: an objective approach to a very subjective*

problem. Cambridge: Cambridge Environmental Research Consultants Limited.

Talaiekhozani, A., Bagheri, M., Goli, A., & khoozani, M. (2015). *An overview of principles of odor production, emission, and control methods in wastewater collection and treatment systems.* Retrieved from :http://www.sciencedirect.com/ science/article /pii/ S0301479716300196

Tchobanoglous, G., Burton, F., & Stensel, H. (2003). *Wastewater engineering: treatment, disposal, and reuse.* New York: McGraw-Hill Education.

Webster Environmental Associates, Inc. (2007). *Richmond Water Pollution Control Plant.* City of Richmond: Webster Environmental Associates, Inc.

Wilson, M. (2016). *Odour Assessment – Proposed Eulie Pggery.* New South Wales: Pacific Environment limited.

WHO. (2000). *Air Quality Guidelines - Second Edition.* Copenhagen: WHO Regional Office for Europe, Copenhagen, Denmark,.

Witherspoon, J., & Barnes, J. (n.d.). *Comparison of Methods Used to Measure Odour at Wastewater Treatment Plant Fecelines.* Bellevue : CH2M HILL, Inc.

Appendixes

Appendix 1

Form No. …….

University of Bahrain
College of Engineering
Mechanical Engineering Department

Questionnaire استبيان

Introduction: The goal of this Survey is to help the researcher to understand who the odor emission from Tubli Sewage Treatment Plant is perceived by the residents in area surrounding. Kindly be advised that the response will be ONLY used for the research purposes. Your response is highly appreciated.

تمهيد: الهدف من هذا الاستبيان هو مساعدة الباحث على استيعاب مدى استقبال و قدرة قاطني المناطق المحيطة بمحطة توبلي لمعالجة مياه الصرف الصحي على شم الروائح المنبعثة من المحطة. مع العلم بأنه سوف يتم استخدام الردود فقط لغرض الدراسة و البحث العلمي.نقدر مساهمتكم في هذا الاستبيان.

Gender: ذكر ( ) Male انثى ( ) Female
Age العمر: …….. **Smoker** مدخن: ( ) **Non-smoker** غير مدخن : ( )
Location Identification
Block No. :…… Road No. : …… Area:……
تحديد الموقع:
رقم المجمع: ..... رقم الطريق: ..... المنطقة: .....
Date تاريخ : …… **Time** الوقت : …….

- Please rank your sense of Tubli Sewage Treatment Plant Odor at this location:
- الرجاء تحديد مدى قدرتك على استقبال أو شم الرائحة في هذا المكان:

( ) No Odor Perceivable
لايمكن استقبال أو شم رائحة

( ) Barely Perceivable
بالكاد يمكن استقبال أو شم

( ) Faintly Perceivable
يمكن استقبال أو شم رائحة بصورة بسيطة

( ) Clearly Perceivable
يمكن استقبال أو شم الرائحة بصورة واضحة

( ) Strong Odor is Perceived
يمكن استقبال أو شم رائحة بصورة قوية

( ) Very Strong Odor is Perceived
يمكن استقبال أو شم رائحة بصورة قوية جدا

- Please rank your sense of Tubli Sewage Treatment Plant Odor at this location in Summer:
- الرجاء تحديد مدى قدرتك على استقبال أو شم الرائحة في هذا المكان في فصل الصيف :

( ) No Odor Perceivable
لايمكن استقبال أو شم رائحة

( ) Barely Perceivable
بالكاد يمكن استقبال أو شم

( ) Faintly Perceivable
يمكن استقبال أو شم رائحة بصورة بسيطة

( ) Clearly Perceivable
يمكن استقبال أو شم الرائحة بصورة واضحة

( ) Strong Odor is Perceived
يمكن استقبال أو شم رائحة بصورة قوية

( ) Very Strong Odor is Perceived
يمكن استقبال أو شم رائحة بصورة قوية جدا

- In general he most detected odor is in the : Night time ( ) Morning Time ( )
- بشكل عام يتم استقبال او شم الروائح المزعجة في فترة: الليل ( ) النهار ( )

Thank you Very much
مع جزيل الشكر والعرفان

Appendix 2

No.	1. Gender	2. Age	3. Do you Smoke?	4. This questionnaire aim to identify the area wher				5. Please rank your sense of Tubli	6. Please rank your sense of	7. In general the most	Date
				Block المجمع	*Road* الطريق	*Area* المنطقة					
1	Male ذكر	20	No لا	711	1103	Tubli		Very Strong Odor is Pe	Very Strong Odor	Morning Time	2017-04-03 19:29
2	Female ،	21	No لا	221	2101	Busiteen		No Odor Perceivable ة	Barely Perceivabl	Morning Time	2017-04-03 19:43
3	Female ،	28	No لا	439	3961		السهلة الشمالية	No Odor Perceivable ة	No Odor Perceiva	Morning Time	2017-04-03 19:45
4	Female ،	23	No لا	333	3321		ام الحصم	Strong Odor is Perceiv	Strong Odor is Pe	Evening time	2017-04-03 19:48
5	Female ،	23	No لا	330	Abuqazal	New zinj		No Odor Perceivable ة	No Odor Perceiva	Evening time	2017-04-03 19:48
6	Female ،٢٢		No لا	110	1004	Hidd		No Odor Perceivable ة	No Odor Perceiva	Morning Time	2017-04-03 20:03
7	Male ذكر	26	No لا	711	1126	Tubli		Strong Odor is Perceiv	Very Strong Odor	Evening time	2017-04-03 20:12
8	Male ذكر	24	Yes نعم	721	2188	Jidali		Faintly Perceivable بطة	Clearly Perceivab	Morning Time	2017-04-03 20:19
9	Female ،	22	No لا	729	2967		جرداب	Barely Perceivable نحة	Faintly Perceivab	Evening time	2017-04-03 21:31
10	Male ذكر	25	Yes نعم	721	2192		جدعلي	Clearly Perceivable حة	Faintly Perceivab	Evening time	2017-04-03 22:28
11	Male ذكر	25	Yes نعم	363	6306		بلاد القديم	No Odor Perceivable ة	No Odor Perceivable	كن شم رائحة	2017-04-04 5:48
12	Male ذكر	37	No لا	709	954	Tubli		Clearly Perceivable حة	Strong Odor is Pe	Evening time	2017-04-04 7:23
13	Male ذكر	27	No لا	360	66	New Zinj		Faintly Perceivable بطة	Very Strong Odor	Evening time	2017-04-04 16:37
14	Female ،	37	No لا	439	3439		السهلة	No Odor Perceivable ة	Barely Perceivabl	Evening time	2017-04-04 16:57
15	Female ،	22	No لا	805	515	Isa Town		Barely Perceivable نحة	Faintly Perceivab	Evening time	2017-04-04 19:48
16	Male ذكر	25	No لا	711	1109	Tubli		No Odor Perceivable ة	Barely Perceivabl	Evening time	2017-04-04 21:15
17	Male ذكر	39	No لا	363	3667		بلاد القديم	No Odor Perceivable ة	No Odor Perceiva	Morning Time	2017-04-05 6:20
18	Male ذكر	39	No لا	328	2827	Alsuqayya		Barely Perceivable نحة	Barely Perceivabl	Evening time	2017-04-05 8:26
19	Male ذكر	63	No لا	711	1113	Tubli		Strong Odor is Perceiv	Strong Odor is Pe	Evening time	2017-04-05 8:26
20	Female ،	1959	Yes نعم	333	3321	umalhasam		No Odor Perceivable ة	No Odor Perceiva	Evening time	2017-04-05 8:17
21	Male ذكر	22	Yes نعم	805	502	isa town		No Odor Perceivable ة	Barely Perceivabl	Evening time	2017-04-05 8:55
22	Male ذكر	51	Yes نعم	721	2182		جد علي	No Odor Perceivable ة	Barely Perceivabl	Evening time	2017-04-05 8:56
23	Male ذكر	20	Yes نعم	711	1113			Strong Odor is Perceiv	Strong Odor is Pe	Evening time	2017-04-05 8:57
24	Female ،٣٢		No لا	٧١١	١١١٤		توبلي	Faintly Perceivable بطة	Faintly Perceivab	Evening time	2017-04-05 8:57
25	Male ذكر ٣٠		No لا	٣٦٢	٦٢		البلاد القديم	Faintly Perceivable بطة	Faintly Perceivab	Evening time	2017-04-05 9:00
26	Male ذكر ٣٠		Yes نعم	٣٥٩	٥٩٠٩		الزنج	Faintly Perceivable بطة	Clearly Perceivab	Evening time	2017-04-05 9:02
27	Female ،٥٢		No لا	١٤٨٠	٣٩٣٥	٤٣٩		No Odor Perceivable ة	No Odor Perceivable	كن شم رائحة	2017-04-05 9:20
28	Female ،	45	No لا	5905	359الزنج		الزنج	Faintly Perceivable بطة	Faintly Perceivab	Evening time	2017-04-05 9:21
29	Female ،	1995	No لا	804	424		مدينة عيسى	No Odor Perceivable ة	Strong Odor is Pe	Morning Time	2017-04-05 9:19
30	Male ذكر	50	No لا	359	5908		359	Clearly Perceivable حة	Clearly Perceivab	Evening time	2017-04-05 9:35
31	Male ذكر ١٨		Yes نعم	٣٥٩	٣٩٠٨		الزنج	No Odor Perceivable ة	Barely Perceivabl	Morning Time	2017-04-05 9:39
32	Male ذكر ٢٧		No لا	٧٢١	٢١٥٢		جدعلي	No Odor Perceivable ة	No Odor Perceivable	كن شم رائحة	2017-04-05 9:38
33	Male ذكر	50	No لا	359	5933	Zinj		Clearly Perceivable حة	Clearly Perceivab	Evening time	2017-04-05 9:48
34	Female ،	48	No لا	721	شارع ٢٩	Jid ali		Barely Perceivable نحة	Barely Perceivabl	Evening time	2017-04-05 9:52
35	Male ذكر	52	Yes نعم	328	5935		زنج	Clearly Perceivable حة	Clearly Perceivab	Evening time	2017-04-05 9:45
36	Male ذكر	52	No لا	701	181	Tubli		No Odor Perceivable ة	No Odor Perceivable	كن شم رائحة	2017-04-05 9:55

No.	1. Gender	2. Age	3. Do you Smoke?	4. This questionnaire aim to identify the area wher				5. Please rank your sense of Tubli	6. Please rank your sense of	7. In general the most	Date
				Block المجمع	*Road* الطريق	*Area* المنطقة					
37	Male ذكر	29	Yes نعم	362	62	Bilad Al Qadeem		No Odor Perceivable ة	No Odor Perceivable كن شم رائحة		2017-04-05 9:59
38	Male ذكر ٥٥		No لا	٣٥٩	٥٩٣١		اسكان بلاد القد يم	Clearly Perceivable حة	Clearly Perceivab	Evening time	2017-04-05 10:04
39	Male ذكر	55	No لا	543	4353		بني جمرة	Strong Odor is Perceiv	Clearly Perceivab	Evening time	2017-04-05 10:12
40	Male ذكر	34	No لا	450	48		المقشع	No Odor Perceivable ة	No Odor Perceiva	Evening time	2017-04-05 10:31
41	Female ،	29	No لا	729	2958	Jerdab		No Odor Perceivable ة	Barely Perceivabl	Evening time	2017-04-05 10:33
42	Male ذكر	40	No لا	360	6016		الزنج	Clearly Perceivable حة	Clearly Perceivab	Evening time	2017-04-05 10:36
43	Male ذكر	24	No لا	360	6016		الزنج	No Odor Perceivable ة	No Odor Perceivable كن شم رائحة		2017-04-05 10:45
44	Male ذكر	47	No لا	626	2641		العكر الغربي	Barely Perceivable ئحة	Clearly Perceivab	Evening time	2017-04-05 10:44
45	Male ذكر	50	Yes نعم	359	5933	Zinj		Faintly Perceivable بطة	Faintly Perceivab	Evening time	2017-04-05 10:48
46	Female ، ١٨		No لا	٧٢١	٢١٦٩		جدعلي	No Odor Perceivable ة	Faintly Perceivab	Evening time	2017-04-05 10:53
47	Male ذكر	42	Yes نعم	359	5908		الزنج	Strong Odor is Perceiv	Very Strong Odor	Evening time	2017-04-05 10:52
48	Male ذكر	37	Yes نعم	362	6231	Bilad Alqadim		No Odor Perceivable ة	Barely Perceivabl	Evening time	2017-04-05 10:57
49	Male ذكر	52	No لا	721	2141	Jid Ali		Barely Perceivable ئحة	Barely Perceivabl	Evening time	2017-04-05 11:00
50	Female ، ٥٤		No لا	815	1545		مدينه عيسي	Faintly Perceivable بطة	Clearly Perceivab	Evening time	2017-04-05 11:03
51	Female ،	30	No لا	365	6521		الخميس	Barely Perceivable ئحة	Faintly Perceivab	Evening time	2017-04-05 11:20
52	Female ،	65	No لا	705	577	Tubli		Clearly Perceivable حة	Strong Odor is Pe	Morning Time	2017-04-05 11:22
53	Male ذكر	29	Yes نعم	813	1314		مدينه عيسى	Strong Odor is Perceiv	Clearly Perceivab	Morning Time	2017-04-05 11:26
54	Female ،	39	No لا	شارع بلاد القديم			الزنج	Faintly Perceivable بطة	Clearly Perceivab	Evening time	2017-04-05 12:00
55	Female ، ٤٧		No لا	٧٢١	٢١٧٤		جدعلي	Faintly Perceivable بطة	Faintly Perceivab	Evening time	2017-04-05 12:01
56	Male ذكر	28	No لا	711	1121	Tubli		Faintly Perceivable بطة	Very Strong Odor	Evening time	2017-04-05 12:03
57	Male ذكر	46	No لا	359	5931		الزنج	Clearly Perceivable حة	Clearly Perceivab	Evening time	2017-04-05 12:11
58	Male ذكر	29	Yes نعم	362	6228	Bilad		Faintly Perceivable بطة	Clearly Perceivab	Evening time	2017-04-05 12:20
59	Female ،	36	No لا	812			مدينة عيسى	No Odor Perceivable ة	No Odor Perceiva	Evening time	2017-04-05 12:23
60	Female ،	42	No لا	711	1121	Tubli		Faintly Perceivable بطة	Faintly Perceivab	Evening time	2017-04-05 12:25
61	Female ،	40	No لا	380	8019	Nabih Saleh		No Odor Perceivable ة	Faintly Perceivab	Evening time	2017-04-05 12:29
62	Male ذكر	48	No لا	241	4135		عراد	No Odor Perceivable لايمكن شم رائحة		Evening time	2017-04-05 12:28
63	Male ذكر	33	No لا	701	184		توبلي	Faintly Perceivable بطة	Faintly Perceivab	Evening time	2017-04-05 12:35
64	Female ، ١٥		No لا	381	8160		النبيه صالح	Clearly Perceivable حة	Clearly Perceivab	Morning Time	2017-04-05 12:33
65	Female ، ٤٠		No لا	٣٦١	٦١١٣		البلاد القديم	No Odor Perceivable ة	Barely Perceivabl	Morning Time	2017-04-05 12:40
66	Male ذكر	31	Yes نعم	709	5		الكوره	Barely Perceivable ئحة	Faintly Perceivab	Evening time	2017-04-05 12:41
67	Female ، ٢٥		No لا	٧٠١	١٥٤		توبلي	No Odor Perceivable ة	No Odor Perceiva	Evening time	2017-04-05 12:43
68	Female ،	38	No لا	381	8161		النبي صالح	Clearly Perceivable حة	Clearly Perceivab	Evening time	2017-04-05 12:44
69	Male ذكر	35	No لا	721	19		الكوره	Strong Odor is Perceiv	Strong Odor is Pe	Evening time	2017-04-05 12:53
70	Male ذكر	23	No لا	709	940		الكورة	Faintly Perceivable بطة	Clearly Perceivab	Evening time	2017-04-05 12:55
71	Female ،	35	No لا	806	632	Isa Town		Strong Odor is Perceiv	Strong Odor is Pe	Morning Time	2017-04-05 12:58
72	Female ، ٢٣		Yes نعم	٧٢١	٢١١٦		جدعلي	Very Strong Odor is Pe	Very Strong Odor	Evening time	2017-04-05 13:15

No.	1. Gender	2. Age	3. Do you Smoke?	4. This questionnaire aim to identify the area wher				5. Please rank your sense of Tubli	6. Please rank your sense of	7. In general the most	Date
				Block المجمع	Road الطريق	Area المنطقة					
73	Male ذكر	46	No لا	707	شارع ٧		توبلي	Strong Odor is Perceived ائحة بصورة قوية	Evening time		2017-04-05 13:17
74	Female ،	14	No لا	707	13	Tubli		Clearly Perceivable حة	Strong Odor is Pe	Evening time	2017-04-05 13:33
75	Female ،	٦٤	No لا	٧١١	١١١١	Tubli		Clearly Perceivable حة	Clearly Perceivab	Evening time	2017-04-05 13:40
76	Male ذكر	65	No لا	814	1448		مدينة عيسى	Clearly Perceivable حة	Clearly Perceivab	Evening time	2017-04-05 13:47
77	Male ذكر	٤٣	No لا	٣٦٣	٦٣٣٩		بلادالقديم	Strong Odor is Perceiv	Clearly Perceivab	Evening time	2017-04-05 13:49
78	Female ،	40	No لا	380	8161		النبيه صالح	Clearly Perceivable حة	Clearly Perceivab	Morning Time	2017-04-05 14:09
79	Female ،	32	No لا	364	6421		البلاد القديم	Faintly Perceivable طة	Clearly Perceivab	Evening time	2017-04-05 14:19
80	Male ذكر	32	No لا	455	55	Bu quwah		Very Strong Odor is P	Very Strong Odor	Evening time	2017-04-05 14:31
81	Female أنثى		No لا	361	6121		البلاد القديم	Barely Perceivable نحة	Strong Odor is Pe	Evening time	2017-04-05 14:40
82	Male ذكر	54	No لا	740	4036	Aali		Clearly Perceivable حة	Strong Odor is Pe	Evening time	2017-04-05 14:50
83	Male ذكر	27	No لا	711	13		توبلي	Very Strong Odor is P	Strong Odor is Pe	Morning Time	2017-04-05 15:10
84	Male ذكر	38	No لا	333	3315	Um Al hassam		Barely Perceivable نحة	Faintly Perceivab	Evening time	2017-04-05 15:21
85	Male ذكر	37	No لا	709	921		توبلي	Barely Perceivable نحة	Faintly Perceivab	Evening time	2017-04-05 15:33
86	Male ذكر	٤٩	Yes نعم	٣٥٩	٥٩٣٢		الزنج	No Odor Perceivable ة	Faintly Perceivab	Evening time	2017-04-05 15:39
87	Female ،	40	No لا	711	13		توبلي	Clearly Perceivable حة	Strong Odor is Pe	Morning Time	2017-04-05 16:05
88	Male ذكر	50	No لا	362	6231		بلادالقديم	Barely Perceivable نحة	Barely Perceivabl	Evening time	2017-04-05 16:07
89	Male ذكر	51	No لا	707	728	Tubli		Very Strong Odor is P	Very Strong Odor	Evening time	2017-04-05 17:13
90	Female ،	43	No لا	729	29		جد علي		Very Strong Odor	Evening time	2017-04-05 17:37
91	Female ،	٦٩	No لا	711	13	Tubli		Strong Odor is Perceiv	Strong Odor is Pe	Evening time	2017-04-05 17:58
92	Female ،	٤٠	No لا	٣٦٢	٦٢٢٨		بلاد القديم	Barely Perceivable نحة	Barely Perceivabl	Evening time	2017-04-05 18:14
93	Male ذكر	44	Yes نعم	333	3330		أم الحصم	Barely Perceivable نحة	Very Strong Odor	Evening time	2017-04-05 18:23
94	Male ذكر	49	No لا	711	1146		توبلي	Faintly Perceivable طة	Faintly Perceivab	Evening time	2017-04-05 18:34
95	Male ذكر	21	No لا	333	3324		ام الحصم	Faintly Perceivable طة	Clearly Perceivab	Evening time	2017-04-05 19:20
96	Female ،	47	No لا	462	6223		بلاد القديم	No Odor Perceivable ة	Barely Perceivabl	Morning Time	2017-04-05 19:24
97	Female ،	35	No لا	359	5911		الزنج	Barely Perceivable نحة	Barely Perceivabl	Evening time	2017-04-05 20:11
98	Female ،	30	No لا	382	8211		النبيه صالح	Clearly Perceivable حة	Clearly Perceivab	Evening time	2017-04-05 20:56
99	Female ،	45	No لا	333	3392		ام الحصم	Clearly Perceivable حة	Strong Odor is Pe	Evening time	2017-04-05 22:13
100	Male ذكر	37	No لا	711	13	Tubli		Very Strong Odor is P	Very Strong Odor	Evening time	2017-04-06 2:59
101	Male ذكر		No لا	363	6305	Khamis		No Odor Perceivable ة	Barely Perceivabl	Evening time	2017-04-06 3:21
102	Female ،	35	Yes نعم	701	Amman avenu	Tubli		Faintly Perceivable طة	Faintly Perceivab	Evening time	2017-04-06 5:07
103	Female ،	50	No لا	381	8115		النبيه صالح	Barely Perceivable نحة	Faintly Perceivab	Evening time	2017-04-06 6:18
104	Male ذكر	٢٧	Yes نعم	٧٢١		2127	جدعلي	Faintly Perceivable طة	No Odor Perceiva	Evening time	2017-04-06 7:03
105	Female ،	36	No لا	711	1144		توبلي	Clearly Perceivable حة	Clearly Perceivab	Evening time	2017-04-06 10:01
106	Male ذكر	50	Yes نعم	333	3329	Um alhassum		No Odor Perceivable ة	Clearly Perceivab	Morning Time	2017-04-06 10:11
107	Male ذكر	٢١	No لا	1063	721		جدعلي	Very Strong Odor is P	Very Strong Odor	Evening time	2017-04-06 10:36
108	Female ،	35	No لا	381	8162		النبيه صالح	Very Strong Odor is P	Very Strong Odor	Evening time	2017-04-06 10:38

No.	1. Gender	2. Age	3. Do you Smoke?	4. This questionnaire aim to identify the area wher				5. Please rank your sense of Tubli	6. Please rank your sense of	7. In general the most	Date
				Block المجمع	*Road* الطريق	*Area* المنطقة					
109	Female ،	42	No لا		381	8162	جزيره النبيه صالح	Faintly Perceivable طة	Faintly Perceivab	Evening time	2017-04-06 11:19
110	Male ذكر	16	No لا		721	2132	Jid ali	Strong Odor is Perceiv	Strong Odor is Pe	Evening time	2017-04-06 12:04
111	Male ذكر	٤٤	Yes نعم	٧٢١	٢١٣٢		جدعلي	Strong Odor is Perceiv	Very Strong Odor	Morning Time	2017-04-06 12:18
112	Male ذكر	25	No لا		721	2121	Jidali	Clearly Perceivable حة	Clearly Perceivab	Evening time	2017-04-06 12:22
113	Male ذكر	24	Yes نعم		722	2136	جدعلي	Faintly Perceivable طة	Faintly Perceivab	Evening time	2017-04-06 12:38
114	Male ذكر	36	No لا		363	6306	البلادالقديم	Faintly Perceivable طة	Faintly Perceivab	Evening time	2017-04-06 12:44
115	Male ذكر	29	No لا		705		Tubli	Clearly Perceivable حة	Very Strong Odor	Evening time	2017-04-06 13:45
116	Male ذكر	18	No لا		729	29	جدعلي	Faintly Perceivable طة	Faintly Perceivab	Evening time	2017-04-06 14:47
117	Male ذكر	48	No لا		701	164	توبلي	Very Strong Odor is Pe	Very Strong Odor	Evening time	2017-04-06 14:53
118	Male ذكر	28	Yes نعم		363	1245	Bilad alquadem	No Odor Perceivable ة	No Odor Perceivable	كن شم رائحة	2017-04-06 15:20
119	Male ذكر	55	Yes نعم		743	4739	Sanad	Barely Perceivable نحة	Strong Odor is Pe	Evening time	2017-04-06 15:23
120	Female ،	٥٢	No لا	٣٣٠	٣٠١٥		ابو غزال	Barely Perceivable نحة	Faintly Perceivab	Evening time	2017-04-06 16:16
121	Male ذكر	49	No لا		729	2968	Jurdab	Barely Perceivable نحة	Faintly Perceivab	Evening time	2017-04-06 17:36
122	Female ،	55	No لا		441	4103	North Sehla	Faintly Perceivable طة	Barely Perceivabl	Evening time	2017-04-06 17:41
123	Male ذكر	47	No لا		721		جدعلي	Faintly Perceivable طة	Clearly Perceivab	Evening time	2017-04-06 17:43
124	Male ذكر	34	No لا		707	747	Tubli	Clearly Perceivable حة	Faintly Perceivab	Morning Time	2017-04-06 19:44
125	Male ذكر	65	Yes نعم		815	1520	مدينة عيسى	Faintly Perceivable طة	Faintly Perceivab	Evening time	2017-04-06 20:05
126	Male ذكر	32	Yes نعم		707	721	توبلي	Clearly Perceivable حة	Clearly Perceivab	Morning Time	2017-04-06 20:09
127	Male ذكر	٢٨	No لا	٧٢١	٢١٣٦		جدعلي	Clearly Perceivable حة	Clearly Perceivab	Evening time	2017-04-06 20:12
128	Male ذكر	34	No لا		705	559	توبلي	No Odor Perceivable ة	Very Strong Odor	Evening time	2017-04-06 20:08
129	Male ذكر	10	No لا		721	2136	Tubli	Faintly Perceivable طة	No Odor Perceiva	Morning Time	2017-04-06 20:26
130	Female ،	36	No لا		707	725	Tubli	Very Strong Odor is Pe	Strong Odor is Pe	Morning Time	2017-04-06 20:28
131	Male ذكر	35 سنه	No لا		705	545	توبلي	Faintly Perceivable طة	Faintly Perceivab	Evening time	2017-04-06 20:29
132	Female ،	19	No لا		701	154	توبلي	Barely Perceivable نحة	Barely Perceivabl	Morning Time	2017-04-06 20:34
133	Male ذكر	35	Yes نعم		359	58	الزنج	Faintly Perceivable طة	Faintly Perceivab	Evening time	2017-04-06 20:36
134	Male ذكر	28	No لا		707	723	توبلي	Very Strong Odor is Pe	Very Strong Odor	Evening time	2017-04-06 20:08
135	Male ذكر	37	No لا		711	11	Tubli	Strong Odor is Perceiv	Strong Odor is Pe	Evening time	2017-04-06 20:47
136	Male ذكر	33			721	2136	Jidali	Clearly Perceivable حة	Clearly Perceivab	Evening time	2017-04-06 20:53
137	Male ذكر	22	Yes نعم		815	1532	مدينة عيسى	No Odor Perceivable ة	No Odor Perceiva	Evening time	2017-04-06 20:59
138	Female ،	٥٠	No لا	٧١١	١١٢١		توبلي	Very Strong Odor is Pe	Very Strong Odor	Evening time	2017-04-06 21:00
139	Male ذكر	34	Yes نعم		721	2165	Jid Ali	No Odor Perceivable ة	No Odor Perceiva	Evening time	2017-04-06 21:14
140	Male ذكر	23	No لا		701	164	tubli	No Odor Perceivable ة	Clearly Perceivab	Evening time	2017-04-06 21:32
141	Male ذكر	43	Yes نعم		721	2124	جد علي	Barely Perceivable نحة	Clearly Perceivab	Evening time	2017-04-06 21:34
142	Male ذكر	27	No لا		721	2121	Jid Ali	Strong Odor is Perceiv	Very Strong Odor	Evening time	2017-04-06 21:35
143	Male ذكر	22	No لا		705	545	توبلي	Clearly Perceivable حة	Strong Odor is Pe	Evening time	2017-04-06 21:42
144	Male ذكر	26	No لا		705	569	Tubli	Clearly Perceivable حة	Clearly Perceivab	Evening time	2017-04-06 21:59

No.	1. Gender	2. Age	3. Do you Smoke?	4. This questionnaire aim to identify the area wher				5. Please rank your sense of Tubli	6. Please rank your sense of	7. In general the most	Date
				Block المجمع	*Road* الطريق	*Area* المنطقة					
145	Male ذكر	33	No لا	705	547	Tubli		Clearly Perceivable حة	Clearly Perceivab	Evening time	2017-04-06 22:44
146	Male ذكر	55	No لا	707	725		توبلي	Clearly Perceivable حة	Strong Odor is Pe	Evening time	2017-04-06 22:57
147	Female ،٣٣		No لا	٧٠١	١٧٣		توبلي	Faintly Perceivable طة	Faintly Perceivab	Evening time	2017-04-06 23:59
148	Male ذكر	23	No لا	705	561	Tubli		Barely Perceivable نحة	Barely Perceivabl	Evening time	2017-04-07 1:47
149	Male ذكر	50	No لا	705	545		توبلي	No Odor Perceivable ة	No Odor Perceiva	Evening time	2017-04-07 2:46
150	Male ذكر	60	No لا	711	1124	TUBLI		Strong Odor is Perceiv	Strong Odor is Pe	Evening time	2017-04-07 4:54
151	Male ذكر	56	No لا	711	1125	Tubli		Clearly Perceivable م الرائحة بصورة واضحة		Evening time	2017-04-07 5:11
152	Male ذكر	53	Yes نعم	711	11	Tubli		Very Strong Odor is Pe	Very Strong Odor	Evening time	2017-04-07 5:12
153	Male ذكر	53	No لا	328	2835		السقية	Very Strong Odor is Pe	Barely Perceivable	يمكن شم رائحة	2017-04-07 7:21
154	Female ،	33	No لا	333	3315		أم الحصم	No Odor Perceivable ة	Barely Perceivabl	Evening time	2017-04-07 9:39
155	Male ذكر	37	No لا	804	8		مدينة عيسى	No Odor Perceivable ة	No Odor Perceivable	كن شم رائحة	2017-04-07 9:53
156	Male ٣٣ ذكر		No لا	٨١٦	١٦٢٥		مدينة عيسى	Barely Perceivable نحة	Barely Perceivabl	Evening time	2017-04-07 9:56
157	Male ذكر	25	Yes نعم	711	11	Tubli		Clearly Perceivable حة	Strong Odor is Pe	Evening time	2017-04-07 10:00
158	Male ٥٠ ذكر		No لا	٧٠١	١٣٩	Tubli		Barely Perceivable نحة	Barely Perceivabl	Evening time	2017-04-07 9:59
159	Male ذكر	32	No لا	711	11	Tubli		Very Strong Odor is Pe	Very Strong Odor	Evening time	2017-04-07 10:08
160	Male ذكر	31	No لا	711	1128	Tubli		Faintly Perceivable طة	Strong Odor is Pe	Evening time	2017-04-07 10:09
161	Male ذكر	26	No لا	709	952	Tubli		Clearly Perceivable حة	Clearly Perceivab	Morning Time	2017-04-07 10:11
162	Female ،	30	Yes نعم	721	2148		جدعلي	No Odor Perceivable ة	No Odor Perceiva	Evening time	2017-04-07 10:19
163	Male ذكر		Yes نعم	711	1103		توبلي	Very Strong Odor is Pe	Very Strong Odor	Evening time	2017-04-07 10:20
164	Female ،٣٧		No لا	١٠٣٨	٣٧٨٢		صدد	Strong Odor is Perceiv	Clearly Perceivab	Evening time	2017-04-07 10:57
165	Female ،٣٧		No لا	١٠٣٨	٣٨٧٢		صدد	No Odor Perceivable ة	No Odor Perceivable	كن شم رائحة	2017-04-07 11:00
166	Male ذكر	51	No لا	721	2127	Jid Ali		Barely Perceivable نحة	Faintly Perceivab	Morning Time	2017-04-07 11:06
167	Female ،٣٠		No لا	٧٢١	٢١٦٤		جدعلي	Faintly Perceivable طة	Faintly Perceivab	Evening time	2017-04-07 11:08
168	Female ،	25	No لا	721	2156	Jidali		No Odor Perceivable ة	No Odor Perceivable	كن شم رائحة	2017-04-07 11:13
169	Female ،	24	No لا	815	1253	Isa town		No Odor Perceivable ة	No Odor Perceiva	Morning Time	2017-04-07 11:14
170	Female ،	25	No لا	721	2121	Jidali		Very Strong Odor is Pe	Very Strong Odor	Evening time	2017-04-07 11:24
171	Female ،٢٥		No لا	721	2121		جدعلي	Faintly Perceivable طة	Clearly Perceivab	Morning Time	2017-04-07 11:31
172	Male ذكر	34	No لا	709	19	Kawarah		Clearly Perceivable حة	Strong Odor is Pe	Evening time	2017-04-07 11:35
173	Male ذكر	23	Yes نعم	711	1134	Tubli		No Odor Perceivable ة	Clearly Perceivab	Evening time	2017-04-07 11:38
174	Male ذكر	34	Yes نعم	705	525		توبلي	No Odor Perceivable ة	No Odor Perceiva	Evening time	2017-04-07 11:37
175	Male ذكر	32	No لا	705	3	tubli		Faintly Perceivable طة	Clearly Perceivab	Evening time	2017-04-07 11:39
176	Male ذكر	36	No لا	363	6345		البلاد القديم	No Odor Perceivable ة	Barely Perceivabl	Evening time	2017-04-07 11:39
177	Female ،	38	No لا	711	1146	Tubli		No Odor Perceivable ة	Faintly Perceivab	Evening time	2017-04-07 11:40
178	Female ،	35	No لا	816	1625		مدينه عيسى	Barely Perceivable نحة	Faintly Perceivab	Morning Time	2017-04-07 11:42
179	Male ذكر	33	No لا	816	1622	Isa Town		No Odor Perceivable ة	No Odor Perceivable	كن شم رائحة	2017-04-07 12:31
180	Female ،	23	No لا	721	2121	JidAli		Clearly Perceivable حة	Strong Odor is Pe	Evening time	2017-04-07 12:33

No.	1. Gender	2. Age	3. Do you Smoke?	4. This questionnaire aim to identify the area wher				5. Please rank your sense of Tubli	6. Please rank your sense of	7. In general the most	Date
				Block المجمع	*Road* الطريق	*Area* المنطقة					
181	Male ذكر	45	Yes نعم		711	11	Tubli	Faintly Perceivable بطة	Clearly Perceivab	Evening time	2017-04-07 12:55
182	Female ،	27	No لا		721	2155	Jidali	No Odor Perceivable ة	No Odor Perceiva	Evening time	2017-04-07 13:05
183	Male ذكر	21	No لا		709	983	Tubli	No Odor Perceivable ة	No Odor Perceiva	Evening time	2017-04-07 13:42
184	Male ذكر	24	No لا		707	721	توبلي	Faintly Perceivable بطة	Clearly Perceivab	Evening time	2017-04-07 13:59
185	Male ذكر	23	No لا		701	143	توبلي	No Odor Perceivable ة	Faintly Perceivab	Morning Time	2017-04-07 14:10
186	Male ذكر	27	No لا		701	143	Tubli	Very Strong Odor is Pe	Very Strong Odor	Evening time	2017-04-07 14:52
187	Male ذكر	25	Yes نعم		721	2178	جد علي	No Odor Perceivable ة	Barely Perceivabl	Evening time	2017-04-07 15:49
188	Female ،	20	No لا		721	2132	Jidali	Strong Odor is Perceiv	Very Strong Odor	Morning Time	2017-04-07 16:37
189	Male ذكر	65	No لا		711	1144	Tubli	Very Strong Odor is Pe	Very Strong Odor	Morning Time	2017-04-07 17:56
190	Male ذكر	25	No لا		711	11	Tubli	Clearly Perceivable حة	Strong Odor is Pe	Evening time	2017-04-07 18:23
191	Female ،	30	Yes نعم		721	2133	جدعلي	No Odor Perceivable ة	No Odor Perceiva	Evening time	2017-04-07 21:32
192	Male ذكر	34	No لا		382	8217	Nabih Saleh	Clearly Perceivable حة	Clearly Perceivab	Evening time	2017-04-08 2:47
193	Male ذكر	49	No لا		701	142	tubli	Strong Odor is Perceiv	Strong Odor is Pe	Evening time	2017-04-08 5:24
194	Male ذكر	41			802	205	Isa town	Clearly Perceivable حة	Clearly Perceivab	Evening time	2017-04-08 5:39
195	Male ذكر	18	No لا		531	3136	Al Markh	No Odor Perceivable ة	No Odor Perceiva	Evening time	2017-04-08 6:01
196	Male ذكر	46	No لا		808	815	Isa town	No Odor Perceivable ة	Barely Perceivabl	Evening time	2017-04-08 6:13
197	Male ذكر	27	No لا		925	2559	Riffa	No Odor Perceivable ة	No Odor Perceiva	Morning Time	2017-04-08 6:16
198	Female ،	18	No لا		812	1232	Isa twon	No Odor Perceivable ة	Barely Perceivable يمكن شم رائحة		2017-04-08 6:21
199	Female ،	51	No لا		373	7319	Manama	Clearly Perceivable حة	Clearly Perceivab	Evening time	2017-04-08 6:31
200	Male ذكر ٣٣		Yes نعم	٣٦٥	٦٥٢١		الخميس	Strong Odor is Perceiv	Strong Odor is Pe	Evening time	2017-04-08 6:34
201	Female ،	26	No لا		815	1525	Isa Town	No Odor Perceivable ة	No Odor Perceivable كن شم رائحة		2017-04-08 7:05
202	Female ،	19	No لا		721	2131	Jidali	Barely Perceivable ئحة	Faintly Perceivab	Evening time	2017-04-08 7:17
203	Female ، ١٨		No لا	٧٢١	٢١٣١		جد علي	Very Strong Odor is Pe	Very Strong Odor	Morning Time	2017-04-08 7:18
204	Female ، ٢٤		No لا	٧٢١	٢١٣١		جدعلي	Faintly Perceivable بطة	Strong Odor is Pe	Evening time	2017-04-08 7:20
205	Female ،	18	No لا		360	60	Zinj	No Odor Perceivable ة	Very Strong Odor	Evening time	2017-04-08 7:28
206	Female أنثى		No لا		812	1226	Isa takin	Barely Perceivable ئحة	Barely Perceivabl	Evening time	2017-04-08 7:33
207	Male ذكر	37	Yes نعم		702	421	سلماباد	Clearly Perceivable حة	Clearly Perceivab	Morning Time	2017-04-08 7:26
208	Male ذكر	42	No لا		743	43	Sanad	No Odor Perceivable ة	No Odor Perceiva	Morning Time	2017-04-08 7:38
209	Male ذكر	60	No لا		733		Al nasafa	Clearly Perceivable حة	Strong Odor is Pe	Evening time	2017-04-08 8:02
210	Female ،	28	No لا		816	1622	Isa Town	No Odor Perceivable ة	No Odor Perceivable كن شم رائحة		2017-04-08 8:06
211	Male ذكر	30	No لا		721	2130	jidali	Barely Perceivable ئحة	Clearly Perceivab	Evening time	2017-04-08 8:18
212	Female ،	55	No لا		358	58	الزنج	Clearly Perceivable حة	Clearly Perceivab	Evening time	2017-04-08 8:19
213	Female ،	22	No لا		721	2174	Jidali	No Odor Perceivable ة	No Odor Perceiva	Evening time	2017-04-08 8:25
214	Female ،	23	No لا		721	2185	jidali	No Odor Perceivable ة	No Odor Perceiva	Morning Time	2017-04-08 8:33
215	Female ،	20	No لا		816	1622	مدينة عيسى	No Odor Perceivable ة	No Odor Perceiva	Morning Time	2017-04-08 8:34
216	Male ذكر ٤٣		No لا	٧٢١	٢١٢٣		جدعلي	Faintly Perceivable شم رائحة بصورة بسيطة ،		Evening time	2017-04-08 8:37

No.	1. Gender	2. Age	3. Do you Smoke?	4. This questionnaire aim to identify the area wher				5. Please rank your sense of Tubli	6. Please rank your sense of	7. In general the most	Date
				Block المجمع	*Road* الطريق	*Area* المنطقة					
217	Female ،	18	No لا		701	143	Tubli	No Odor Perceivable ة	Faintly Perceivab	Evening time	2017-04-08 8:37
218	Female ،	32	No لا		359	5911	الزنج	Barely Perceivable نحة	Faintly Perceivab	Evening time	2017-04-08 8:42
219	Female ،	24	No لا		333	3329	Umm alhassam	Strong Odor is Perceiv	Very Strong Odor	Evening time	2017-04-08 8:49
220	Female ،	31	No لا		816	1601	مدينة عيسى	No Odor Perceivable ة	Faintly Perceivab	Morning Time	2017-04-08 8:55
221	Female ،	32	No لا		711	11	Tubli	Faintly Perceivable بطة	Clearly Perceivab	Evening time	2017-04-08 8:56
222	Male ذكر	24	No لا		711	1125	Tubli	Clearly Perceivable حة	Strong Odor is Pe	Morning Time	2017-04-08 8:57
223	Female ،	27	No لا		711	11	Tubli	Strong Odor is Perceived	يمكن شم رائحة بصورة قوية		2017-04-08 8:58
224	Female ،	27	No لا		740	4032	عالي	Clearly Perceivable حة	Clearly Perceivab	Evening time	2017-04-08 9:02
225	Male ذكر	56	No لا		721	2166	Jid ali	Faintly Perceivable بطة	Faintly Perceivab	Evening time	2017-04-08 9:12
226	Male ذكر	40	No لا		721	2165	جدعلي	Faintly Perceivable بطة	Faintly Perceivab	Evening time	2017-04-08 9:11
227	Male ذكر	20	No لا		721	2155	جدعلي	Faintly Perceivable بطة	No Odor Perceiva	Evening time	2017-04-08 9:17
228	Male ذكر	50	No لا		711	1121	Tubli	Strong Odor is Perceiv	Strong Odor is Pe	Morning Time	2017-04-08 9:20
229	Female ،	31	No لا		721	2153	Jidali	Faintly Perceivable بطة	Clearly Perceivab	Evening time	2017-04-08 9:23
230	Male ذكر	60	No لا		705	587	توبلي	No Odor Perceivable ة	No Odor Perceiva	Evening time	2017-04-08 9:23
231	Male ذكر	26	Yes نعم		701	181	Tubli	Faintly Perceivable بطة	Faintly Perceivab	Evening time	2017-04-08 9:29
232	Female ،	29	No لا		721	2174	Jid Ali	No Odor Perceivable	لايمكن شم رائحة	Evening time	2017-04-08 9:33
233	Male ذكر	23	Yes نعم		705	٥٨٦	الكورة	No Odor Perceivable ة	No Odor Perceiva	Evening time	2017-04-08 9:32
234	Male ذكر ٤٦		Yes نعم	٧٠١		١٨٤	توبلي	Faintly Perceivable بطة	Faintly Perceivab	Evening time	2017-04-08 9:35
235	Female ،	48	No لا		441	4158	السهله الشماليه	No Odor Perceivable ة	No Odor Perceiva	Evening time	2017-04-08 9:35
236	Male ذكر ٥٨		No لا	٧٢١		٢١٦٦	جدعلي	Strong Odor is Perceiv	Strong Odor is Pe	Morning Time	2017-04-08 9:37
237	Male ذكر	36	Yes نعم		341	4125	الجفير	No Odor Perceivable ة	No Odor Perceivable كن شم رائحة		2017-04-08 9:38
238	Female ،	43	No لا		361	6105	البلاد القديم	Barely Perceivable نحة	Faintly Perceivab	Evening time	2017-04-08 9:41
239	Female ،	40	Yes نعم		701	184	توبلي	Faintly Perceivable بطة	Very Strong Odor	Evening time	2017-04-08 9:40
240	Male ذكر	39	No لا		368	6824	السهلة الجنوبية	Clearly Perceivable حة	Clearly Perceivab	Evening time	2017-04-08 9:40
241	Male ذكر	50	No لا		729	1870	Jurdab	Barely Perceivable نحة	No Odor Perceiva	Evening time	2017-04-08 9:53
242	Male ذكر	30	Yes نعم		711	11	Tubli	No Odor Perceivable ة	No Odor Perceivable كن شم رائحة		2017-04-08 9:55
243	Male ذكر	20	No لا		711	11	Tubli	No Odor Perceivable ة	No Odor Perceiva	Evening time	2017-04-08 9:56
244	Female ،	27	No لا		721	2958	Isa town	Faintly Perceivable بطة	Clearly Perceivab	Evening time	2017-04-08 9:55
245	Male ذكر	55	No لا		733	3323	Alnasfa	Faintly Perceivable بطة	Clearly Perceivab	Evening time	2017-04-08 9:57
246	Male ذكر ٥٣		Yes نعم	٧٢١		٢١٤٨	JedAli	No Odor Perceivable ة	Barely Perceivabl	Evening time	2017-04-08 10:05
247	Female ،	29	No لا		462	62	Bilad Al Qadeem	No Odor Perceivable ة	No Odor Perceiva	Evening time	2017-04-08 10:08
248	Female ،	23	No لا		333	3329	Um Al hassam	Faintly Perceivable بطة	Clearly Perceivab	Evening time	2017-04-08 10:10
249	Female ،٢٧		No لا	٧٢١		٢١٥٣	جدعلي	Barely Perceivable نحة	Barely Perceivabl	Evening time	2017-04-08 10:12
250	Female أنثى		No لا	٧٢١		٢١٣٣	جدعلي	Clearly Perceivable م	الرائحة بصورة واضحة	Evening time	2017-04-08 10:15
251	Female ،٤٩		No لا	٧٢١		٢١٨٨	جدعلي	No Odor Perceivable ة	No Odor Perceivable كن شم رائحة		2017-04-08 10:19
252	Female ،	33	No لا		701	143	Tubli	No Odor Perceivable ة	Barely Perceivabl	Evening time	2017-04-08 10:22

No.	1. Gender	2. Age	3. Do you Smoke?	4. This questionnaire aim to identify the area wher				5. Please rank your sense of Tubli	6. Please rank your sense of	7. In general the most	Date
				Block المجمع	*Road* الطريق	*Area* المنطقة					
253	Female ،	23	Yes نعم	721	2191	JidAli		Faintly Perceivable طة	Faintly Perceivab	Morning Time	2017-04-08 10:28
254	Male ذكر	68	No لا	813	1309	Isa Town		Barely Perceivable نحة	Barely Perceivabl	Evening time	2017-04-08 10:24
255	Female ،	48	Yes نعم	721	2189	Jid Ali		Faintly Perceivable طة	Faintly Perceivab	Morning Time	2017-04-08 10:30
256	Male ذكر	50	No لا	701	164		توبلي	Clearly Perceivable حة	Clearly Perceivab	Evening time	2017-04-08 10:31
257	Female ،	26	No لا	721	2191	jidali		No Odor Perceivable ة	No Odor Perceiva	Morning Time	2017-04-08 10:35
258	Female ،	53	No لا	721	2191	Jid ali		Clearly Perceivable حة	Clearly Perceivab	Evening time	2017-04-08 10:35
259	Male ذكر	48	Yes نعم	804	409		مدينة عيسي	No Odor Perceivable ة	No Odor Perceivable	كن شم رائحة	2017-04-08 10:38
260	Male ذكر ٥٥		No لا	٧٢١	٢١٦٩		جدعلي	Very Strong Odor is Pe	Very Strong Odor	Morning Time	2017-04-08 10:38
261	Female ،	22	No لا	701	142	Tubli		No Odor Perceivable ة	No Odor Perceiva	Morning Time	2017-04-08 10:44
262	Female ،	44	No لا	82	382		النبيه صالح	No Odor Perceivable	لايمكن شم رائحة	Morning Time	2017-04-08 10:52
263	Female ،	20	No لا	705	531	Tubli		Faintly Perceivable طة	Faintly Perceivab	Evening time	2017-04-08 10:56
264	Female أنثى		No لا	363	بلاد القديم		بلاد القديم	Faintly Perceivable طة	Clearly Perceivab	Morning Time	2017-04-08 10:59
265	Female ،٣٩		No لا	362	6216		البلاد القديم	Barely Perceivable نحة	Barely Perceivabl	Morning Time	2017-04-08 11:06
266	Female ،	28	No لا	711	11	Tubli		Very Strong Odor is Pe	Strong Odor is Pe	Morning Time	2017-04-08 11:12
267	Female ،٤٨		No لا	٧٠٩	٩٤٨		الكورة٤	No Odor Perceivable ة	Barely Perceivabl	Evening time	2017-04-08 11:12
268	Female ،	58	No لا	358	الشيخ سلمان		الزنج	No Odor Perceivable ة	Barely Perceivabl	Evening time	2017-04-08 11:15
269	Female ،	28	No لا	381	8162		النبيه صالح	No Odor Perceivable ة	Barely Perceivabl	Evening time	2017-04-08 11:24
270	Female ،	31	No لا	360	6025	Zinj		No Odor Perceivable ة	Barely Perceivabl	Evening time	2017-04-08 11:43
271	Male ذكر	33	No لا	373	7330		بو غزال	No Odor Perceivable ة	Faintly Perceivab	Morning Time	2017-04-08 11:56
272	Male ذكر	60	No لا	701	154		توبلي	Clearly Perceivable حة	Clearly Perceivab	Morning Time	2017-04-08 12:01
273	Male ذكر	41	No لا	705	3		توبلي	Faintly Perceivable طة	Faintly Perceivab	Evening time	2017-04-08 12:10
274	Male ذكر	37	No لا	٧٠٥	٥٥٥		توبلي	Very Strong Odor is Pe	Very Strong Odor	Evening time	2017-04-08 12:13
275	Female ،	19	No لا	6521	365	Bilad alqadeem		Barely Perceivable نحة	Barely Perceivabl	Evening time	2017-04-08 12:18
276	Female ،	25	No لا	721	2182	Jidali		Barely Perceivable نحة	Faintly Perceivab	Morning Time	2017-04-08 12:21
277	Male ذكر ،49		Yes نعم	801	184		توبلي	Strong Odor is Perceiv	Clearly Perceivab	Evening time	2017-04-08 12:22
278	Female ،	18	No لا	181	701		توبلي	Very Strong Odor is Pe	Very Strong Odor	Evening time	2017-04-08 12:31
279	Male ذكر	18	No لا	701	184	Tubli		Clearly Perceivable حة	Strong Odor is Pe	Evening time	2017-04-08 12:33
280	Male ذكر		No لا	711	11	Tubli		Faintly Perceivable طة	Barely Perceivabl	Morning Time	2017-04-08 12:35
281	Male ذكر	32	No لا	729	29	jurdab		Barely Perceivable نحة	Barely Perceivabl	Evening time	2017-04-08 12:37
282	Male ذكر	44	No لا	707	747		توبلي	Clearly Perceivable حة	Strong Odor is Pe	Evening time	2017-04-08 12:36
283	Male ذكر	60	No لا	812	1229		812	Strong Odor is Perceiv	Strong Odor is Pe	Evening time	2017-04-08 12:46
284	Male ذكر	40	No لا	364	868		بلاد القديم	Clearly Perceivable حة	Clearly Perceivab	Evening time	2017-04-08 12:55
285	Male ذكر	50	Yes نعم	709	983		توبلي	Barely Perceivable نحة	Barely Perceivabl	Evening time	2017-04-08 13:19
286	Male ذكر	31	Yes نعم	705	589		توبلي	Faintly Perceivable طة	Clearly Perceivab	Evening time	2017-04-08 13:27
287	Female ،	40	No لا	361	6126	Belad al qadeem		Faintly Perceivable طة	Clearly Perceivab	Evening time	2017-04-08 13:37
288	Male ذكر	29	Yes نعم	802	205	Isa twon		Faintly Perceivable طة	Faintly Perceivab	Evening time	2017-04-08 13:46

No.	1. Gender	2. Age	3. Do you Smoke?	4. This questionnaire aim to identify the area wher				5. Please rank your sense of Tubli	6. Please rank your sense of	7. In general the most	Date
				Block المجمع	*Road* الطريق	*Area* المنطقة					
289	Female ،	29	No لا		711	1122	توبلي	Clearly Perceivable حة	Faintly Perceivab	Evening time	2017-04-08 14:16
290	Female ،	20	No لا		701	143	Tubli	No Odor Perceivable ة	No Odor Perceiva	Evening time	2017-04-08 15:08
291	Female ،	44	Yes نعم		711	1122	Tubli	Faintly Perceivable طة	Faintly Perceivab	Morning Time	2017-04-08 15:18
292	Female ،	44	No لا		702	163	توبلي	Faintly Perceivable طة	Clearly Perceivab	Evening time	2017-04-08 15:35
293	Male ذكر	٣٠	No لا	٧٠٧	٧٢٥		توبلي	Strong Odor is Perceiv	Strong Odor is Pe	Morning Time	2017-04-08 15:53
294	Female ،	23	No لا		711	1144	tubli	Clearly Perceivable حة	Faintly Perceivab	Morning Time	2017-04-08 16:25
295	Male ذكر	42	No لا		729	77	مدينه عيسى	Faintly Perceivable طة	Very Strong Odor	Evening time	2017-04-08 16:23
296	Female ،	36	No لا		365	6510	Khamis	Very Strong Odor is Pe	Very Strong Odor	Morning Time	2017-04-08 17:06
297	Female ،	22	No لا		711	1144	Tubli	No Odor Perceivable ة	Barely Perceivabl	Evening time	2017-04-08 17:14
298	Male ذكر	30	No لا		711	11	Tubli	Faintly Perceivable طة	Barely Perceivabl	Evening time	2017-04-08 17:45
299	Male ذكر	34	No لا		814	1466	isa town	Barely Perceivable نحة	Faintly Perceivab	Evening time	2017-04-08 18:01
300	Male ذكر	30	No لا		812	1218	مدينة عيسى	Faintly Perceivable طة	Clearly Perceivab	Morning Time	2017-04-08 18:09
301	Female ،	23	Yes نعم		711	1132	Tubli	Clearly Perceivable حة	Very Strong Odor	Evening time	2017-04-08 18:48
302	Male ذكر	26	No لا		363	6353	البلاد القديم	Barely Perceivable نحة	Faintly Perceivab	Evening time	2017-04-08 19:26
303	Male ذكر	23	No لا		808	805	مدينة عيسى	Clearly Perceivable حة	Faintly Perceivab	Morning Time	2017-04-08 19:51
304	Male ذكر	45	No لا		713	1332	Tubli	Very Strong Odor is Pe	Very Strong Odor	Morning Time	2017-04-08 20:23
305	Male ذكر	33	Yes نعم		709	946	Tubli,alkawara	Clearly Perceivable حة	Strong Odor is Pe	Evening time	2017-04-08 20:49
306	Female أنثى		No لا	٧٤٥	٤٥٤٦		سند	Strong Odor is Perceiv	Very Strong Odor	Evening time	2017-04-08 21:23
307	Female ،	24	No لا		705	747	توبلي	Very Strong Odor is Pe	Very Strong Odor	Morning Time	2017-04-09 2:21
308	Male ذكر	49	No لا		701	162	Tubli	Very Strong Odor is Pe	Very Strong Odor	Evening time	2017-04-09 3:58
309	Male ذكر	49	No لا		707	728	توبلي	Clearly Perceivable حة	Strong Odor is Pe	Evening time	2017-04-09 4:33
310	Male ذكر	45سنه	Yes نعم		701	151	توبلي	Very Strong Odor is Pe	Very Strong Odor is Perceived	ا	2017-04-09 8:39
311	Male ذكر	46	No لا		7001	181	توبلي	Very Strong Odor is Pe	Very Strong Odor	Evening time	2017-04-09 11:11
312	Male ذكر	27	Yes نعم		813	1312	Isa Town	No Odor Perceivable ة	No Odor Perceiva	Evening time	2017-04-09 12:00
313	Female ،	27	No لا		701	154	توبلي	Barely Perceivable نحة	Faintly Perceivab	Evening time	2017-04-09 12:32
314	Female ،	23	No لا		701	154	Tubli	Clearly Perceivable حة	Clearly Perceivab	Evening time	2017-04-09 12:55
315	Male ذكر	39	Yes نعم		729	29	Jirdab	No Odor Perceivable ة	No Odor Perceiva	Evening time	2017-04-09 13:09
316	Male ذكر	33	No لا		813	1312	Isa Town	Barely Perceivable نحة	Barely Perceivabl	Evening time	2017-04-09 13:34
317	Male ذكر	٢٢	Yes نعم		743	4329	Sanad	Barely Perceivable نحة	Faintly Perceivab	Morning Time	2017-04-09 16:29
318	Male ذكر	28	Yes نعم		743	4334	Sanad	Very Strong Odor is Pe	Very Strong Odor	Morning Time	2017-04-09 20:42
319	Female ،	44	No لا		711	1132	توبلي	No Odor Perceivable ة	Clearly Perceivab	Evening time	2017-04-10 6:52
320	Male ذكر	25	No لا		721	2122	Jidali	Clearly Perceivable حة	No Odor Perceiva	Evening time	2017-04-10 9:34
321	Male ذكر	33	No لا		364	6426	Bilad alqadeem	Faintly Perceivable طة	Clearly Perceivab	Evening time	2017-04-10 10:46
322	Female ،	25	No لا		709	985	tubli	Clearly Perceivable حة	Clearly Perceivab	Evening time	2017-04-10 12:16
323	Female ،	25	No لا		721	2121	Jidali	Strong Odor is Perceiv	Clearly Perceivab	Morning Time	2017-04-10 12:17
324	Female ،	25	No لا		816	1601	Jerdab	No Odor Perceivable ة	No Odor Perceiva	Evening time	2017-04-10 12:18

No.	1. Gender	2. Age	3. Do you Smoke?	4. This questionnaire aim to identify the area wher				5. Please rank your sense of Tubli	6. Please rank your sense of	7. In general the most	Date
				Block المجمع	*Road* الطريق	*Area* المنطقة					
325	Female ،	29	No لا		711	1121	Tuble	Clearly Perceivable حة	Very Strong Odor	Morning Time	2017-04-10 12:18
326	Female ،	٢٩	No لا		721	2158	Jidali	Very Strong Odor is Pe	Very Strong Odor	Evening time	2017-04-10 12:21
327	Female ،	٢٦	No لا	٧١١	١١٠٣		توبلي	Clearly Perceivable حة	Strong Odor is Pe	Morning Time	2017-04-10 12:23
328	Male ذكر	30	No لا		701	173	توبلي	Very Strong Odor is Pe	Very Strong Odor	Evening time	2017-04-10 12:21
329	Female ،	24	No لا		361	6119	البلاد القديم	Barely Perceivable ئحة	Faintly Perceivab	Evening time	2017-04-10 12:26
330	Female ،	30	No لا		815	1538	مدينة عيسى	No Odor Perceivable ة	No Odor Perceiva	Evening time	2017-04-10 12:32
331	Female ،	45	Yes نعم		711	1128	توبلي	Strong Odor is Perceiv	Strong Odor is Pe	Evening time	2017-04-10 12:35
332	Female ،	27	No لا		711	11	Tubli	Very Strong Odor is Pe	Strong Odor is Pe	Evening time	2017-04-10 12:28
333	Male ذكر	58	No لا		709	985	توبلي	Strong Odor is Perceiv	Strong Odor is Pe	Evening time	2017-04-10 12:39
334	Female ،	22	No لا		701	143	Tubli	No Odor Perceivable ة	No Odor Perceiva	Evening time	2017-04-10 12:47
335	Male ذكر	17	No لا		709	985	tubliy	Strong Odor is Perceived	ائحة بصورة قوية	Morning Time	2017-04-10 12:49
336	Female ،	30	No لا		701	181	توبلي	Barely Perceivable ئحة	Faintly Perceivab	Morning Time	2017-04-10 12:50
337	Female ،	28	No لا		721	2118	Jidd Ali	Barely Perceivable ئحة	Barely Perceivabl	Morning Time	2017-04-10 12:52
338	Female أنثى		No لا		709	5	Alkawaraa	Barely Perceivable ئحة	Faintly Perceivab	Evening time	2017-04-10 12:54
339	Female ،	٢٥	No لا	٧٠٩	٥		الكورة	Faintly Perceivable بطة	Faintly Perceivab	Evening time	2017-04-10 12:58
340	Female ،	47	No لا		709	985	الكورة	Clearly Perceivable حة	Clearly Perceivab	Evening time	2017-04-10 13:01
341	Female ،	٢٤	No لا	٧٠٥	٥٥٥		توبلي	No Odor Perceivable ة	Barely Perceivable يمكن شم رائحة		2017-04-10 13:01
342	Female ،	30	No لا		705		الكورة	Barely Perceivable ئحة	Clearly Perceivab	Evening time	2017-04-10 13:18
343	Male ذكر	24	No لا		705	525	Tubli	Clearly Perceivable حة	Strong Odor is Pe	Evening time	2017-04-10 13:21
344	Female ،	33	No لا		709	19	الكوره	Clearly Perceivable حة	Strong Odor is Pe	Evening time	2017-04-10 13:21
345	Male ذكر	31	Yes نعم		711	1076	Tubli	No Odor Perceivable ة	Faintly Perceivab	Evening time	2017-04-10 13:23
346	Male ذكر	59	No لا		711	1119	توبلي	Very Strong Odor is Pe	Very Strong Odor	Evening time	2017-04-10 13:25
347	Male ذكر	33	Yes نعم		426	26	Bilad Al Qadim	Faintly Perceivable بطة	Faintly Perceivab	Morning Time	2017-04-10 14:11
348	Female ،	24	No لا		721	2182	Jid Ali	No Odor Perceivable ة	Barely Perceivabl	Evening time	2017-04-10 14:13
349	Female ،	24	No لا		709	985	Tubli	Barely Perceivable ئحة	Faintly Perceivab	Morning Time	2017-04-10 14:15
350	Male ذكر	26	No لا		814	1450	Isa Town	No Odor Perceivable ة	No Odor Perceivable كن شم رائحة		2017-04-10 14:31
351	Male ذكر	48	No لا		455	5548	Bu Quwah	Barely Perceivable ئحة	Barely Perceivabl	Evening time	2017-04-10 14:34
352	Male ذكر	35	Yes نعم		711	1121	Tubli	Clearly Perceivable حة	Strong Odor is Pe	Evening time	2017-04-10 14:40
353	Female ،	٢٧	No لا	٧٠٥	٥٨٧		Al kawara	No Odor Perceivable ة	No Odor Perceiva	Evening time	2017-04-10 14:56
354	Male ذكر	٣٥	No لا	٨١٦	١٦١٩		جرداب	Barely Perceivable ئحة	Barely Perceivabl	Evening time	2017-04-10 14:57
355	Male ذكر	46	No لا		705	587	توبلي	Faintly Perceivable بطة	Faintly Perceivab	Morning Time	2017-04-10 15:47
356	Female ،	٣١	No لا	٣٣٣	٣٣٠٦		الزنج	No Odor Perceivable ة	Clearly Perceivab	Morning Time	2017-04-10 16:13
357	Male ذكر	27	No لا		711	11	Tubli	Barely Perceivable ئحة	Faintly Perceivab	Evening time	2017-04-10 16:25
358	Female ،	37	No لا		711	2211	Tubli	Barely Perceivable ئحة	Faintly Perceivab	Evening time	2017-04-10 17:48
359	Female ،	27	No لا		721	2153	Jid ali	No Odor Perceivable ة	No Odor Perceiva	Morning Time	2017-04-10 13:06
360	Female ،	30	No لا		721	2118	Jidali	Faintly Perceivable بطة	Clearly Perceivab	Evening time	2017-04-11 6:40

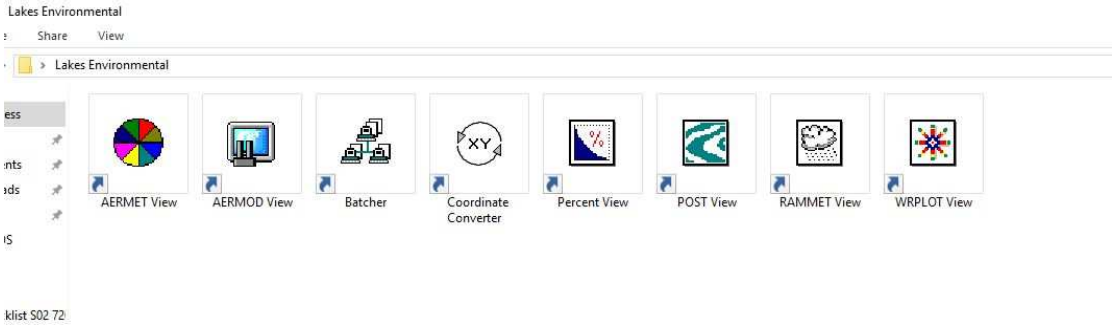
No.	1. Gender	2. Age	3. Do you Smoke?	4. This questionnaire aim to identify the area wher			5. Please rank your sense of Tubli	6. Please rank your sense of	7. In general the most	Date
				Block المجمع	*Road* الطريق	*Area* المنطقة				
361	Female	27	No لا	701	173	Tubli	Strong Odor is Perceiv	Clearly Perceivab	Evening time	2017-04-11 7:28
362	Male ذكر	37	No لا	707	11	توبلي	Very Strong Odor is Pe	Very Strong Odor	Evening time	2017-04-11 18:15
363	Male	55	smoker	702	Salmabad Ave	Salmabad	No Odor	No Odor	N/A	2017-01-29 0:00
364	Male	30	Non- smoker	711	Avenue 13	Tubli	Faintly Perceivable	Faintly Perceivab	Night Time	2017-04-05 0:00
365	Male	32	Non- smoker	711	Avenue 13	Tubli	Barely Perceivable	Barely Perceivabl	Night Time	2017-04-05 0:00
366	Male	30	Non- smoker	711	Avenue 13	Tubli	Faintly Perceivable	Faintly Perceivab	Morning Time	2017-04-05 0:00
367	Female	20	Non-Smoker	331	Shaikh Isa Bin S	Bu Ghazal	No Odor	No Odor	N/A	2017-04-07 0:00
368	Female	39	Non-Smoker	331	Shaikh Isa Bin S	Bu Ghazal	Barely Perceivable	Barely Perceivabl	Morning Time	2017-04-07 0:00
369	Female	22	smoker	331	Shaikh Isa Bin S	Bu Ghazal	Barely Perceivable	Barely Perceivabl	Morning Time	2017-04-07 0:00
370	Female	30+	Non- smoker	311	Shaikh Isa Bin S	Bu Ghazal	No Odor	No Odor	N/A	2017-04-07 0:00
371	Male	30	-	711	Avenue 13	Tubli	Very Strong Odor is Pe	Very Strong Odor	Night Time	2017-04-07 0:00
372	Male	24	Smoker	711	Avenue 13	Tubli	Very Strong Odor is Pe	Very Strong Odor	Night Time	2017-04-07 0:00
373	Female	37	Non-Smoker	711	Avenue 13	Tubli	No Odor	No Odor	N/A	2017-04-07 0:00
374	Male	30	-	711	1114	Tubli	Very Strong Odor is Pe	Very Strong Odor	Morning Time	2017-04-05 0:00
375	Male	30	Non- smoker	711	1111	Tubli	Strong Odor is Preceiv	Strong Odor is Pr	Morning Time	2017-04-05 0:00
376	Female	30	Non- smoker	711	1111	Tubli	Faintly Perceivable	Faintly Perceivab	Night Time	2017-04-05 0:00
377	Female	26	Non- smoker	711	1111	Tubli	Clearly Perceivable	Strong Odor is Pr	Morning Time	2017-04-05 0:00
378	Female	32	Non-Smoker	711	1111	Tubli	Faintly Perceivable	Faintly Perceivab	Night Time	2017-04-05 0:00
379	Male	50	Non-Smoker	711	1111	Tubli	Faintly Perceivable	Faintly Perceivab	Night Time	2017-04-05 0:00
380	Male	50	Non- smoker	711	1111	Tubli	Clearly Perceivable	Clearly Preceivab	Night Time	2017-04-05 0:00
381	Female	20	Non- smoker	711	1111	Tubli	Faintly Perceivable	Faintly Perceivab	Morning Time	2017-04-05 0:00
382	Male	32	Non- smoker	711	1111	Tubli	Barely Perceivable	Barely Perceivabl	Night Time	2017-04-05 0:00
383	Female	33	non - Smoker	711	1109	Tubli	Clearly Perceivable	Clearly Preceivab	Night Time	2017-04-05 0:00
384	Male	50	Non-Smoker	711	Avenue 11	Tubli	Very Strong Odor is Pe	Very Strong Odor	Night Time	2017-04-05 0:00
385	Male	50	Non -Smoker	711	1111	Tubli	No Odor Preceivable	No Odor Preceiva	N/A	2017-04-05 0:00
386	Male	35	Smoker	373	7303	Bu Ghazal	No Odor Preceivable	Clearly Preceivab	Night Time	2017-04-05 0:00
387	Male	26	Non-Smoker	373	7303	Bu Ghazal	Faintly Perceivable	Faintly Perceivab	Night Time	2017-04-05 0:00
388	Male	25	non - Smoker	711	Avenue 13	Tubli	No Odor Preceivable	No Odor Preceiva	N/A	2017-04-05 0:00
389	Male	30	Non- smoker	711	Avenue	Tubli	Clearly Perceivable	Clearly Preceivab	Night Time	2017-04-05 0:00
390	Female	48	Non- smoker	359	Abu Gazal Ave	Zinj	No Odor Preceivable	No Odor Preceiva	N/A	2017-03-09 0:00
391	Male	26	Non- smoker	711	Avenue 11	Tubli	Faintly Perceivable	Faintly Perceivab	Night Time	2017-04-08 0:00
392	male	29	Non- smoker	711	Avenue 11	Tubli	Faintly Perceivable	Faintly Perceivab	Night Time	2017-07-08 0:00
393	Male	22	non - Smoker	711	Avenue 11	Tubli	Very Strong Odor is Pe	Very Strong Odor	Morning Time	2017-04-08 0:00
394	Male	27	Non- smoker	711	Avenue 11	Tubli	Strong Odor is Preceiv	Strong Odor is Pr	Morning Time	2017-04-08 0:00
395	Male	32	smoker	711	Avenue 11	Tubli	Very Strong Odor is Pe	Very Strong Odor	Morning Time	2017-04-08 0:00
396	Male	24	Non- smoker	711	Avenue 11	Tubli	Strong Odor is Preceiv	Strong Odor is Pr	same	2017-04-08 0:00

No.	1. Gender	2. Age	3. Do you Smoke?	4. This questionnaire aim to identify the area wher *Block* المجمع	*Road* الطريق	*Area* المنطقة	5. Please rank your sense of Tubli	6. Please rank your sense of	7. In general the most	Date
397	Male	40	Non- smoker	366	Shaikh Isa Bin !	Adhari	Very Strong Odor is Pe	Very Strong Odor	Morning Time	2017-04-09 0:00
398	Male	50	Non-Smoker	366	Shaikh Isa Bin !	Adhari	Very Strong Odor is Pe	Very Strong Odor	Morning Time	2017-04-09 0:00
399	Female	32	Non-Smoker	366	Shaikh Isa Bin !	Adhari	No Odor Preceivable	No Odor Preceiva	N/A	2017-04-09 0:00
400	Female	40	Non- smoker	366	Shaikh Isa Bin !	Adhari	No Odor Preceivable	No Odor Preceiva	N/A	2017-04-09 0:00
401	Female	26	Non- smoker	366	376	Adhari	No Odor Preceivable	No Odor Preceiva	N/A	2017-04-09 0:00
402	Female	26	Non- smoker	711	1131	Tubli	Clearly Perceivable	Clearly Preceivab	Night Time	2017-04-09 0:00
403	Female	25	Non- smoker	366	376	Adhari	No Odor Preceivable	No Odor Preceiva	N/A	2017-04-09 0:00
404	Female	40	Non- smoker	364	6465	Bilad Al Qadeem	Very Strong Odor is Pe	Very Strong Odor	Night Time	2017-04-09 0:00
405	Female	40	Non-Smoker	364	6465	Bilad Al Qadeem	Very Strong Odor is Pe	Very Strong Odor	Night Time	2017-04-09 0:00
406	Female	30	Non-Smoker	364	6465	Bilad Al Qadeem	Clearly Perceivable	Strong Odor is Pr	Morning Time	2017-04-09 0:00
407	Female	36	Non-Smoker	364	6465	Bilad Al Qadeem	No Odor Preceivable	No Odor Preceiva	N/A	2017-04-09 0:00
408	Male	29	Smoker	364	6465	Bilad Al Qadeem	Clearly Perceivable	Clearly Preceivab	Morning Time	2017-04-09 0:00
409	Female	25	Non-Smoker	364	6465	Bilad Al Qadeem	No Odor Preceivable	No Odor Preceiva	N/A	2017-04-09 0:00
410	Female	44	Non- smoker	364	6465	Bilad Al Qadeem	Faintly Perceivable	Faintly Perceivab	Morning Time	2017-04-09 0:00

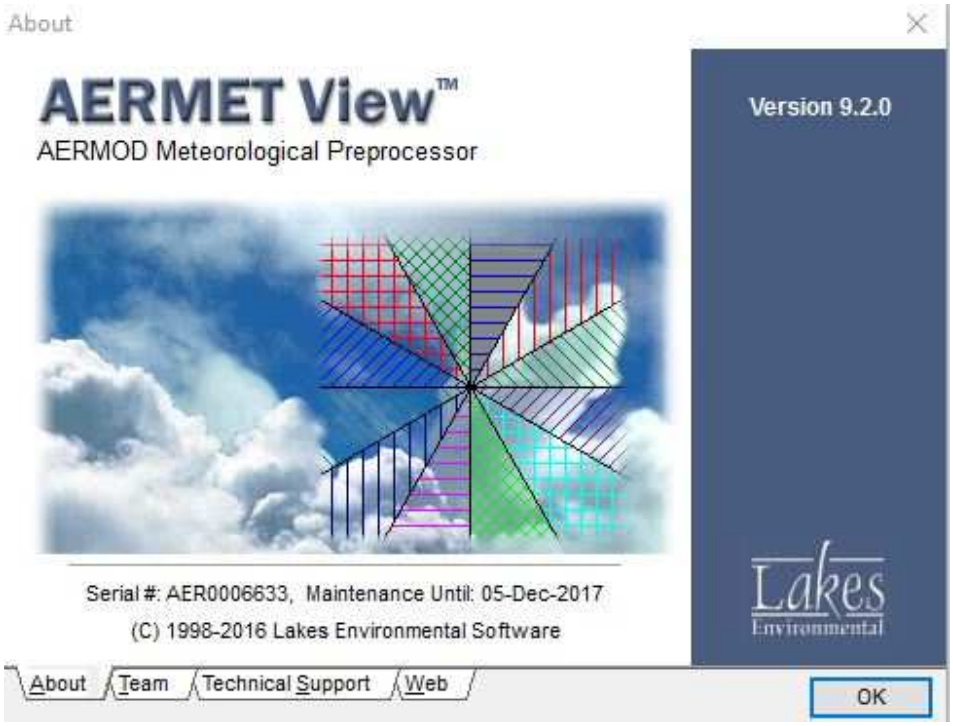
Appendix 3

AERMET File Step by Step

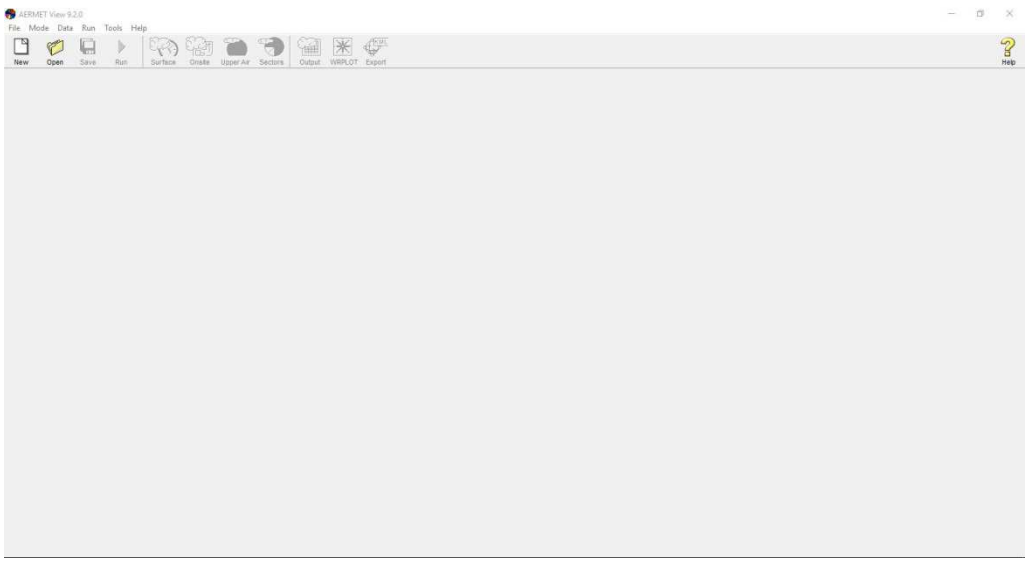
1. AERMET shortcut and the entire softwares comes with AERMOD package .



2. AERMET view

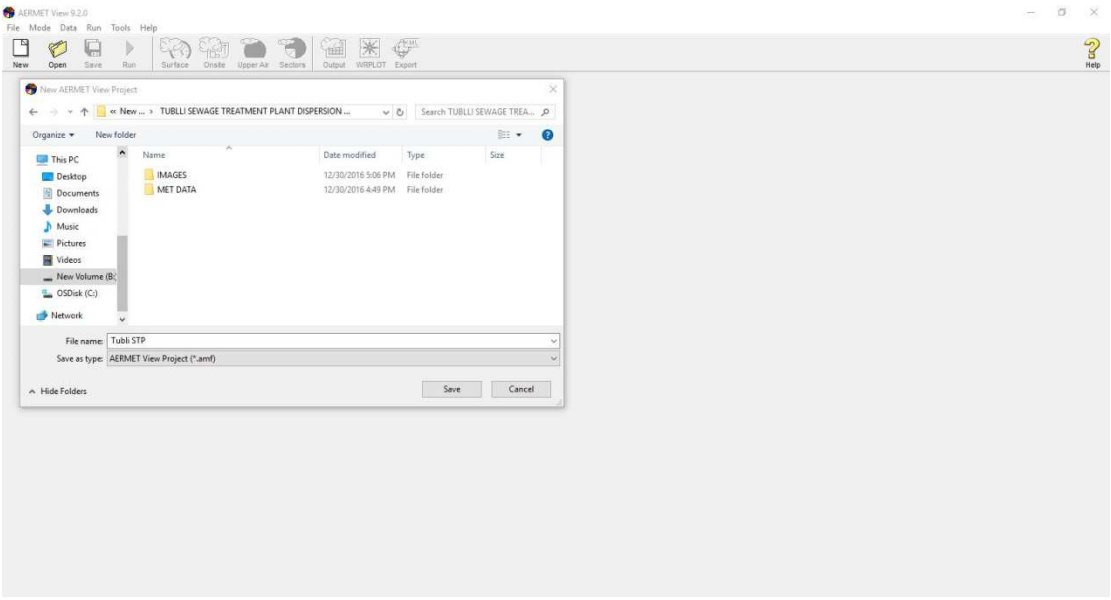


3. AERMET Home page

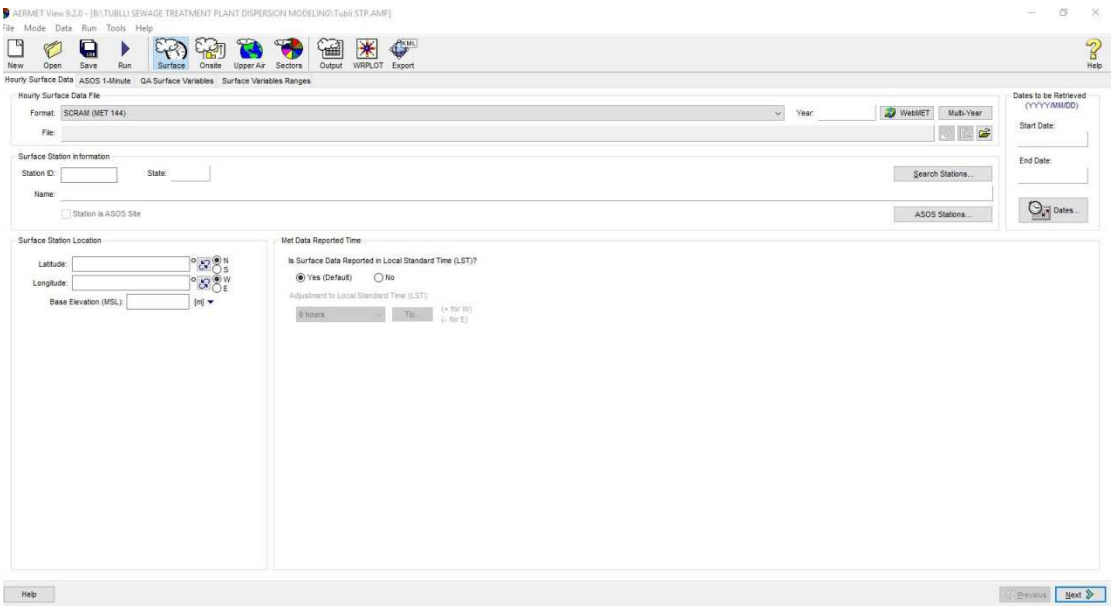


AERMET File Step by Step

4. creating the file

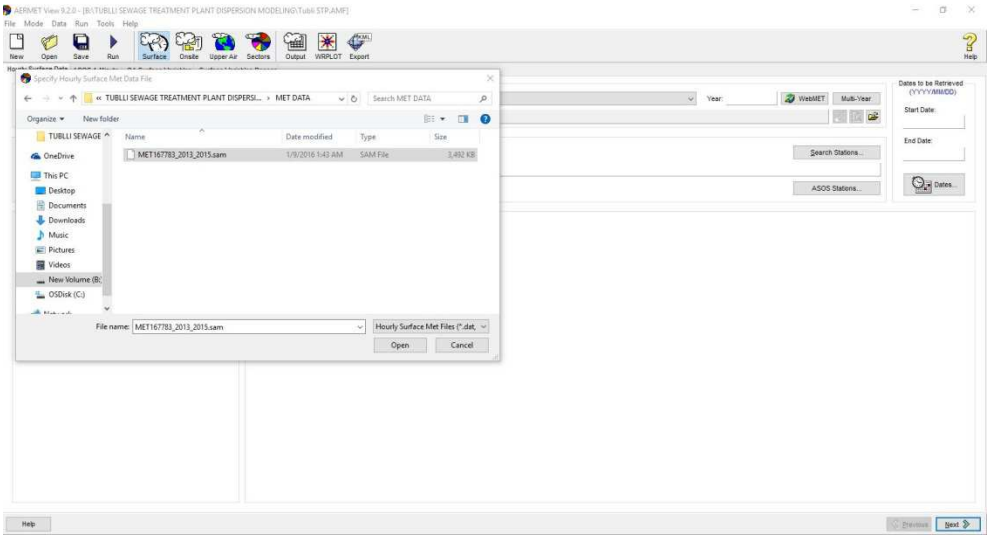


5. AERMET processer homage

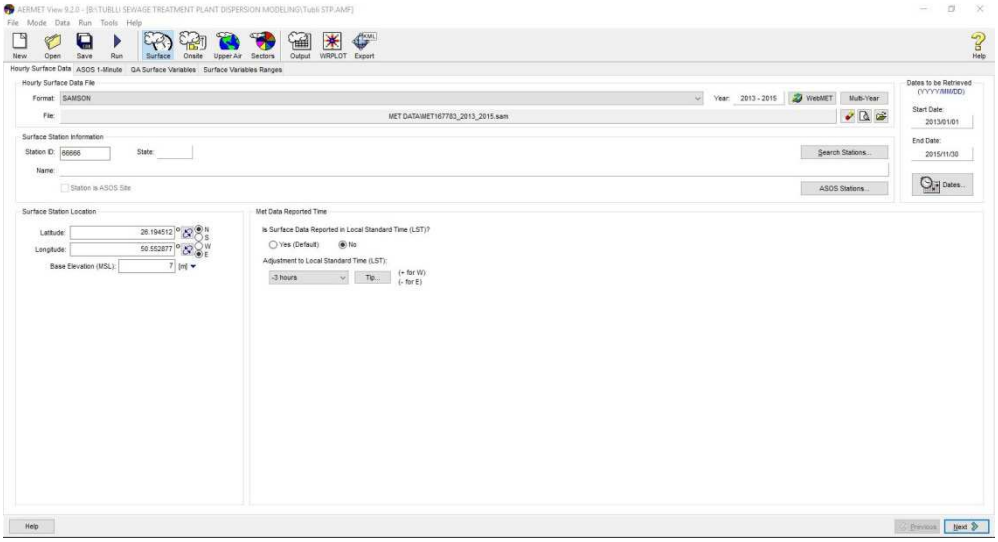


AERMET File Step by Step

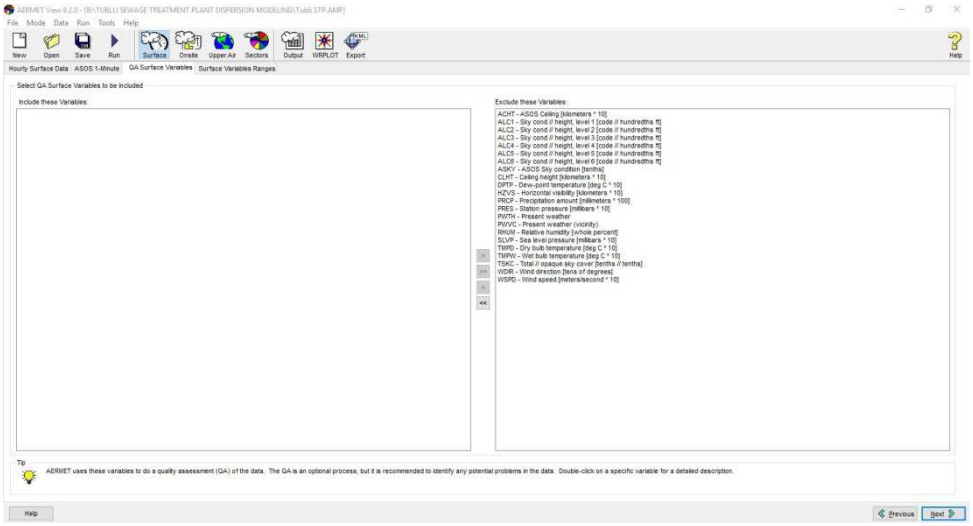
6. MET data Insertion (samson file)



7. MET data setting

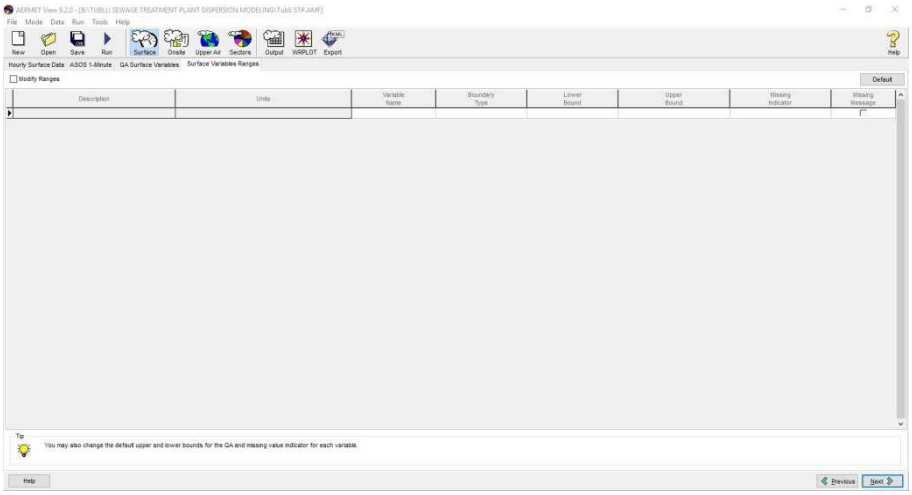


8. QA surface sheet setting

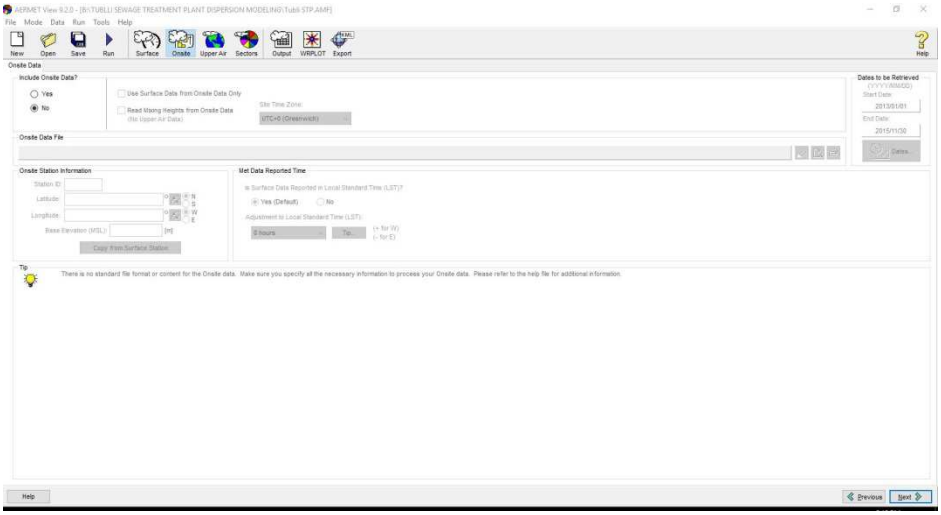


AERMET File Step by Step

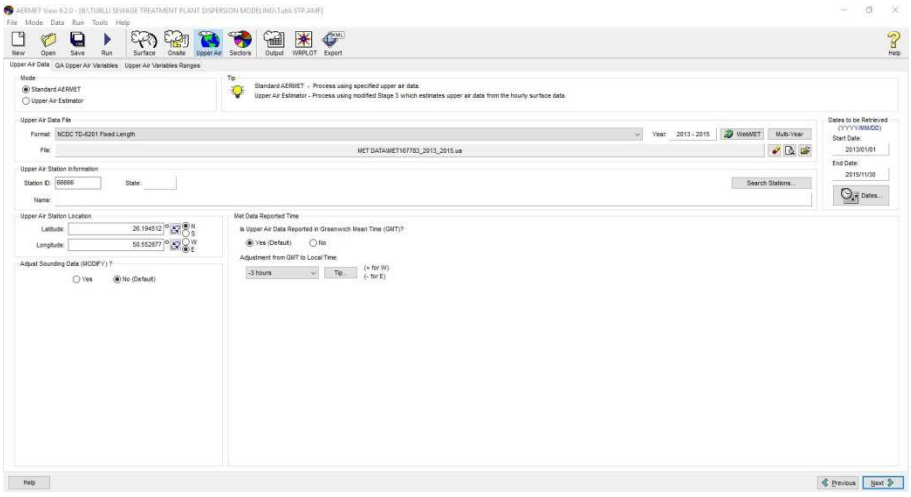
9. Surface Variable ranges



10.Onsite Surface data

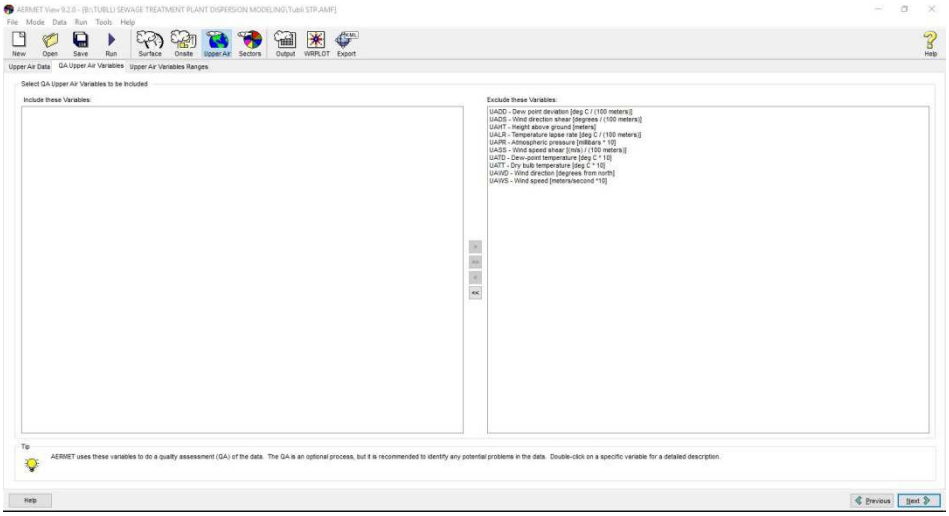


11.Upper Air Data

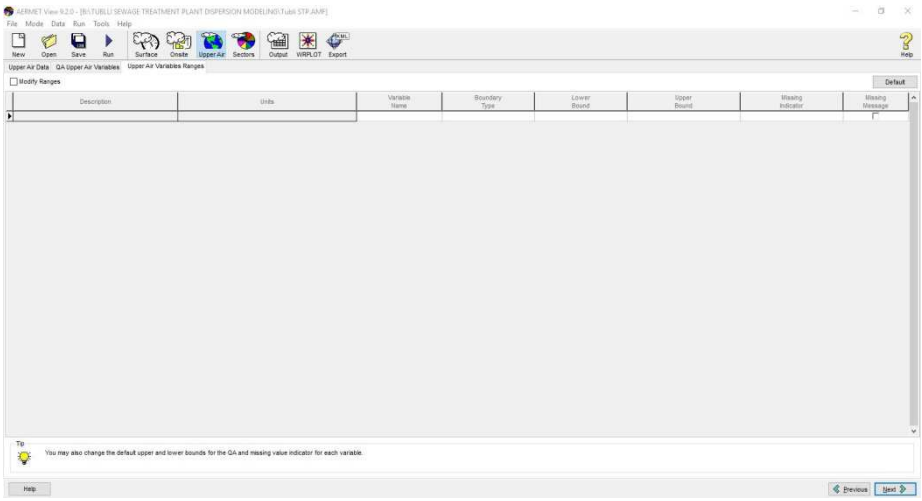


AERMET File Step by Step

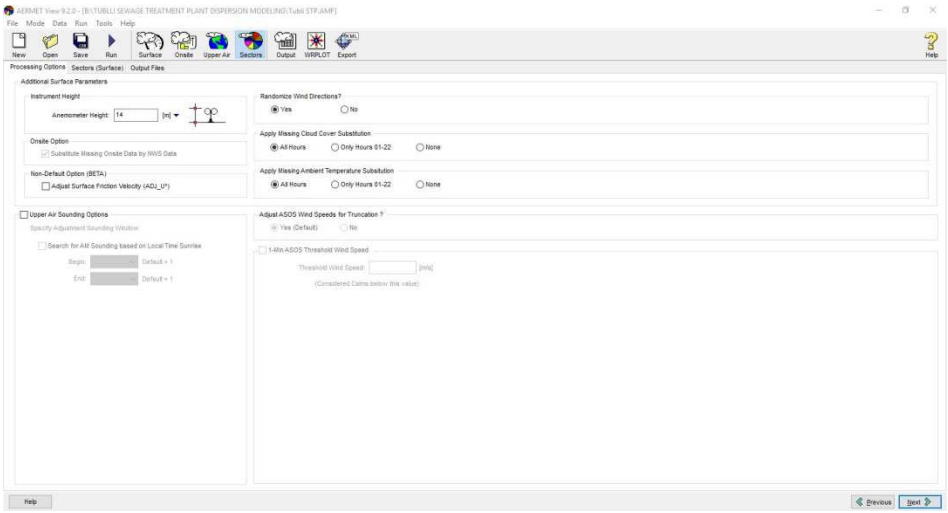
12. QA upper Air data



13. upper air variable ranges

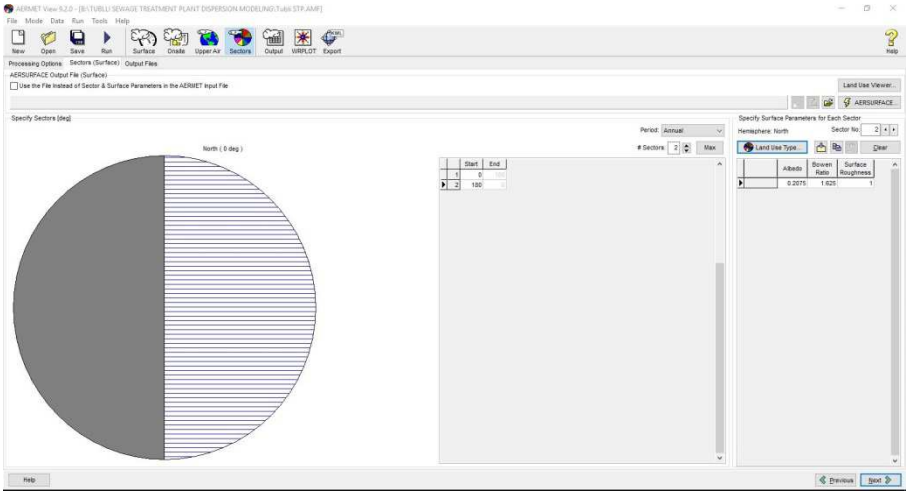


14. Processing option

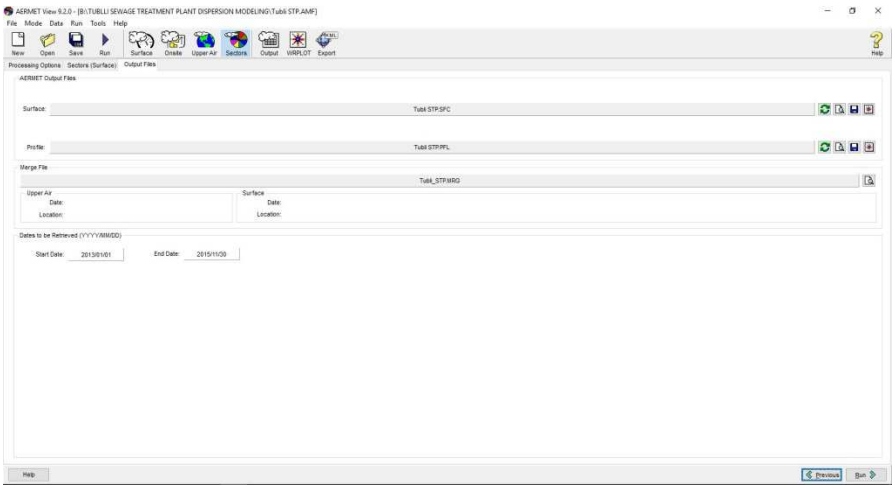


AERMET File Step by Step

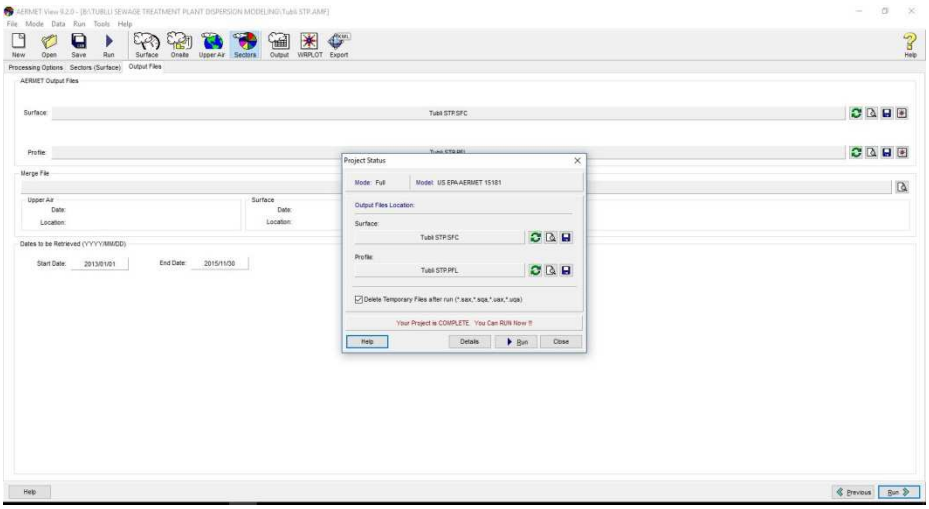
15.Section selection (Water surface and Urban)



16. Output file

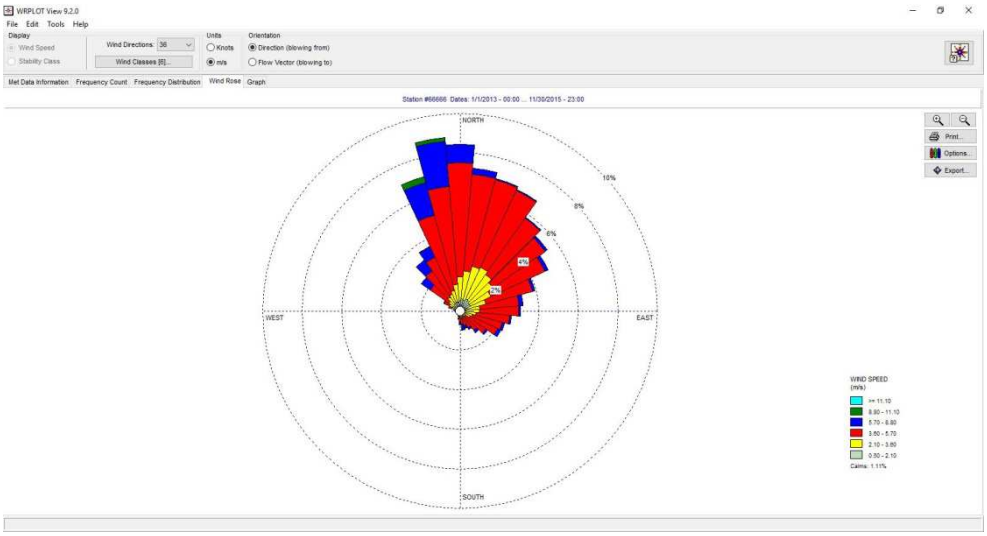


17. AERMET run

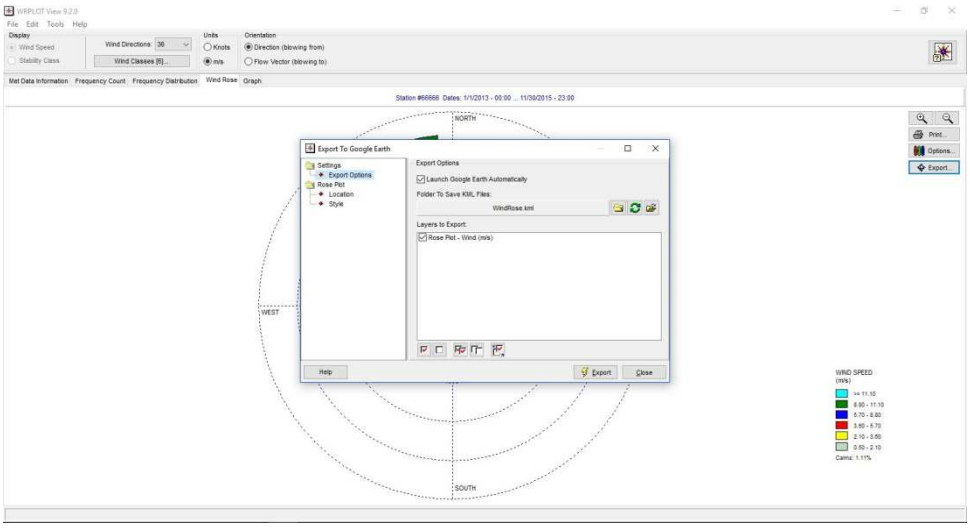


AERMET File Step by Step

18. Wind Rose (AERMET output)



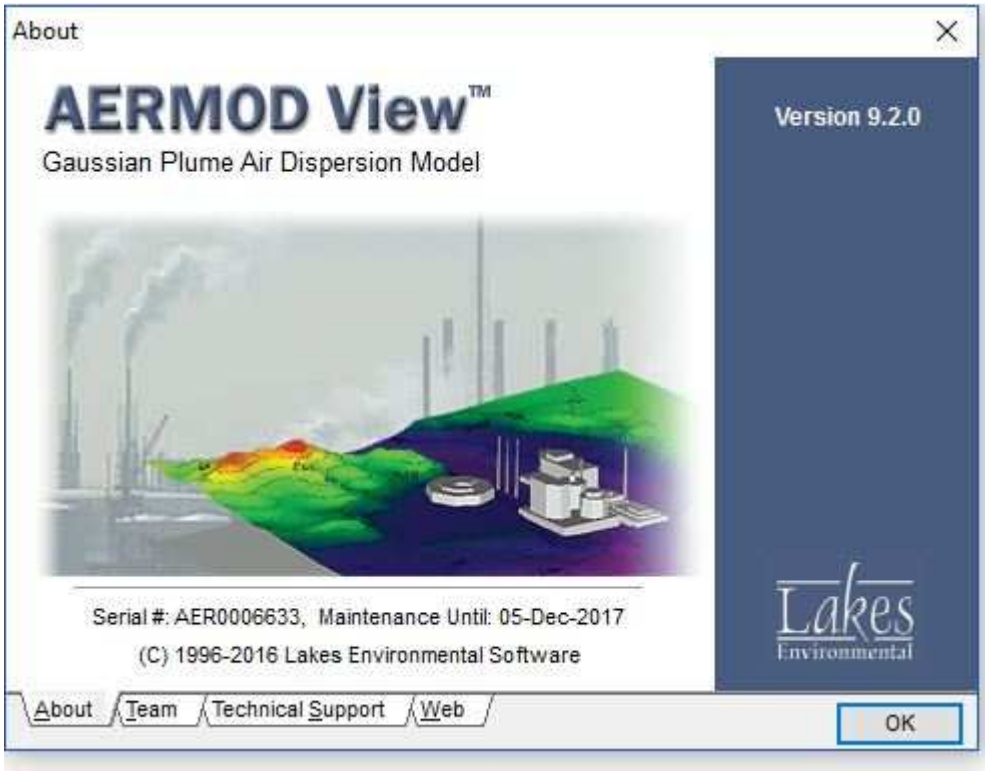
19.Export to google Earth



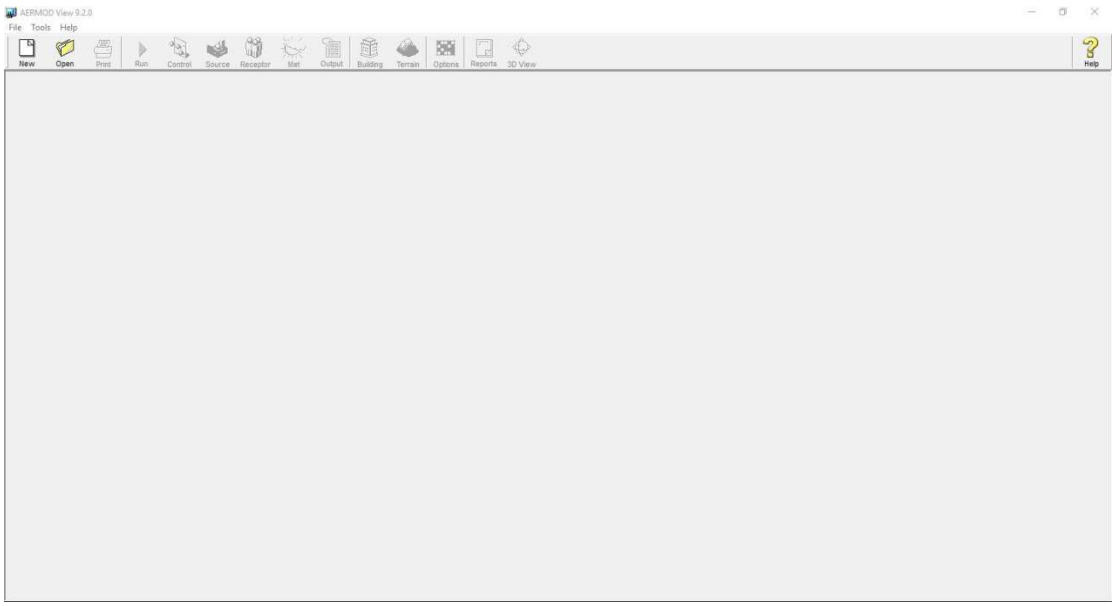
Appendix 4

Running AERMOD step by step

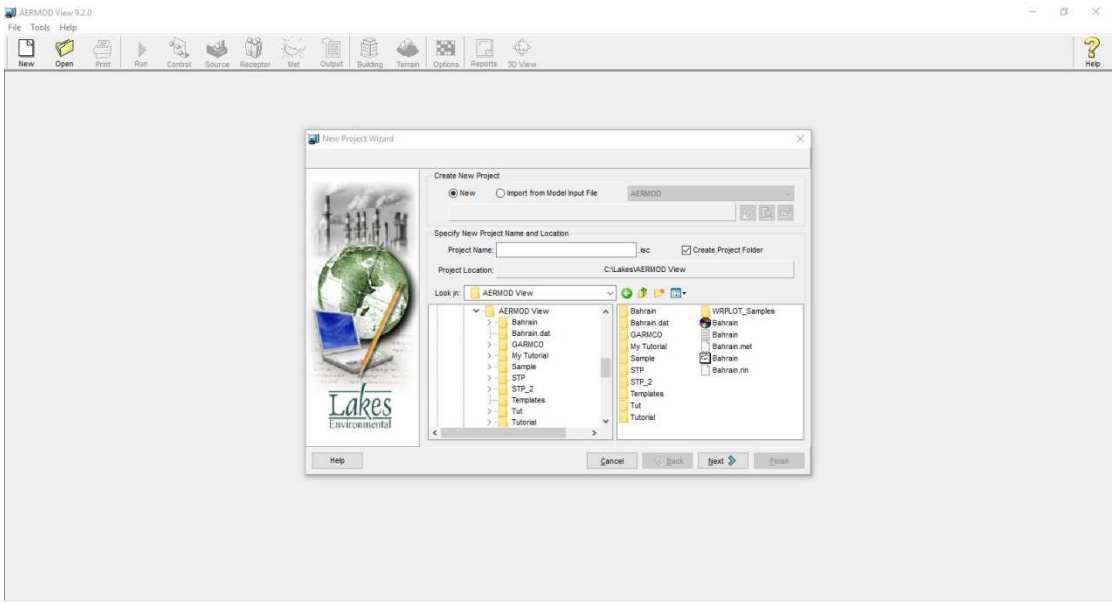
1. AERMOD front screen.



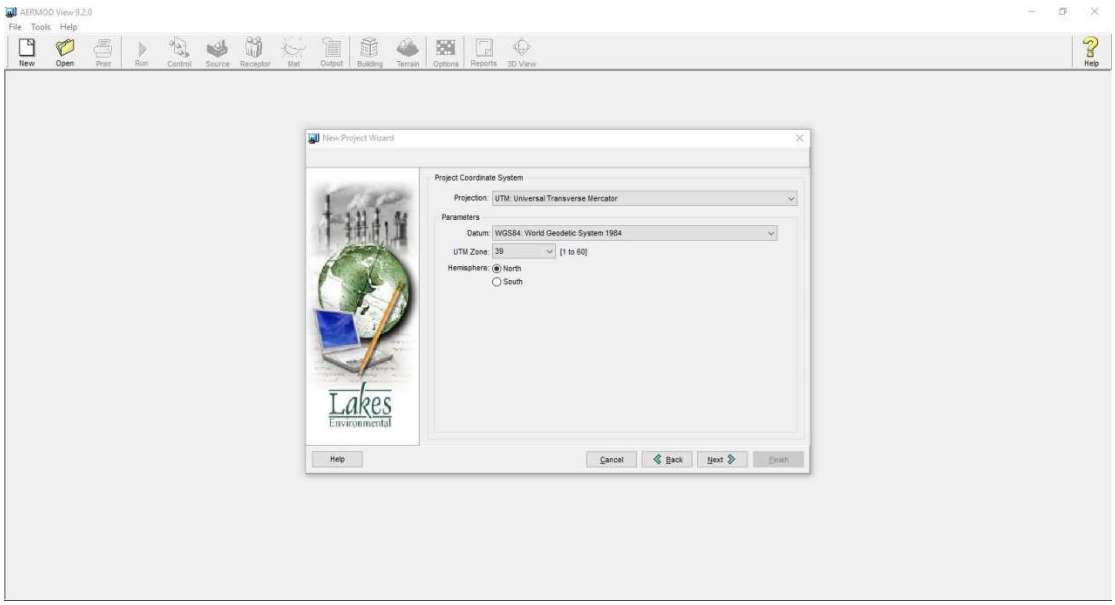
2. AERMOD home page.



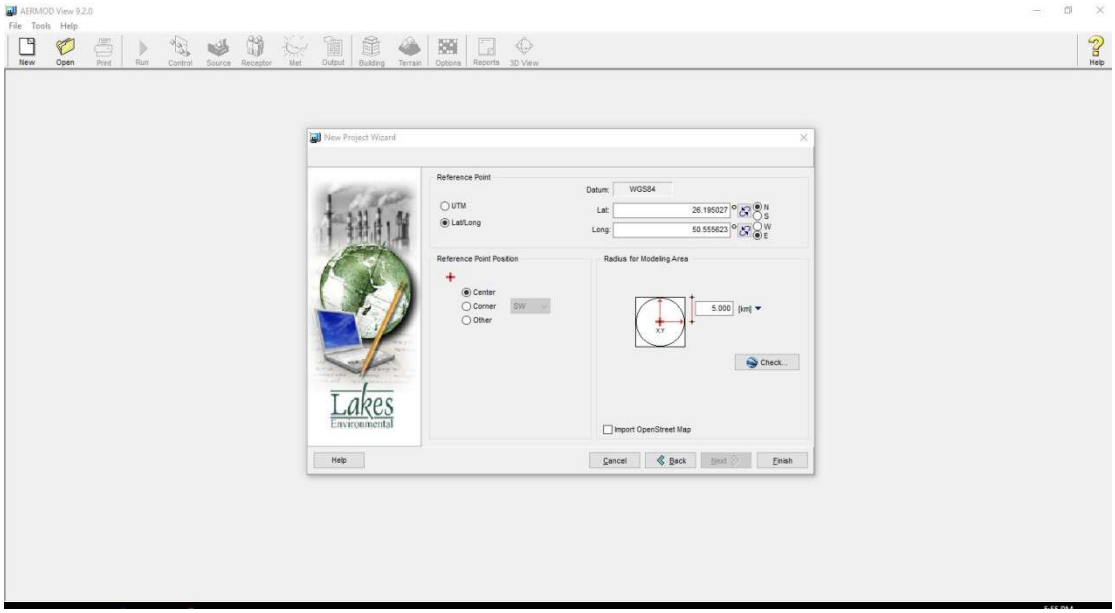
3. Step 1 – creating the project file



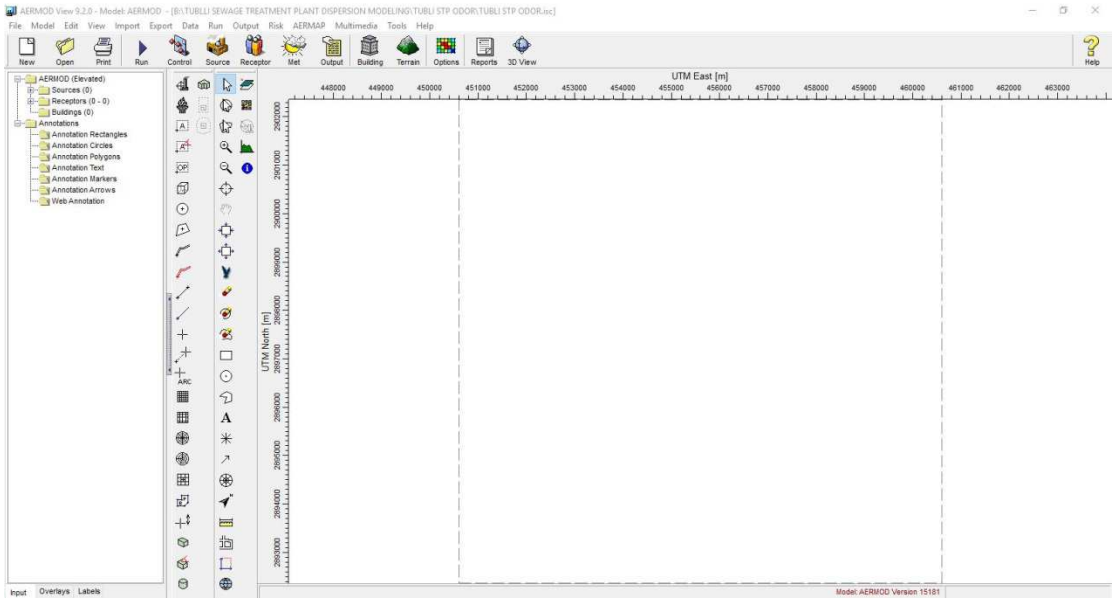
4. Setting the project coordinate system



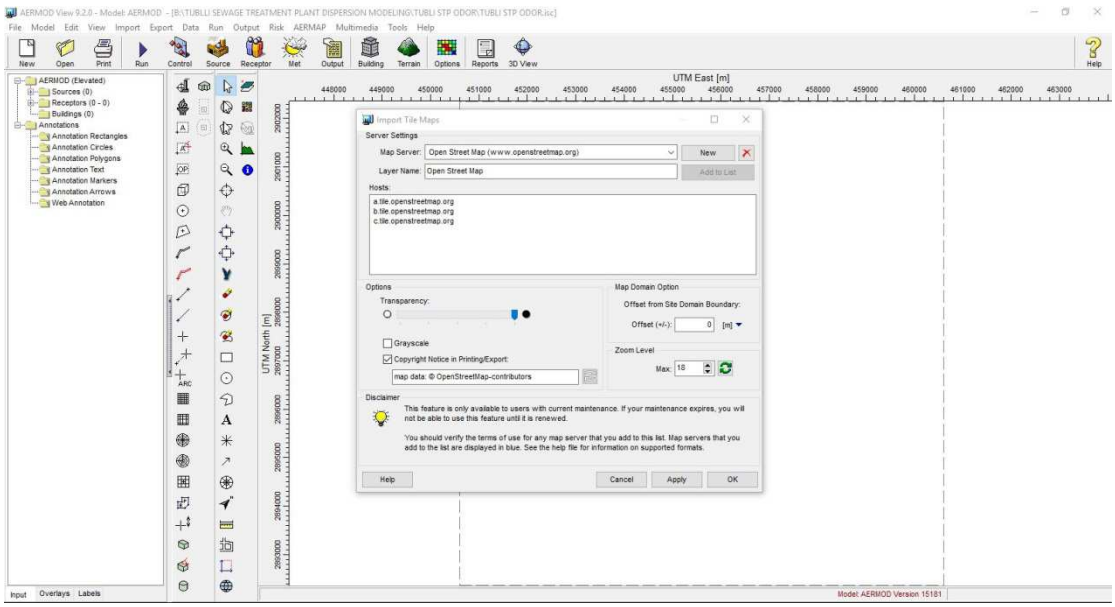
5. Step3 – selecting reference point



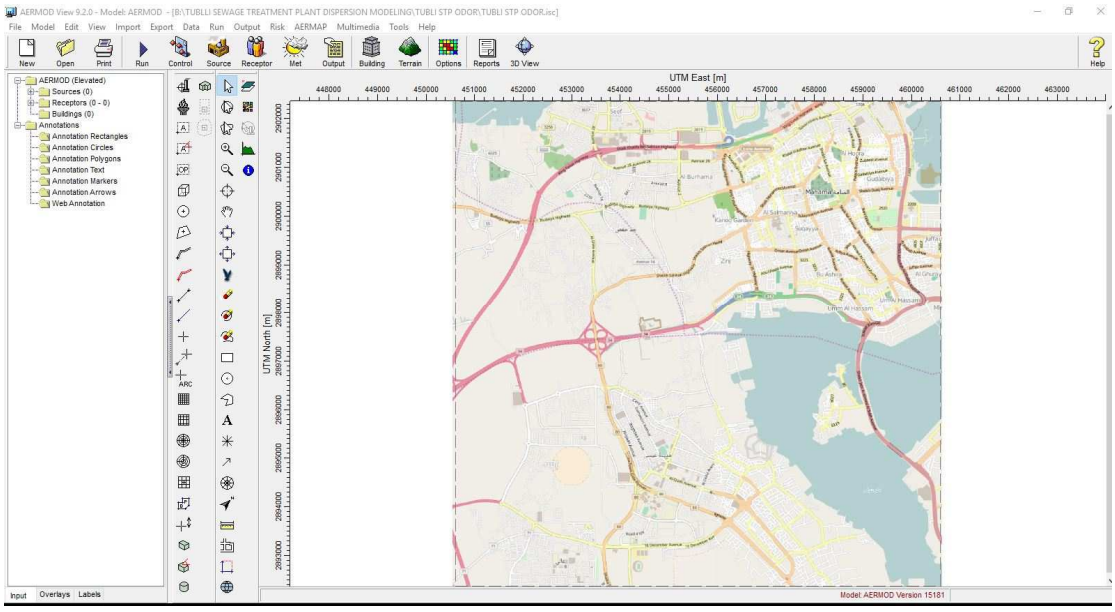
6. Step 4 – importing tile map



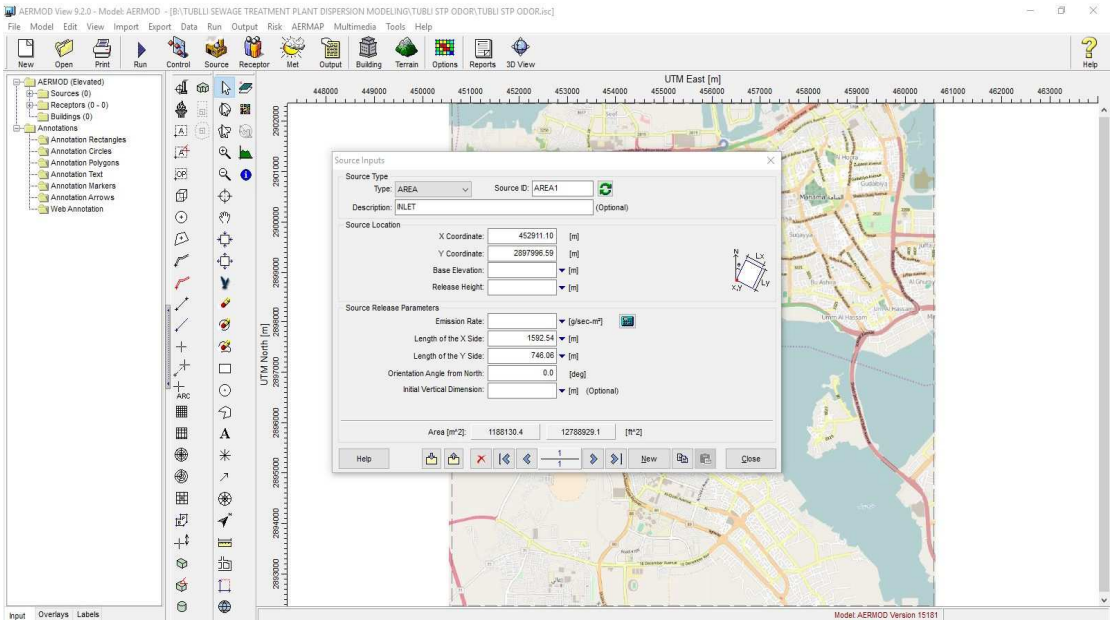
7. Step 5 - Tile map selection



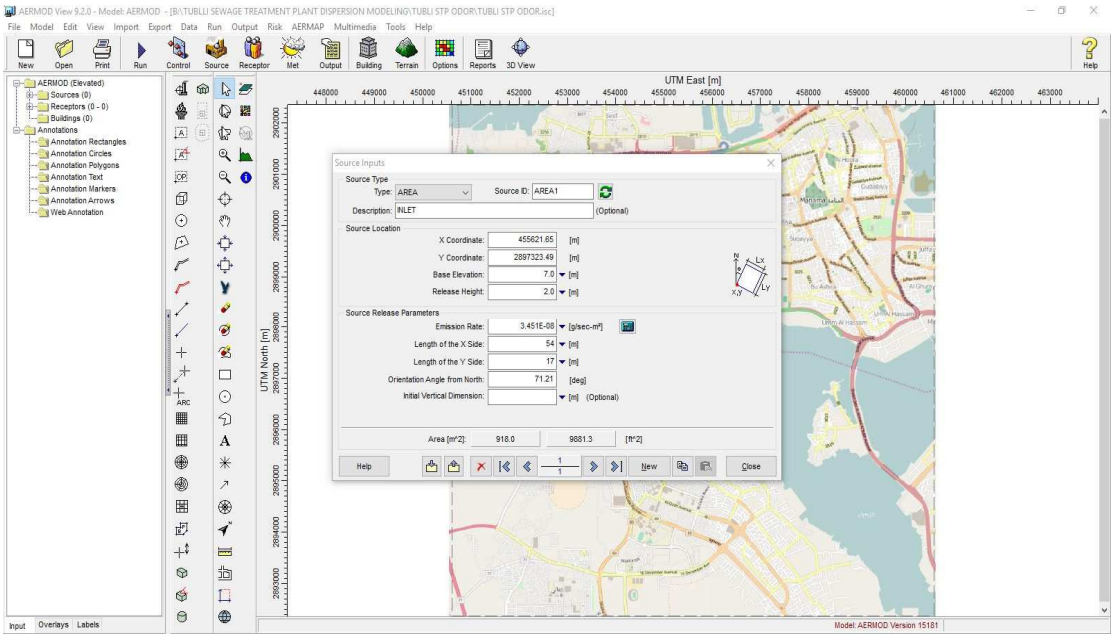
8. Tile map imported



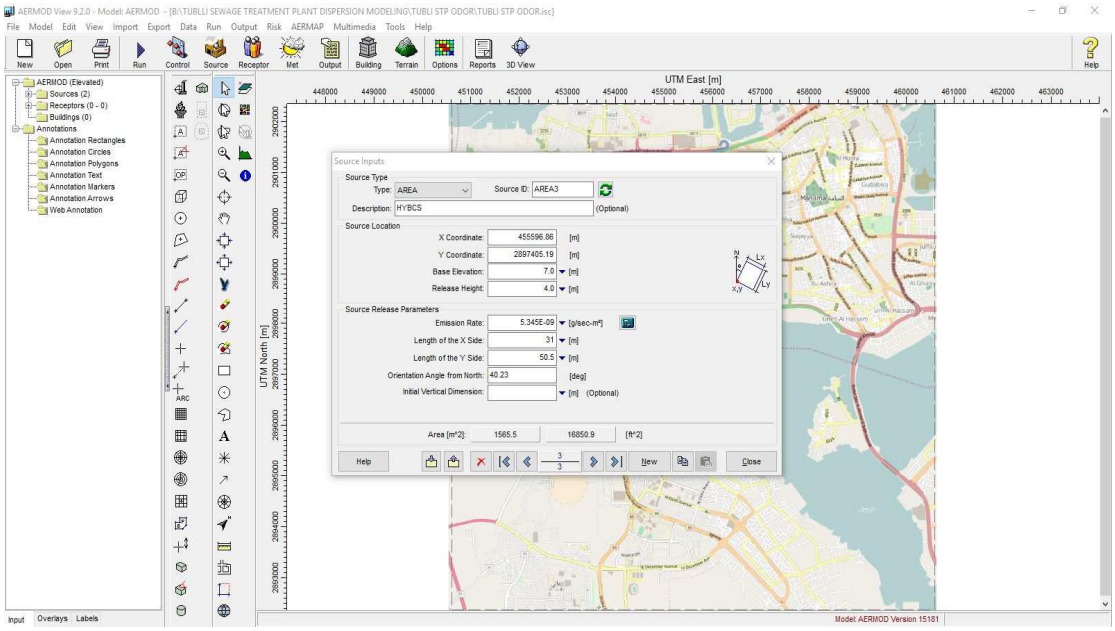
9. Step 6 A– setting area source No. 1



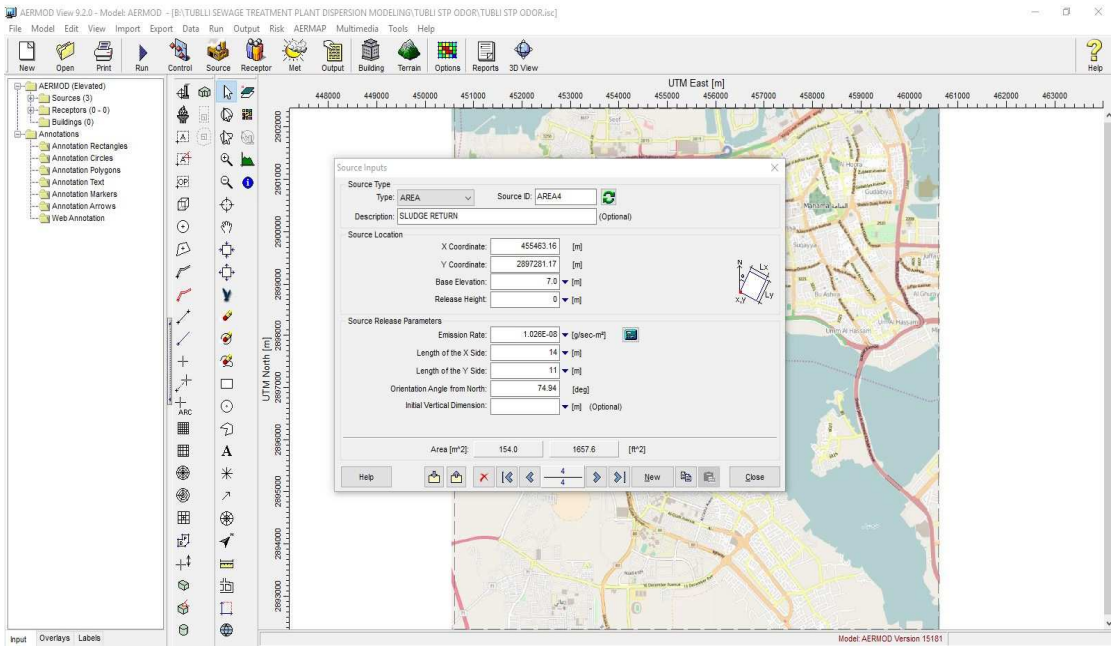
10. Step 6 B – setting area source No. 2



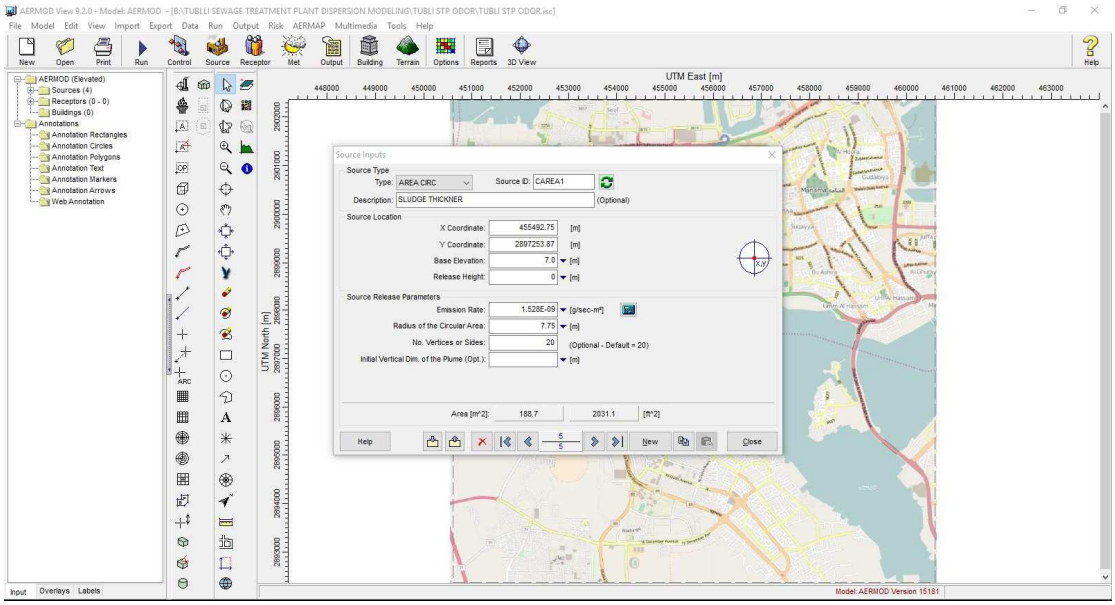
11. Step 6C - setting area source No. 3

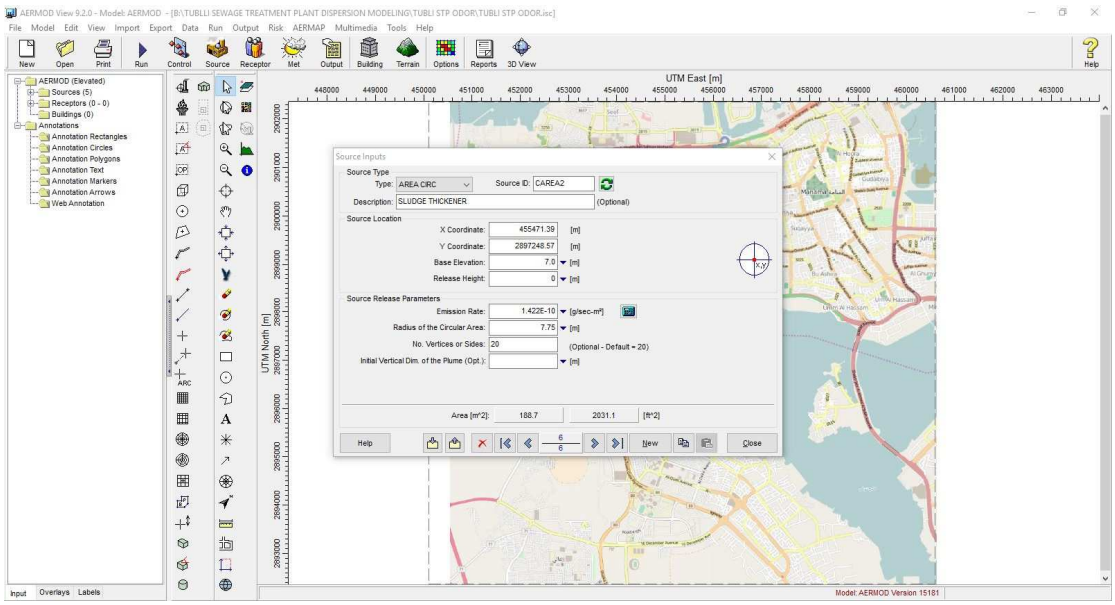


12. Step 6D – setting area No. 4

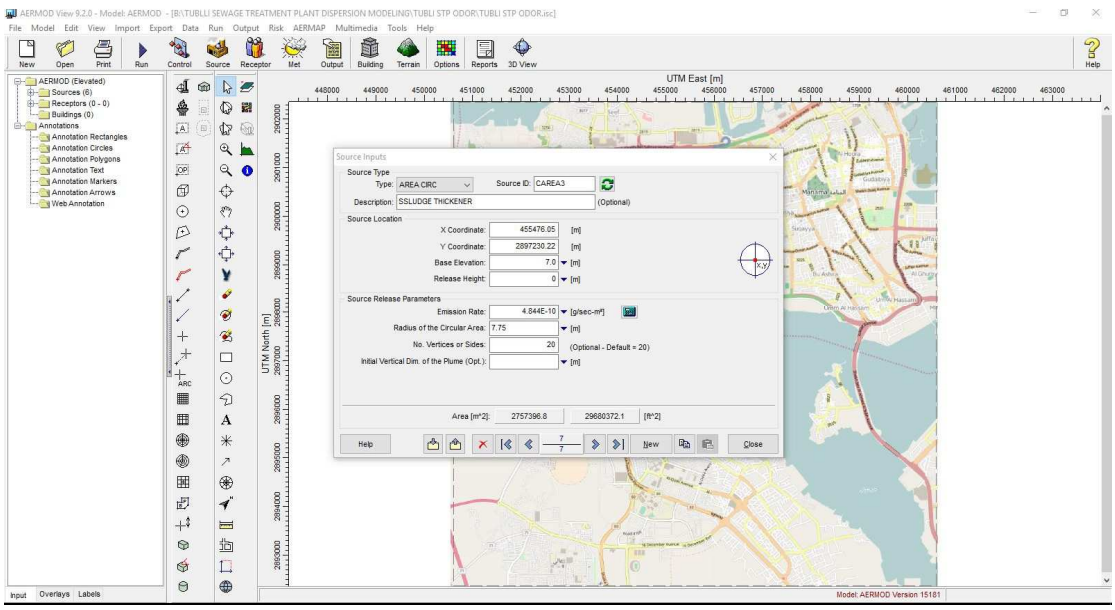


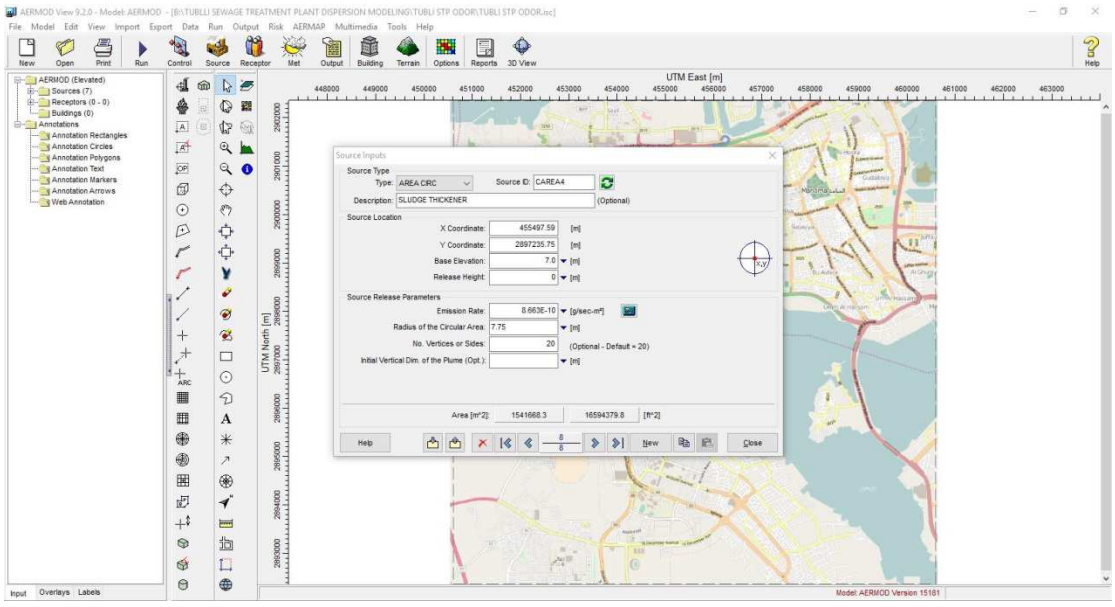
13. Step 6E – setting (4 circles – with coordinates) area source No. 5



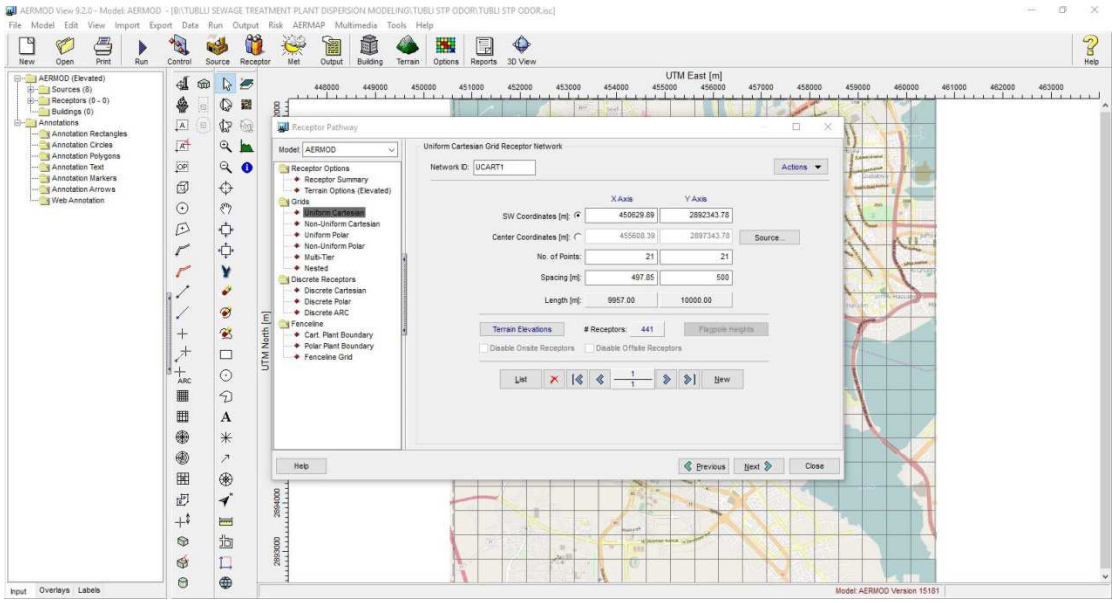


14. Step 6E – continue

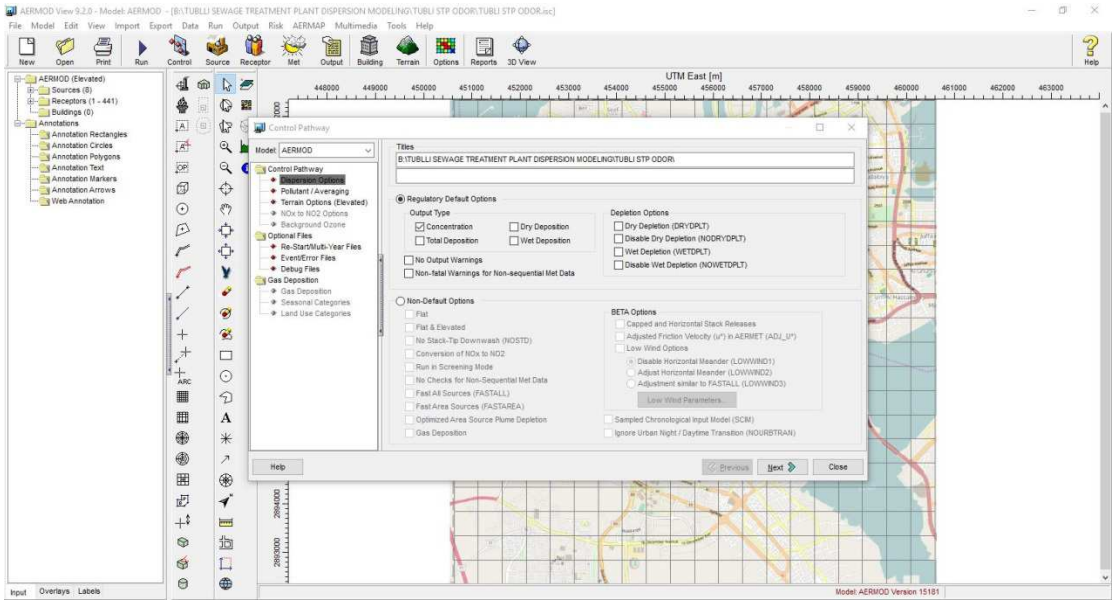




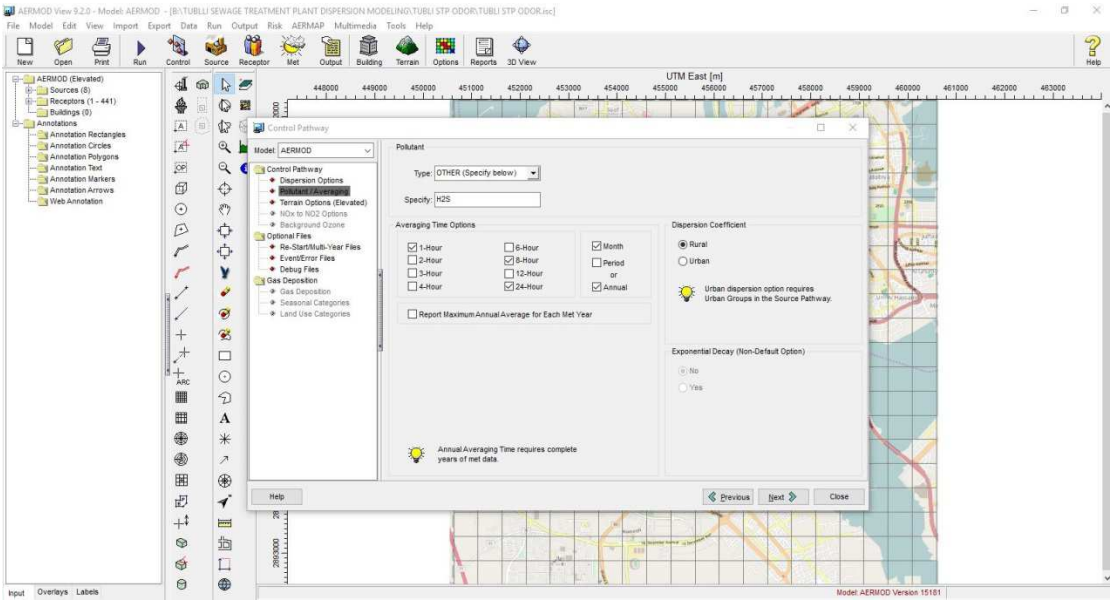
15. Step 7 – Receptor selection (uniform Cartesian)



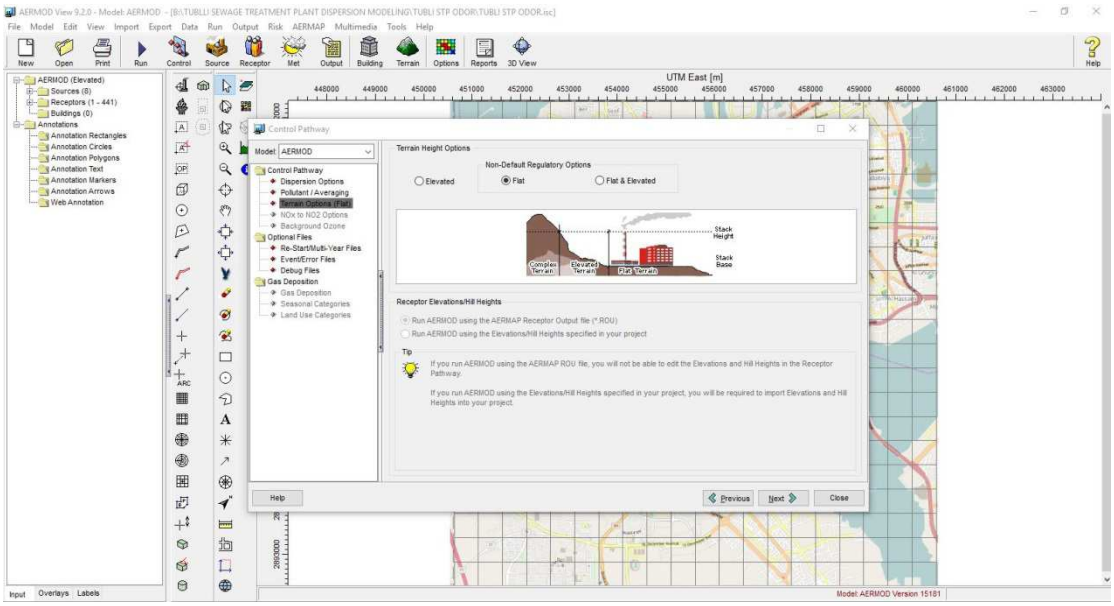
16. Step 8 – Control pathway, dispersion option



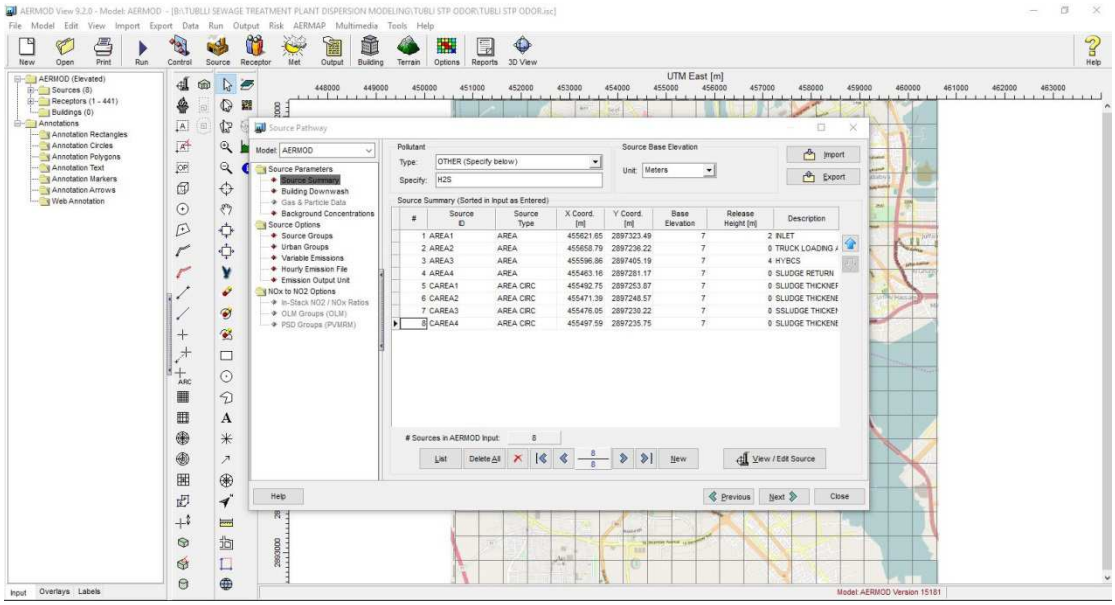
17. Step 9 – Control pathway : pollutant and averaging selection



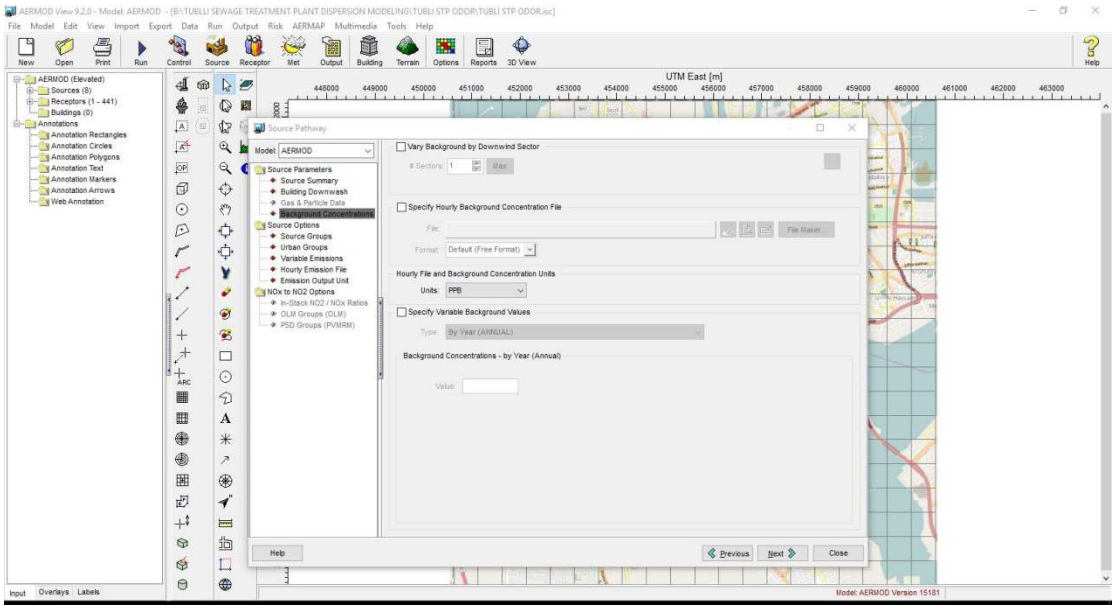
18. Step 10 – Control pathway: terrain selection.



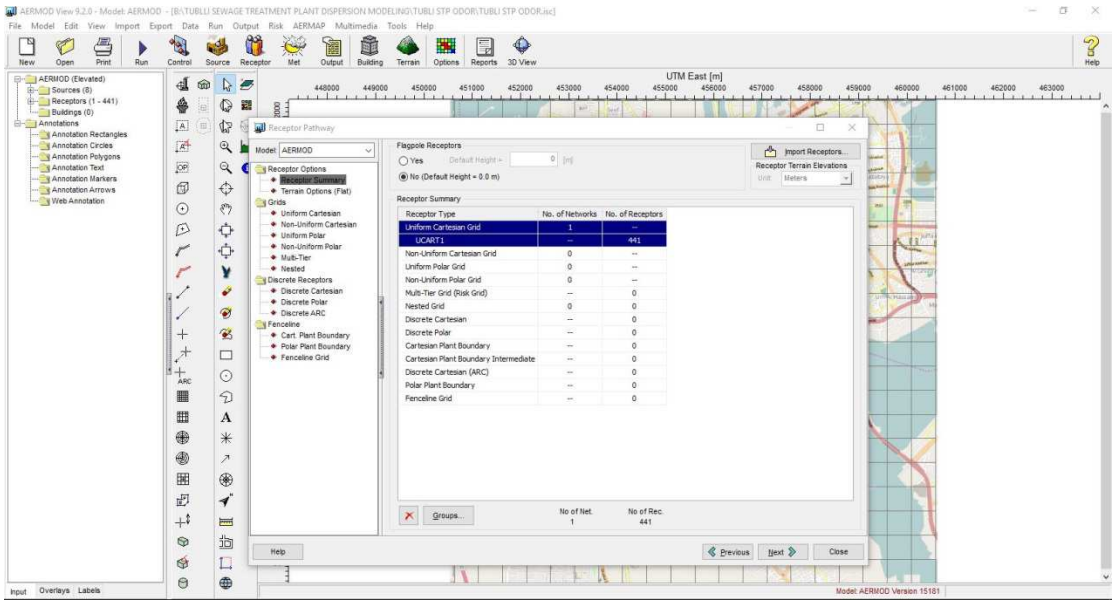
19. Step 11 – Control pathway, source summary



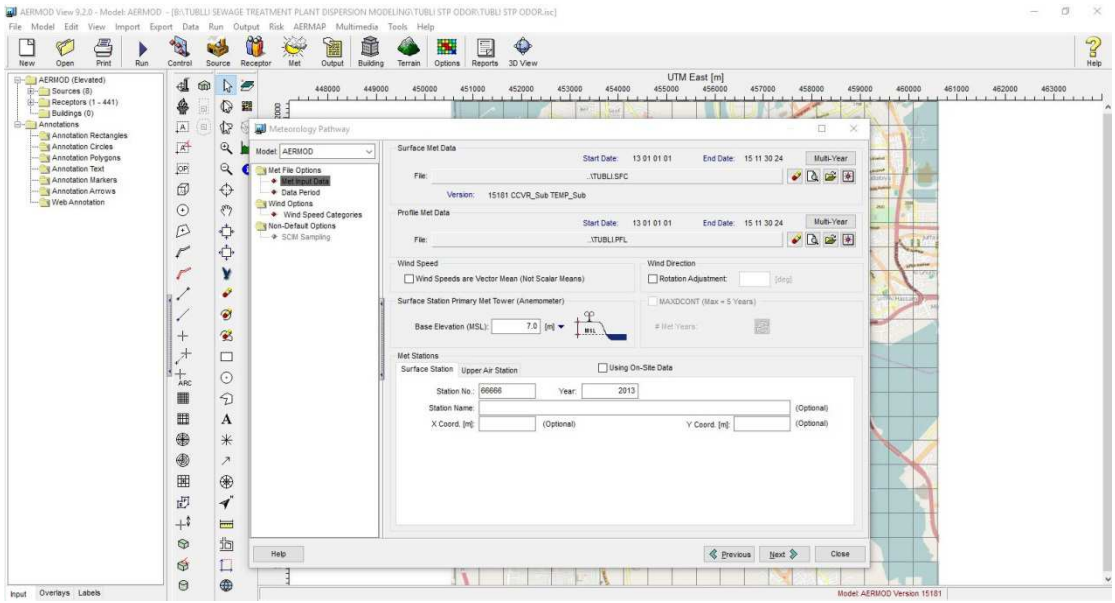
20. Step 12 – Control pathway, output concentration



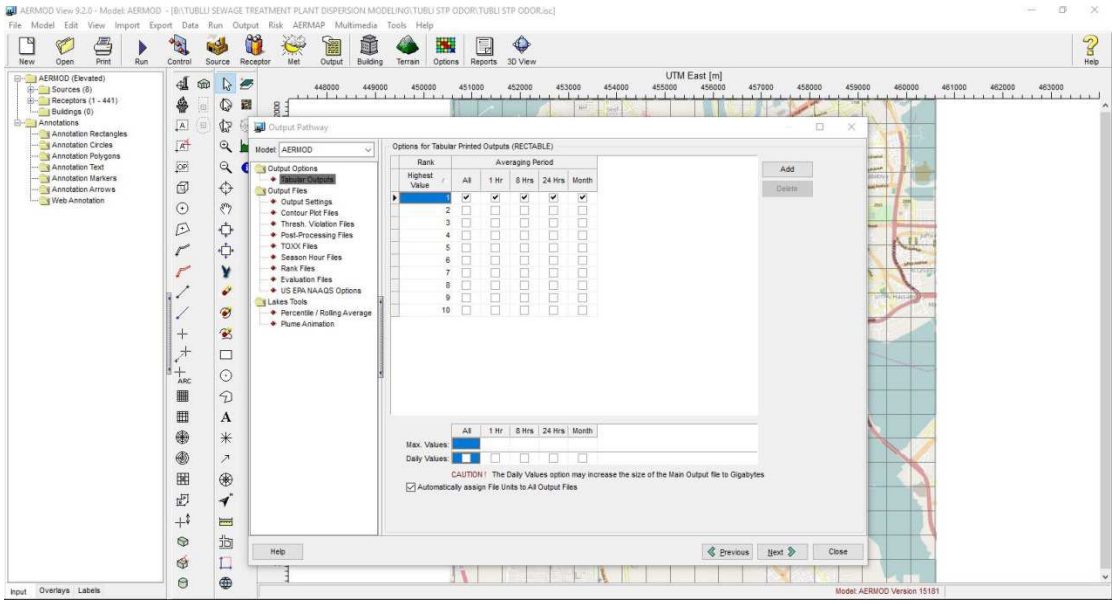
21. Step 13 - control pathway, receptor selection



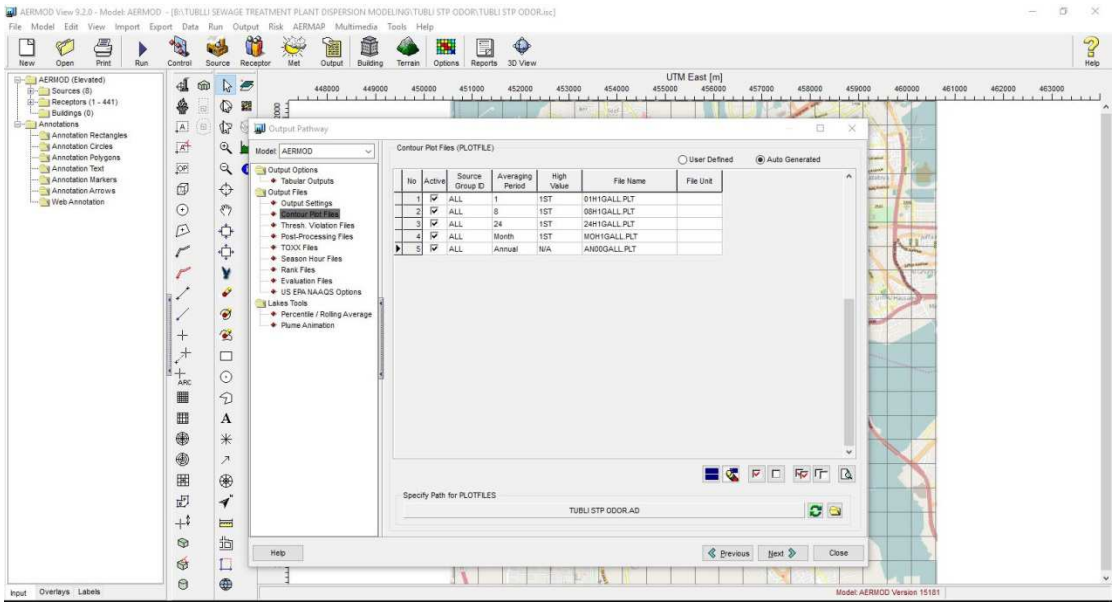
22. Step 14 – Metrological (MET) input data



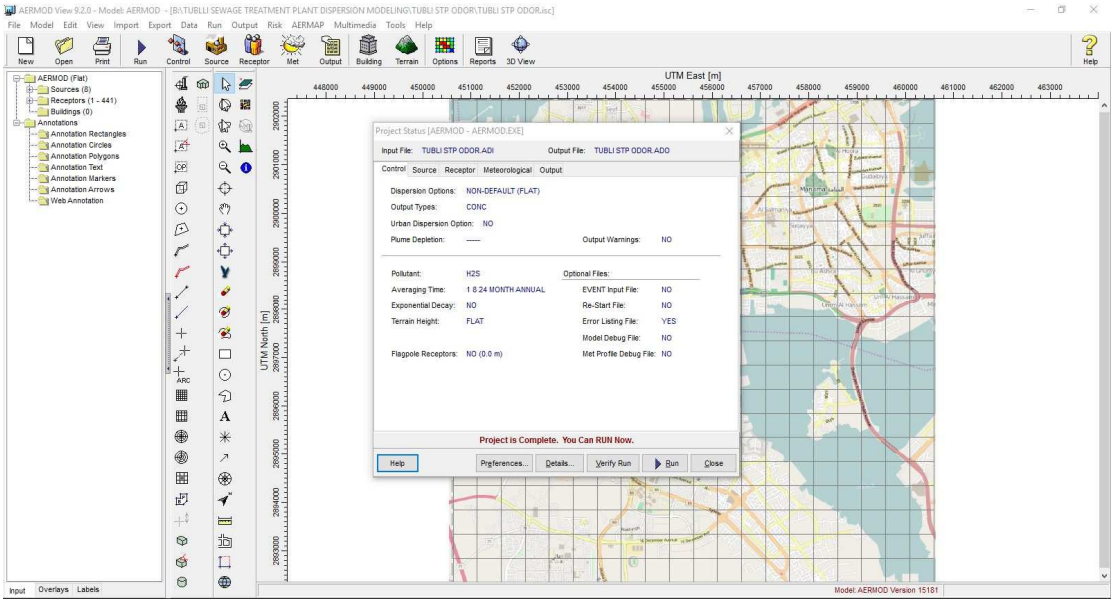
23. Step 15 – Output pathway, tabular output



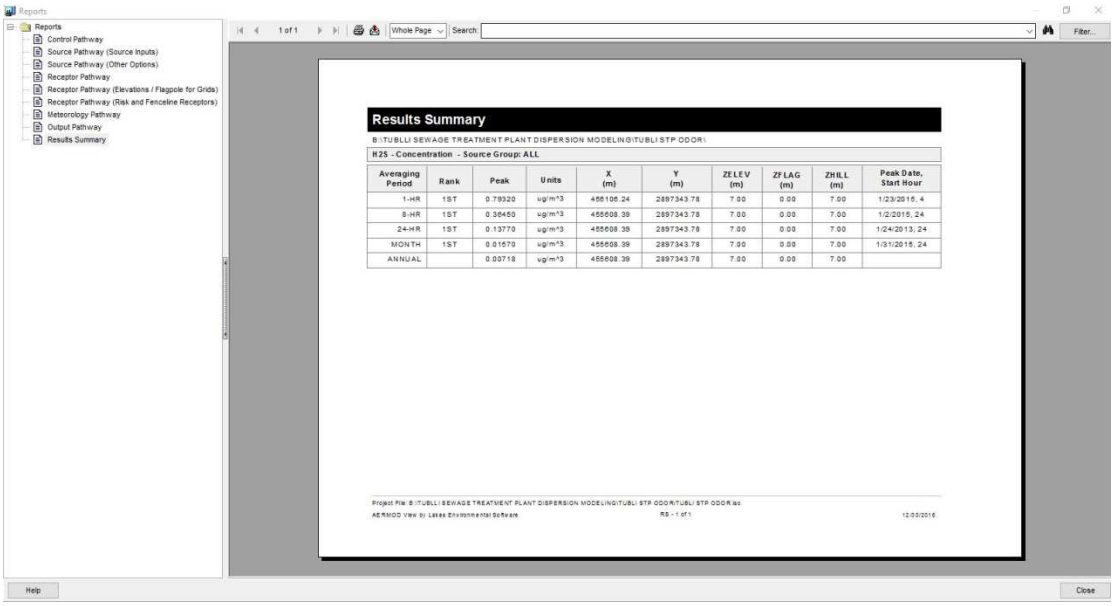
24. Step 16 – Output pathway, contour plot files



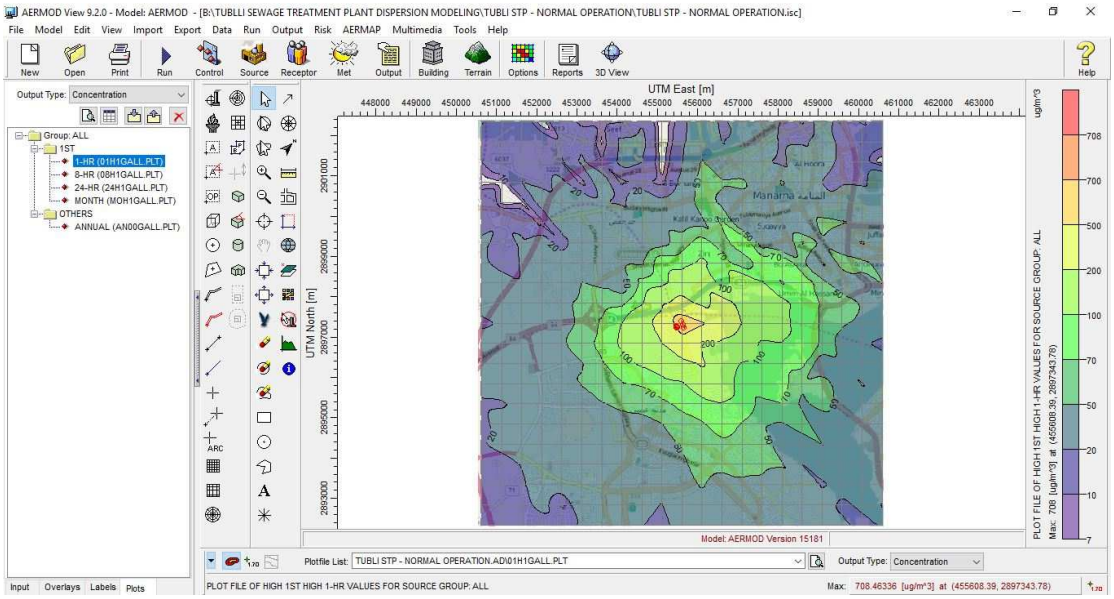
25. Step 17 – Run AERMOD



26. Result Summary



27. Output file



جامعة البحرين

كلية الهندسة
الميكانيكية

قسم الهندسة



تقييم, وتحكم وإدارة الروائح من محطة توبلي لمعالجة مياه الصرف الصحي

بحث لاستكمال متطلبات الحصول على درجة (الماجستير) في برنامج الإدارة الهندسية

إعداد

نور عبد الشهيد أبوحسان

20035248

إشراف

الأمين الكنزي

(أســـــــــتاذ)

جامعة البحرين

مملكة البحرين

ديسمبر2017

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إشراف

الأمين الكنزي

(أســـــــــتاذ)

جامعة البحرين

مملكة البحرين

ديسمبر 2017

ملخص الرسالة

تعتبر الروائحة المنبعثة من محطة توبلي لمعالجة مياه الصرف الصحي مصدر إزعاج وقلق لغالبية قاطني المناطق المجاورة للمحطة. وذلك لقرب هذه المناطق من محيط المحطة وقدرة أغلبية السكان لشم هذه الروائح وإن كانت تتواجد بتراكيز بسيطة مما يجعل عملية التحكم بانتشار هذه الروائح بهذه التراكيز الصغيرة المحسوسة بالأمر الصعب. ويتم إلقاء الضوء في هذه الدراسة على مشكلة الروائحة المنبعثة من محطة توبلي وكيفية إدارة والتحكم بها. وقد تم تقيم هذه المشطلة من خلال استخدام نموذج يحاكي المحطةوانبعاثاتها بالاضافة إلى استخداماستبيان قياس لقاطني المناطق المجاورة للمحطة. وقد توصلت اهم نتائج التقييم إلى وقوع المناطق المجاورة تحت منطقة أنتشار الروائح المنبعثة كما لخصت الدراسة إلى ضرورة تطوير اساليب ادارة ومتابعة الروائح المنبعثة من داخل المحطة بالاضافة إلى تركيب أجهزة قياس الروائح على حائط المحطة وذلك للتأكد من نسب الغازات المنبعثة. وقد نصت أهم مقترحات الدراسة إلى إمكانية تركيب وحدة معالجة للمنطقة استقبال مياه الصرف الصحي وإلى ضرورة توفير منطقة خضراء عازلة للمحطة.