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Air Quality Impact of the Upgraded Al-Samra Waste Water Treatment Plant

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Abstract

In 2008, a new wastewater treatment plant at Al-Samra replaced the old wastewater ponds, which were designed in the sixties of the 20th century to treat the sewage influx from Amman-Zarqa areas. The upgrade has significantly improved the water quality in the Zarqa river and is believed to be a key point in restoring aquatic life in the river. It also reduced atmospheric pollution in Al-Hashemeyyah, which reduced the complaints of the neighboring residents about the odors and flies. In the present study, data for atmospheric pollution at Al-Hashemeyyah were acquired from the Ministry of Environment and investigated in order to detect the changes of air pollution levelsin the town. Data clearly show that concentrationof the atmospheric H_2S has declined significantly after 2008. AERMOD dispersion Modeling was deployed in order to quantify the contribution of Al-Samra wastewater treatment plant to ambient air pollution at Al-Hashemyyah. AERMOD results revealed that concentrations of ambient H_2S, CH_4, and NH_3in the vicinity of Al-Samra wastewater treatment facilities are well below the national and the international standards of ambient air quality. The outcomesof AERMOD also revealed that the concentrations of gasses mentioned above vanish within a short distance downwind from Al-Samra. Thus, Al-Samra wastewater treatment plant is no longer a potential source of air pollution in Al-Hashemeyyah town.

Keywords: Jordan, Air Pollution, Wastewater Treatment, Methane, Hydrogen Sulfide.

1. Introduction

Jordan has stretched water resources of only 150 m^3 per capita per year, which is at the survival level and is considered to be one of the most water scarce countries in the world. The 150 m^3 per capita per year is continuously decreasing due to rapid population growth and global warming-induced drought. This harsh situation requires Jordan to adopt a strict integrated water management plan that promotes water recycling. Therefore the local regulations allow for the direct reuse of reclaimed water to irrigate fodder and flowers. However, the reclaimed water is not to be used to irrigate vegetables or fruits unless mixed with freshwater including storm water.

Al-Samrawastewater treatment plant (ASWWTP) is the largest wastewater treatment station in Jordan. It was built in the sixties of the 20th century for the purpose of promoting water recycling and to protect ground water aquifers in Zarqa-Amman basin. Al-Samra serves a population of about 5million inhabitants living in Amman and Zarqa which are experiencing a rapid population growth due to natural, social, and political factors.Prior to the current substantial upgrade of Al-Samra, received sewage was diverted into wastewater stabilization ponds where it stayed and settled for about 48 hours before being released to Wadi Dhuleil, which empties in Zarqa river after about 10km. The quality of the released water failed the national and international corresponding standards of reclaimed wastewater, which imposed devastating impacts on the Zarqa river and King Talal dam downstream. The latter is the second largest dam in Jordan. King Talal dam stores treated sewage and storm water to be released into the Jordan valley where it is used for irrigation. Public complaints of rodents, flies, and mosquitoes were common among local communities along the route of Wadi Dhuleil and Zarqa river. Air quality was also impacted by the uncontrolled release of hydrogen sulfide (H_2S), methane (CH_4), and other odorous compounds.

In order to improve the water quality in the Zarqa river and King Talal dam, the Jordanian Ministry of Water and Irrigation decided to replace the old and overloaded Al-Samra wastewater stabilization ponds by a modernized wastewater treatment plantat a cost of $169M. The new plant treats wastewater by using the activated sludge technology. The construction of the new plant started in 2003 and ended in 2008. The new facility was officially commissioned in August 2008. The new facility treats an average flow of 267,000 cubic meters of wastewater on a daily basis. Upgrading of Al-Samra wastewater treatment plant has significantly improved the water quality in the Zarqa river (Al-Omari et, al., 2013) and is believed to be a key factor for the restoration of the aquatic life therein.

Air pollution continues to receive a great deal of interest

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worldwide due to its negative impacts on human health and welfare. Several studies reported significant correlations between air pollution and certain diseases, including shortness of breath, sore throat, chest pain, nausea, asthma, bronchitis and lung cancer (Dockery and Pope, 1994). Extreme effects of air pollution include high blood pressure and cardiovascular problems (Pope et. al., 2002; Sanjay, 2008). Correlations between air pollution and increased morbidity and mortality rates were also reported (Laden et. al., 2000; Pope et. al., 1995).The World Health Organization states that 2.4 million people die each year from causes directly attributed to air pollution (WHO, 2007). Epidemiological studies suggest that more than 500,000 Americans die each year from cardiopulmonary diseases linked to breathing fine particle air pollution (Marsh and Bernstein, 2008). Another study showed a strong correlation between pneumonia related deaths and air pollution from motor vehicles in UK (Knox, 2008). In addition to its negative health impacts, air pollution is known to cause injuries to animals, forests and vegetation, as well as to aquatic ecosystems. Its impacts on metals, structures, leather, rubber, and fabrics include cracks, soiling, deterioration, and erosion (Boubel et. al., 1994).

Odors are the main cause of nuisance associated with wastewater treatment facilities. Inlet works, grit channels, screening and grit handling, aeration tanks, as well as sludge holding and dewatering units are the main sources of odor at the wastewater treatment facility.Hydrogen sulfide (H_2S) is the most prevalent malodorous gas associated with the domestic wastewater collection and treatment. The conditions leading to H_2S formation usually favor the production of other odorous gases, such as ammonia and mercaptants, which may have considerably higher detectable odor thresholds, and consequently H_2S may be an indicator of their presence.

In addition to odors and aerosols, wastewater treating generates methane. Wastewater is treated to remove the organic matter using biological processes in which microorganisms consume the organic matter for maintenance and growth. The anaerobe organism digests the organic component of the sewage and produces biogas, which is a mixture of methane (about 70%), carbon dioxide (about 20%), hydrogen sulfide (3%), among other gases. Most released methane at Al-Samra wastewater treatment plant is harnessed and burned to generate electricity used to operate its machineries.

The aim of the present study is to assess the impact of the newly upgraded Al-Samra wastewater treatment plant on air quality at neighboring communities.

2. Study Area

Al-Samra wastewater treatment plant (coordinates: Longitude 36° 04′ to 39º 09′ east and Latitude 32º 04′ to 32 10 north) is located approximately 50 km to the North-East of Amman within the valley of Wadi Dhuleil (Figure 1). Al-Samra falls within a semi-arid climate characterized by hot-dry summer and wet-mild winter with less than 150 mm total annual rainfall. The average annual temperature is 17.1 °C, with a minimum temperature of 2.4 °C recorded during January and a maximum temperature of 32.6 °C recorded during August. Average relative humidity ranges between 39.3% during May and 70.3% during January. Wind direction fluctuates between North-West to South-West during autumn and winter, whereas westerly wind dominates summer days (Odat, 2009).

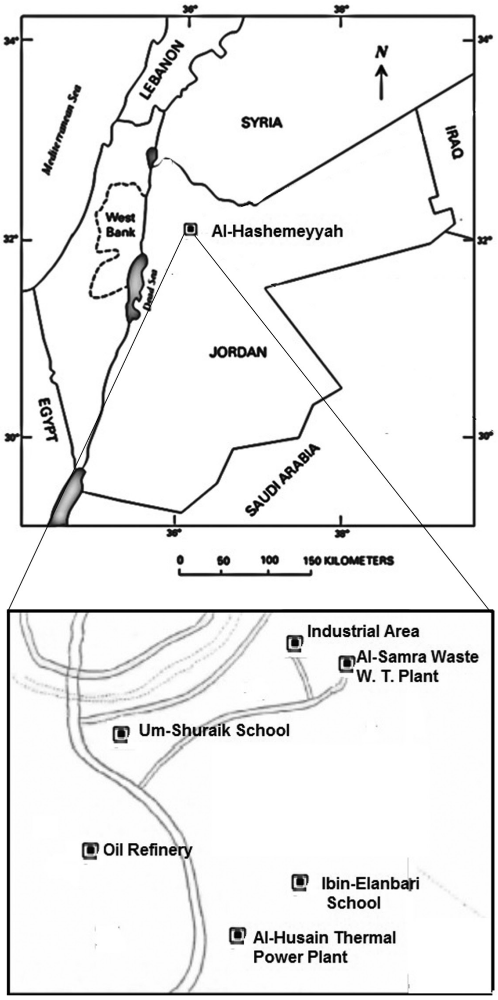

Figure 1. Location of the study area (modified after Odat, 2012)

3. Research Method

This study investigates the impact of Al-Samra water treatment plant on the air quality in the neighboring communities within Al-Hashemeyyah town. The required air quality data, through the period 2006-2010, were obtained from the Jordanian Ministry of Environment (JMOE). In addition, AERMOD (EPA, 2004) is used to estimate the concentrations of NH_3, CH_4, and H_2S in ambient air based on emissions emanated fromASWWTP.

AERMOD uses a Gaussian and a bi-Gaussian approach in its dispersion models. It generates daily, monthly as well as annual concentrations of pollutants in ambient air. The model handles a variety of pollutant sources in a wide variety of settings such as rural and urban as well as flat and complex terrain. It is an updated version of the Industrial Source Complex (ISCST3) model being proposed by the USEPA for assessing air quality impact from industrial sources in the coming years. One of the major improvements that AERMOD brings is its ability to characterize the planetary boundary layer (PBL) through both surface and mixed layer scaling (EPA, 2004).

4. Analysis of Air Quality Data

Qualification and quantification of all odorants in the vicinity of Al-Samra wastewater treatment plants is quite complex because there are many odorants that are present in very low concentrations. However, hydrogen sulfide is such an odorous compound that is often present in higher concentrations than other odorants, especially in sewer networks and in primary treatment of domestic wastewaters; therefore, it can give a general indication of the overall odor concentration. Hydrogen sulfide can be measured in very low concentrations (down to parts per billions levels).

The Ministry of Environment keeps records of measured H_2S and methane as measured in the two monitoring stations at Um-Shuraik school and Ibin-Elanbari school. Concentrations of ambient H2S for the period 2003-2010 are presented in Tables 1 and 2.

A careful reading of Table 1 leads to the conclusion that Al-Hashemyyah town is experiencing severe air pollution by H2S. In fact, a measured one-hour H2S concentration frequently exceeds the Jordanian standard of 0.03 ppm. The percentage number of exceedances at Ibin El-Anbary could be as high as 38% of the total measurements. Similarly, up to 27% of total hourly H2S measurements at Um Shuraik in 2005-2006 exceeded the Jordanian standard. The daily-averaged H2S concentration at Ibin El-Anbari and Um Shuraik also exhibited many exceedances of the 24-hr Jordanian standard of 0.01ppm. The percentage of daily exceedances could be as high as 84% and 70% at Ibin El-Anbari school and Um Shuraik, respectively.

There are several local sources that may contribute to the buildup of H2S concentration at Al-Hashemeyyah including the oil refinery and the thermal power plant in addition to Al-Samra wastewater treatment. Fortunately, the ambient concentration of H_2S decreased significantly after 2008 as compared with preceding years. This could imply that the new Al-Samra plant, which was put in service in 2008, no longer spews excessive amount of H_2S to ambient air, leaving only the oil refinery and the thermal power plant as the main polluters in the town. This important finding requires a further investigation in order to assess how much exactly Al-Samra contributes to H_2S in ambient air at Al-Hashemyyah. This is done through a dispersion modeling of H_2S, which is discussed in the next chapter.

Table 1: Summary of maximum hourly H_2S concentration in ambient air at Al-Hashemyyah town during the period 2006-2010. Maximum allowed value is 0.03 ppm not to be exceeded more than three times a year

Location	Period	Max H_2S (ppm)	Number of Exceedings	Percent of Exceedings
Ibin El-Anbari	2010	0.259	33	0.42%
	2009	0.528	839	11.30%
	2007-2008	0.068	35	0.41%
	2006-2007	0.742	2689	38.10%
	2005-2006	0.426	1771	24.30%
Um Shuraik	2010	0.206	202	2.50%
	2009	0.139	508	7.40%
	2007-2008	0.287	750	11.10%
	2006-2007	0.933	1344	17.74%
	2005-2006	0.828	1941	26.90%

Table 2: Summary of Maximum Daily Concentration Rate of H_2S at Al-Hashemyyah (2006-2010) (ppm). Maximum allowed value is 0.01 ppm not to be exceeded more than three times a year

Location	Period	Max. Daily H_2S (ppm)	Number of Exceedings	Percent of Exceedings
Ibin El-Anbari	2010	0.053	3	0.89%
	2009	0.112	122	33.70%
	2007-2008	0.011	3	0.87%
	2006-2007	0.092	240	83.92%
	2005-2006	0.074	234	77.50%
Um Shuraik	2010	0.35	27	7.69%
	2009	0. 34	68	21.10%
	2007-2008	0.057	104	38.81%
	2006-2007	0.188	144	48.81%
	2005-2006	0.308	216	69.70%

The measured H_2S data revealed that the maximum concentration occurs during the cold periods (winter time and in the evening). This shows that atmospheric stability is an important factor of pollution dispersion. Cold time periods often experience thermal inversion, which means that air temperature increases with altitude. During thermal inversion convection currents cease and air mixing will be suppressed, which in turn inhibits dilution of air pollution. This implies that air pollution increases during the thermal inversion.

Our findings go along with a previous study by Saffarini and Odat (2008) who deployed a different time series analysis of monthly air pollution at Al-Hashimeyyah, finding that air pollution data for the period 1992–2004 exhibited an overall decreasing trend in the concentrations of NO_2, CO, H_2S, NO and TSP, but with an increasing trend in PM_{10}, and Pb, whereas SO_2 did not significantly change. Odat (2009) investigated the impact of weather parameters (air temperature, wind speed, rainfall, wind direction, cloud and relative humidity) on the concentrations of air pollution at Al-Hashemeyyah and found that wind and relative humidity were the main parameters that impacted the H_2S concentration in ambient air.

4.1. Input of AERMOD Model

Odors emitted from wastewater treatment plants are becoming a significant source of environmental annoyance. Odor-related complaints from the communities surrounding the wastewater treatment plants have been constantly increasing since the past decade. This fact is typically the result of a new residential development near the plants. The main emanated odorous compounds are ammonia, methane, and sulfur containing substances such as hydrogen sulfide, methyl mercaptan, dimethyl sulfide, dimethyl disulfide, ethyl mercaptan, carbon disulfide and carbonyl sulfide. Nitrogen, containing substances such as ammonia, amines, indole and skatole, may also cause problems (Abbott, 1993; Gostelow and Parsons, 2000; Easter et. al., 2005). All of these substances are the products of anaerobic decay and, hence, wastewater which, as it is allowed to become septic, has a strong potential to become odorous. Although various odorous compounds may be present, the most significant is the hydrogen sulfide.

The main impact from the existence of H_2S in the atmosphere is the annoyance caused to humans. The detection

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and perception of odors by humans is an extremely complex process. The main factors determining whether an odor causes annoyance are the concentration of the odorous compound in the air, the "odor quality," the odor appearance frequency and the odor duration (EPA, 2006).

AERMOD dispersion modeling was applied for the assessment of the odor impacts on ambient air quality. Emission rates of CH_4 and H_2S are presented in Table 3.Required surface meteorological data and upper sounding for year 2012 were obtained from Amman Airport.

Table 3: Emission rates of methane, and hydrogen sulfide

Substance	Emission Rate (g/s)
Methane (CH_4)	40.5
Hydrogen sulfide (H_2S)	2.4

4.2. AERMOD Modeling Results

4.2.1. Predicted Concentration of Hydrogen Sulfide

Predicted H_2S concentrations in ambient air are illustrated in Figures 2-4. It is clear that the highest predicted one-hour H_2S concentration is less than 8ppb, which is which is well below the Jordanian standard of 0.03 ppm (30 ppb) measured values at Um Shuraik school and Ibin El-Anbary school. 24-hr and annual H_2S concentrations in the vicinity of Al-Samra wastewater treatment plant are way below the measured values at the two monitoring sites. This is a strong piece of evidence that Al-Samra wastewater treatment plant is no longer the main source of H_2S in Al-Hashemeyyah town.

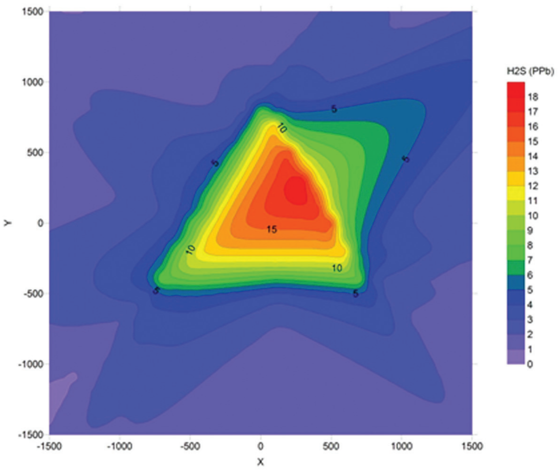

Figure 2. Contour plot for predict one-hour H_2S (ppb) in the vicinity of ASWWTP which is assumed to be at the center of the map at coordinates (0, 0)

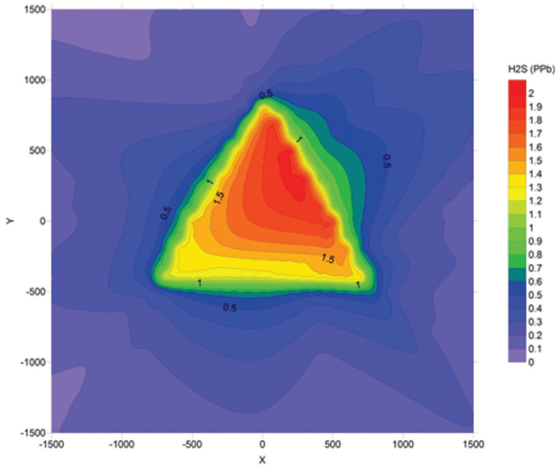

Figure 3. Contour plot for predict 24-hours H_2S (ppb) in the vicinity of ASWWTP which is assumed to be at the center of the map at coordinates (0, 0)

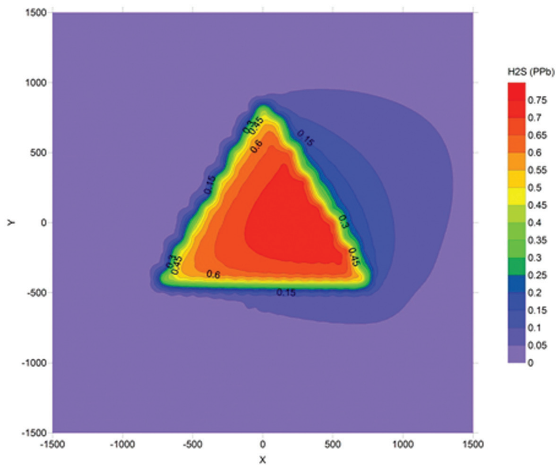

Figure 4. Contour plot for annual H_2S (ppb) in the vicinity of ASWWTP which is assumed to be at the center of the map at coordinates (0, 0)

4.2.2. Predicted Concentration of Methane

The predicted methane concentrations in ambient air are illustrated in Figures 5-7. It is clear that the highest predicted methane concentrations are about 290 ppb, 35ppb, and 13 ppb for 1-hr, 24-hrs, and annual time intervals, respectively. Because methane is a natural constituent of the air, there are no national standards that regulate its ambient concentration. In addition, most of the generated methane is harnessed locally and used to generate electricity that helps maintain a state-of-art integrated environmental management plan adopted by Al-Samra in its reformed configuration.

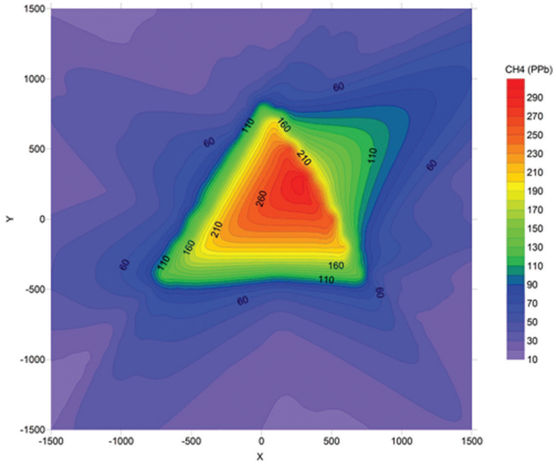

Figure 5. Contour plot for one-hour methane (ppb) in the vicinity of ASWWTP which is assumed to be at the center of the map at coordinates (0, 0)

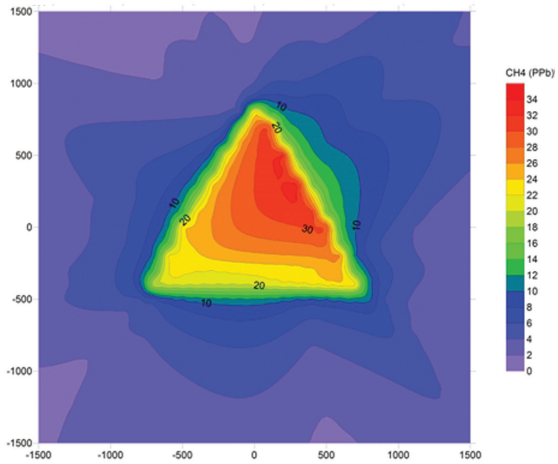

Figure 6. Contour plot for 24-hours methane (ppb) in the vicinity of ASWWTP which is assumed to be at the center of the map at coordinates (0, 0)

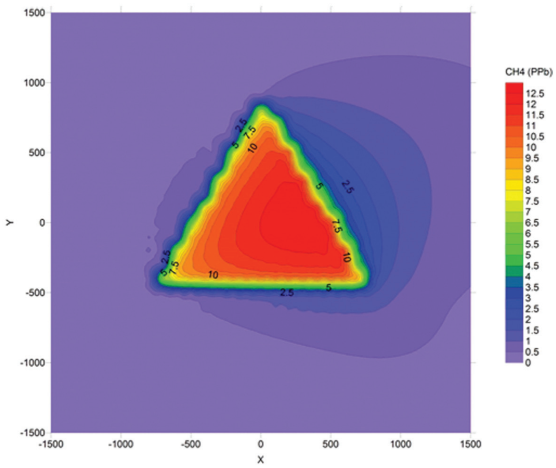

Figure 7. Contour plot for annual methane (ppb) in the vicinity of ASWWTP which is assumed to be at the center of the map at coordinates (0, 0)

4.2.3. Predicted Concentration of Ammonia

Predicted ammonia concentrations in ambient air are illustrated in Figures 8-10. It is clear that the highest predicted concentrations of ammonia are 75 ppb, 8 ppb, and 3 ppb which are well below standards suggested by the World Bank of 800 ppb, 400ppb, and 140 ppb for 1-hr, 24-hrs, and annual time intervals, respectively. Standards suggested by the World Bank are used for comparisons, because there are no Jordanian standards for ammonia in ambient air to compare our findings with.

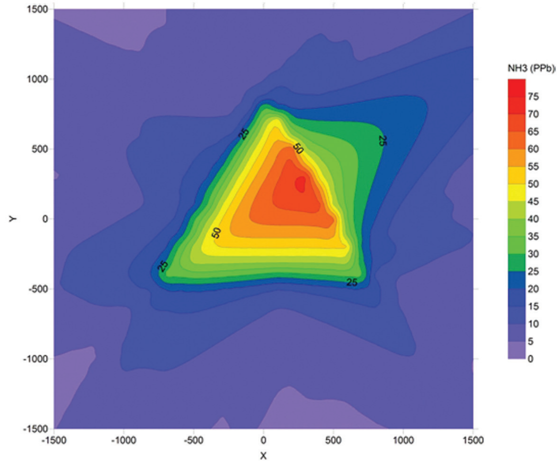

Figure 8. Contour plot for one-hour ammonia (ppb) in the vicinity of ASWWTP which is assumed to be at the center of the map at coordinates (0, 0)

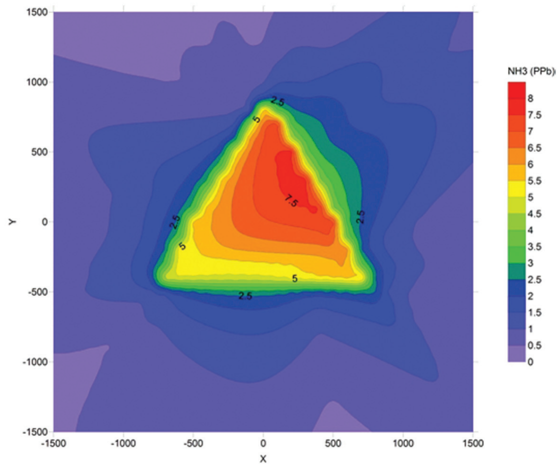

Figure 9. Contour plot for 24-hours ammonia (ppb) in the vicinity of ASWWTP which is assumed to be at the center of the map at coordinates (0, 0)

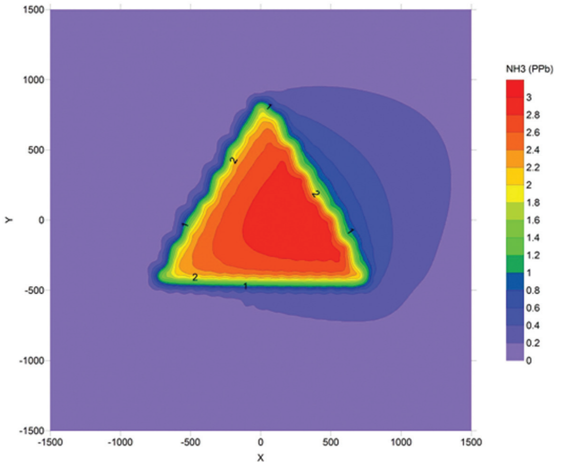

Figure 10. Contour plot for annual ammonia (ppb) in the vicinity of ASWWTP which is assumed to be at the center of the map at coordinates (0, 0)

4.3. Local Community Complains

After the construction of the new Al-Samra wastewater treatment plant, complains by local communities at Al-Hashemeyyah town significantly decreased. Currently, the main reason for annoyance is the flies invasion during the summer time. The officers at Al-Samra plant are working with local municipalities to fight flies, but still more efforts are required to prevent the flies invasion.

Another intermittent source of annoyance is the odors during moments of inversion, which are frequent during the autumn months. In late summer and early autumn, the earth surface and the adjacent air warm rapidly during the day time. During the night time, the earth surface cools rapidly but the air cools at a slower rate. Any air parcels that cool become denser and sink down leaving behind warm air molecules. These processes lead to an unusual situation where cold air is trapped below the warm air, which causes thermal inversion, the condition that suppresses dilution of H_2S, CH_4, and NH_3. Therefore, these gases are trapped close to the earth surface and travel horizontally to longer distances until reaching, and thus annoying, the neighboring communities.

The odor perception by humans is proportional to the instantaneous peak concentration of the odorant rather than to mean values (Latoset. al., 2011). AERMOD, like other dispersion models, is set for calculation of at least half-hour mean concentrations. The sensation of odor, however, depends on the momentary (peak) odor concentration and not on a mean value. Therefore, the H_2S concentrations illustrated in Figure 1 are adjusted to 5 seconds average concentration and then converted into odors unit (AU), which is equivalent to 0.47 ppb. In order to calculate the 5-second average concentration, the hourly averaged concentrations predicted by AERMOD are first converted to 3-minute average concentrations using the formula below (Duffee et. al., 1991):

$$C_l / C_s = (t_s / t_l)^n$$

where C_l and C_s are the time averaged odor concentrations in longer and shorter periods,

respectively; t_l and t_s are the longer and shorter time averaging periods respectively; and

n is an exponential value which depends upon the stability class; it is considered to be 0.167. Note that same formula can be used to estimate the 1-minute concentration but with different values for n (usually between 0.35 and 0.65).

The 3-minute average concentration is converted to 5-second average concentrations by multiplying by a factor of 5 (OME, 1996). The findings are illustrated in Figure 11. It is now evident that the odors concentration could be as high as 800 AU inside Al-Samra plant itself, but the concentration drops exponentially to less than 50 AU at 2000m downwind from the facility.

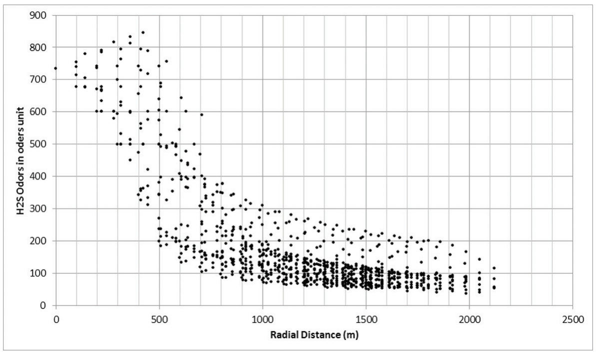

Figure 11. Spatial variation of the five-second average odors concentration in the vicinity of ASWWTP in odors unit

4. Results and Discussion

The challenge of sustainable water management in semi-arid countries like Jordan is magnified by the country's geography, hydrology, climate and trans-boundary issues. The country is divided into semi-arid, arid or hyper-arid regions with at least six rainless months per year. Rainfall variations occur from year to year, with periods of multi-year droughts or near droughts interspersed with periods of heavy rainfall.

Water scarcity has been of concern to Jordan since the fifties of the 20th century when Israel diverted Jordan River to southern regions. The rapid increase in population as a result of natural birth and refugee-waves from the neighboring states due to political instabilities and/or economic crises, coupled with extensive agricultural growth, have placed a continuous and growing demand on Jordan's limited water resources. This harsh situation persuades Jordan to adopt an integrated water management plan that promotes a sustainable use of water resources.

Among the practices that Jordan prides itself with is water recycling through the construction of several wastewater treatment stations. Sewage treatment is being accepted worldwide as an important component of integrated water management plans because it protects surface water bodies as well as groundwater aquifers and aids the agricultural sector by water of excellent quality that could be used in drip irrigation, which, in turn, increases fresh water allocations to domestic and industrial sectors.

In Jordan, there are more than 26 wastewater plants that treat about 0.5 billion cubic meter of row sewage per year. Al-Samra is the largest wastewater treatment plant nationwide; it treats about half quantity mentioned above. Al-Samra receives sewage from Amman and Zarqa cities and discharges its effluents to Wadi-Dhuleil, which is one of the tributaries of the Zarqa river. The treated water is mixed with storm water at King Talal dam and then the mixed water is released to the

Jordan Valley where it is used for irrigation.

Al-Samra wastewater treatment plant is an important component in the water management plan in Jordan. However, it used to have devastating impacts on environmental receptors in the region including the deterioration of the water quality in the Zarqa river to the extent that no aquatic life could exist in the river. Odors and sulfur compounds released during the sewage treatment was another obvious local problem. These negative impacts, in addition to Jordan's real need for every water droplet, have convinced the Ministry of Irrigation to upgrade Al-Samra wastewater treatment plant. Thereby, in 2000, the Ministry of Irrigation invited the private sector to share in building a new facility based on the Build-Operate-and Transfer (BOT) principle. In 2008, the new facility was officially opened and replaced the old plant. The new Al-Samra wastewater treatment plant produces reclaimed water with excellent properties that meet the national and the international standards.

The air quality in Al-Hashemyyah town has improved as well after upgrading ASWWTP. Staff at the Hashemite University (HU), which is located about 8km to the south-east of Al-Samra, felt the improvement of the air quality, especially during autumn. Before 2008, morning odors of urea and H_2S were very common in late summer and early autumn months. Currently, odors have almost disappeared, and HU staff experience lesser events of bad smells inside the campus.

In order to investigate the impact of upgrading the ASWWTP on air quality, the present study is undertaken. The study is divided into two phases. In the first phase, air quality data for the years 2003-2010 were investigated. The findings of this phase showed that atmospheric H_2S were often higher than the national standards of 0.03 ppm up to 2008. After 2008, atmospheric H_2S concentration decreased significantly.

In phase two, the famous AERMOD dispersion model was deployed to quantify the contribution of the upgraded Al-Samra wastewater treatment plant on atmospheric H_2S, CH_4, and NH_3. The findings of this phase revealed that Al-Samra wastewater treatment plant is no longer a potential source of the gasses mentioned above in Al-Hashemeyyah town and the surrounding areas. The concentrations of these gases in ambient air almost vanish within a short distance (2km) of the plant. However, the neighboring communities complain of H_2S odors during moments of thermal inversion due to the absence of air mixing.

5. Summary and Conclusions

The 2008 extension and upgrade of Al-Samra wastewater treatment plant led to a significant reduction of atmospheric H_2S, which used to be a main source of annoyance for the nearby communities. Thus, Al-Samra wastewater treatment plant is no longer a potential source of air pollution in Al-Hashemeyyah town, yet local residents still suffer from the high levels of air pollution, especially during the night time. This implies that there is a real need for a local emission inventory and a comprehensive source attribution study in order to determine the potential sources of air pollution and to quantify their fractional contributions to ambient air pollution.

Acknowledgment

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This study is part of the master thesis of the first author.

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