TACKLING KUWAIT'S AIR POLLUTION THROUGH A REGULATORY-BASED APPROACH – A CASE STUDY

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ABSTRACT

Kuwait is one of the largest oil producers in the world. However, it is also the tenth most polluted nation in the world, as per a WHO report in 2011 [1], which has created public health concerns in Kuwait. Kuwait Oil Company (KOC), which is involved in the exploration, drilling and production of oil and gas within the State of Kuwait, has undertaken a landmark project in conjunction with the Kuwait Environment Public Authority (KEPA), to develop and implement a regulatory air compliance management programme (ACMP). The ACMP is the first-ever joint venture of its type between the industry and regulators, and it includes development of a system providing real-time measurement of pollution across the country as well as a pioneering national air quality inventory with research-grade dispersion modelling techniques to determine human health risk. Subsequently, an innovative source apportionment study is undertaken, utilizing satellite-based techniques to define pollutant source contributions from various sources and develop abatement strategies. The ACMP is a successful demonstration of the implementation of latest technologies like hyperspectral remote imagery for surrogate estimation, remote sensing information for tracking pollutant masses during the project to provide inputs and conduct a comprehensive Human Health Risk Assessment (HHRA) based on US EPA's Human Health Risk Assessment Protocol (HHRAP).

Keywords: air quality, dispersion modelling, emissions, emissions inventory, human health risk assessment, source apportionment.

1 INTRODUCTION

The Kuwait Oil Company air compliance management programme (KOC ACMP) is a five-year initiative that commenced in 2011 and whose overall objective is to improve air quality in Kuwait through the development of a regulatory ACMP. The programme was designed to comply with legal requirements of Section 1 of Article 76 – Ambient Air Quality – which states that the purpose of the article is to manage ambient air quality to protect public health and welfare from the effects of air pollution, and that the article applies to air outside of a facility's boundary. Consequently, in accordance with Article 76, the KOC ACMP ambient air quality monitoring (AAQM) stations are all located outside of KOC facility boundaries, and with the exception of the background sites, in areas where the public may be present.

The KOC ACMP describes a strategy for Kuwait to move forward with a programme for attaining the Kuwait Ambient Air Quality Standards (KAAQS). This strategy adopts a multi-faceted approach that includes the following key parameters:

- Gaining a solid understanding of the current air quality situation
- Understanding and evaluating regulatory requirements
- Developing a permitting programme for industrial sources of air pollution
- Developing monitoring and enforcement programmes to ensure those industrial sources are complying with the terms and conditions of their permits

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The overall project scope broadly encompasses the following activities:

1. Emissions inventory – Development of an emissions inventory, both at the national and the facility levels
2. Hotspot modelling – Evaluation of air quality 'hotspots' and implementation of a modelling programme
3. Air quality monitoring – Expansion and potential modification of the existing national AAQM network
4. Emissions estimation and reporting – Emissions reporting and establishment of an enforcement programme
5. Source apportionment study – Calculation of the KOC's contribution to total Kuwait emissions
6. Risk assessment – Human Health Risk Assessment (HHRA)

The overriding aim of the project is to support the development and implementation of a regulatory-based air emissions and compliance management system, as part of a larger objective to establish a national regulatory framework in mutual agreement with the regulatory body, Kuwait Environment Public Authority (KEPA).

The project was borne out of a memorandum of understanding between KOC and the KEPA, to work together to improve air quality. There is no other comparable project in the Middle East, where a company and regulator are working together in such a way, and the effects of the initiative will be felt nationwide. The initiative is particularly important in an era of low oil prices when there are pressures to produce greater quantities of oil whilst minimizing costs; the ACMP will help ensure that rigorous environmental standards will be adhered to.

2 PROJECT DETAILS

The project was spread out over various phases over a period of 5 years (2011–2016). The details of the various activities under each major phase of the project are given below.

2.1 Emissions inventory development

Emissions inventories (EIs) are used for a wide variety of purposes. EIs are most often developed in response to air quality regulations and reporting obligations as well as based on company policies geared towards proactively managing air quality resources. The 2010 KOC baseline EI (2010 KOC EI) was developed not only to support traditional EI reporting and regulatory objectives but also to facilitate air dispersion and hotspot modelling. For this reason, the inventory required the collection and processing of additional information related to physical source characteristics such as stack heights, stack exit temperatures and stack diameters.

Specifically, the 2010 KOC EI includes information regarding emission sources, pollutants emission rates, emission factors, process rates, release parameters and other supporting attributes. The collection and review of emission-related information are intermediate steps in estimating emissions, in that relevant information is first entered into the Kuwait Air Compliance Management System (KACMS), which contains all the necessary emissions equations and functionality to automatically calculate emission rates and populate the inventory.

The primary goal of the 2010 KOC EI was to develop a technically defensible baseline EI upon which important objectives could be achieved. Examples include the following:

- Tracking progress towards compliance with applicable regulatory guidelines
- Siting baseline levels for planning purposes and quantifying the effects of emission reduction efforts over time.
- Identifying general emissions levels, patterns, and effects of operational changes such as increasing process capacity, building a new facility or applying air pollution controls
- Facilitating air dispersion modelling studies
- Providing input to perform hotspot modelling, including exposure and human health assessments
- Siting AAQM stations

The usefulness of an emission inventory for modelling source contribution depends critically on accurate source characteristics. Hence satellite data was used to cross-check locations of selected emission sources and also identify unreported large sources in Kuwait not identified in the existing databases used for baseline EI development. Unreported sources could be new sources, sources that were mistakenly aggregated, sources that were too small or sources that simply did not register to be included in government-level reporting for the Intergovernmental Panel on Climate Change (IPCC). This information was used to further refine the baseline EI (refer to Table 1 for further details).

The EI includes all reported KOC point sources consisting of 693 unique point sources located within 55 primary processing facilities and over 430 manifold locations. In addition, the inventory includes emissions from 3,408 KOC on-road vehicles and 67 non-road construction assets. Emissions have been estimated for the following general pollutant categories:

Table 1: A summary of primary remote sensing data used for EI refinement.

Data set	Variables	Resolution	Source – agency website
Google Earth	Visual imagery, source geometry	2.5 m	Google – https://www.google.com
IKONOS	Visual imagery, source geometry	0.8–3.2 m	IKONOS https://apollomapping.com
LandSat 8	VIS, NIR, TIR	15–90 m	LanSat Archive – http:/earthexplorer.usgs.gov
ASTER	VIS, TIR, GDEM	15–90 m	NASA LPDACC Collection – http:/earthexplorer.usgs.gov
OMI	NO_2, SO_2, HCHO, O_3, AOD	3–12.5 km	NASA EOSDIS – http://reverb.echo.nasa.gov
MODIS	AOD, Surface Temperature	250–1 km	NASA LPDAAC Collection – http:/earthexplorer.usgs.gov
Suomi OMP	SO_2, AOD, O_3	10–50 km	http://www.nasa.gov/mission_pages/NPP/main/
Suomi NPP	VIIRS, AOD	750 m	NASA – http://earthobservatory.nasa.gov/NightLights

- Criteria pollutants
- Hazardous air pollutants
- Metals
- Greenhouse gases

Where possible, component species are separately identified and quantified in emission estimates. In total the KOC EI includes 92 speciated pollutants.

This phase also consists of the development of a regulatory-based electronic air emissions inventory software system. The system is intended to provide KOC with the capabilities necessary to establish an effective environmental regulatory framework and implement a comprehensive ACMP designed to facilitate legal compliance with KEPA advancing air regulatory programmes. Hence the KACMS was developed as part of a joint initiative between KOC and the KEPA to improve air quality in Kuwait. KACMS is a comprehensive Web-based environmental IT solution that provides the following capabilities:

- Emission inventory management system
- Air dispersion and hotspot modelling
- Inventory reporting system
- Record keeping/file repository
- Reporting system
- Mapping and data visualization
- Ambient monitoring

Figure 1 shows the layout of the KACMS dispersion modelling dashboard and its various options.

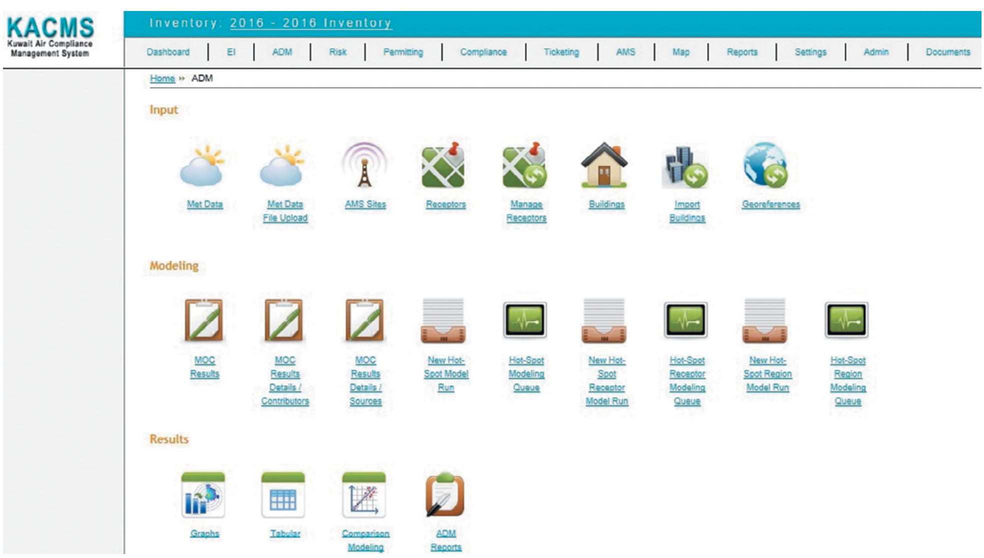

Figure 1: A view of the KACMS modelling dashboard.

2.2 Hotspot modelling

The second step of this project was to conduct air dispersion modelling for all KOC emission sources, including point sources, fugitive area sources, on-road mobile and non-road mobile. The state-of-the-art meteorological and regulatory-approved air dispersion modelling system – AERMOD, developed by the American Meteorological Society/Environmental Protection Agency Regulatory Model Improvement Committee – was used to conduct air dispersion modelling for this study. The technical approaches used to perform air dispersion modelling are consistent with standard practices in regulatory air dispersion modelling, as prescribed by US EPA's Air Quality Modelling Group.

To facilitate modelling on this scale, air dispersion modelling was conducted on a source-by-source basis using a unitized emission rate of 1 g/s. Air dispersion modelling results are then post-processed by applying source- and pollutant-specific emission rates to the unitized modelling results to estimate source- and pollutant-specific pollutant concentrations in units of micrograms per cubic metre (μg/m^3). These results are further processed to generate aggregate hotspot concentrations by adding pollutant-specific contributions across all source types.

This approach provides significant advantages to the project as source-specific emission rates can be quickly changed without having to rerun hundreds of sources in AERMOD. This approach is particularly important for this project as model run times, even when executed

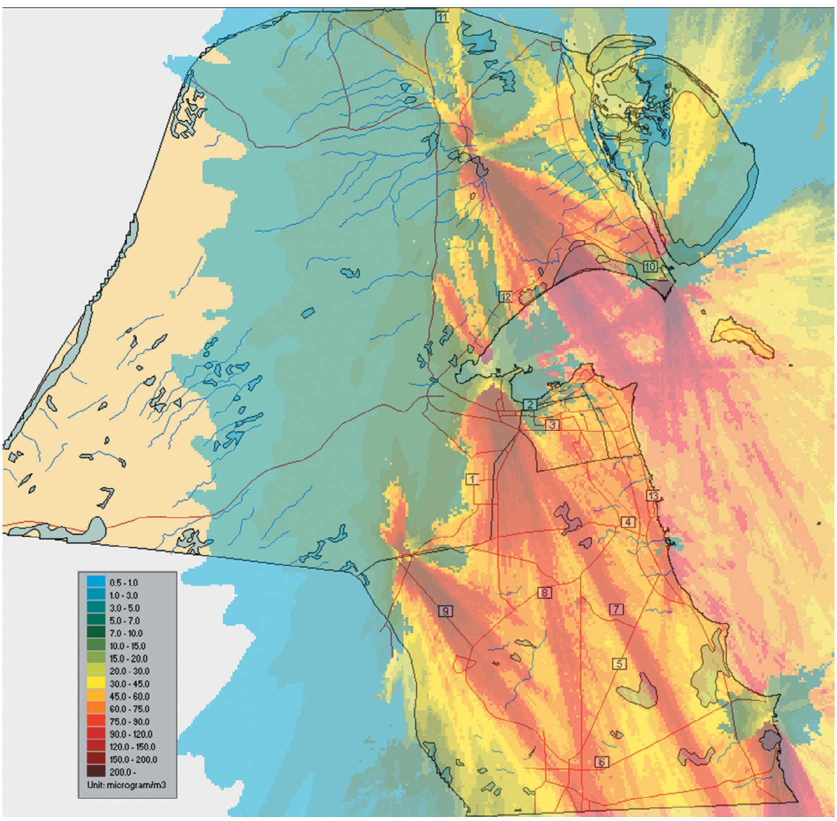

Figure 2: Sample AERMOD hotspot modelling output for SO_2.

in a multi-core cloud environment, can take several days to complete. The modelling domain for this project covers all of Kuwait and utilizes a universal modelling grid resolution with spacing of 90 × 90 m. Five years of representative MM5 meteorological data were processed for the period 2007–2011. Source-specific modelling was conducted using a source-specific modelling domain of 40 × 40 km which aligns with the universal grid. In addition, on-road mobile monitoring was performed which consisted of over 700 km of primary roadways in Kuwait.

Subsequently, hotspot analysis was performed to identify areas across Kuwait that are potentially subjected to adverse impacts from emissions originating from KOC operations. Pollutant-specific hotspot contour maps were generated to provide geospatial context to the results as well as facilitate communication of results to project stakeholders. Based on the hotspot results final selection of ambient air monitor locations across Kuwait was completed. Hotspot maps include identification of residential population centres where the potential for exposure to the community is higher. Additional background information presented on maps includes transportation network, geopolitical boundaries and KOC-specific information such as facility boundaries emissions source locations and security fences. A sample of hotspot model output run is shown in Fig. 2.

2.3 Ambient air quality monitoring

Based on the hotspot modelling results, KOC established a network of six AAQM stations at identified sensitive locations across the State of Kuwait. KOC has since further expanded the existing AAQM network to include total 15 AAQM stations including two mobile stations. Each station is equipped with

- OPSIS-DOAS and dust-monitor systems for the measurement of NO_2, NO, NO_x, PM_{10}, $PM_{2.5}$, SO_2, O_3, NH_3, CH_4, Cl_2, CO_2 and a range of hydrocarbon compounds (like benzene, trimethylbenzene, ethylbenzene, toluene, styrene, m-xylene, o-xylene, p-xylene, phenol, acetaldehyde and formaldehyde);

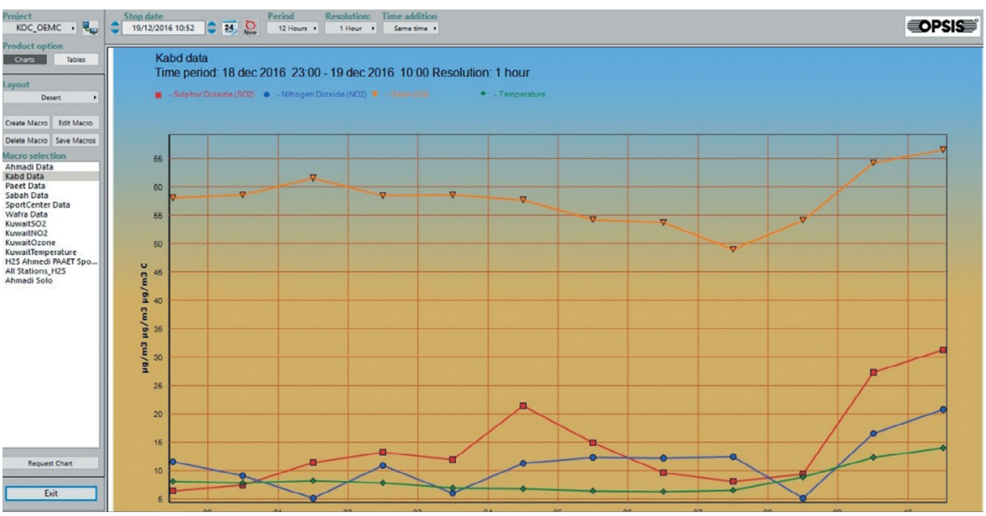

Figure 3: Air quality monitoring data presentation dashboard.

- conventional gas analysers for the measurement of CO and H_2S;
- meteorological sensors for the measurement of temperature, barometric pressure, solar radiation, wind speed and direction, precipitation, relative humidity and cloud cover;
- additionally, TSP, which is also measured at the two mobile stations.

Filters collected from the PM_{10}/$PM_{2.5}$ samplers are analysed further in a laboratory to determine monthly mean concentrations of the heavy metals such as lead, cadmium, nickel and mercury.

Live AQM data for all the stations is reported to KOC through online reporting system. Furthermore, validated data is reported on a daily, weekly and monthly basis through AQM reports. A snapshot of the AQM reporting dashboard is shown in Fig. 3. The data is used for AQ monitoring, compliance, modelling and various other purposes.

2.4 Emissions estimation and reporting

The emissions estimation and reporting phase broadly encompasses the following activities:

- Acquire and improve upon (where necessary) monthly data collection.
- Prepare detailed air emissions reports on a monthly basis detailing the results obtained.
- Compare estimated emissions with local regulations (i.e. KEPA) and international standards (i.e. US EPA NSPS).
- Provide recommendations on reducing emissions from KOC facilities including (but not limited to) control measures, best available control technologies (BACT) and alternatives.
- Compare KOC greenhouse gas emissions (expressed as CO_2 equivalent) with emissions from other oil companies in Gulf Cooperation Council (GCC) and at a global level.
- Set targets for KOC for major pollutants.

KOC facility emissions are estimated by first collecting a series of fixed and variable data from all individual source or process types. Fixed data includes, for example, the dimensions of hydrocarbon storage tanks or the maximum heat input rating for a boiler, which do not change from month to month. Variable data includes, for example, the number of operating hours in the month or throughput of product. These fixed and variable data were then used as inputs to various US EPA AP-42 [1] prediction methods that provide formulas and factors for calculating emissions for a wide range of pollutants. The KOC EI has also been extended to include emissions from non-road vehicles/mobile plants as well as on-road vehicles using appropriate US EPA methodologies.

Additional steps in emissions reporting include improving emissions estimates (by direct measurements, predictive modelling, engineering estimates etc.), if possible, emissions database management, quality assurance and auditing, compliance reporting and emissions abatement strategy. Potential pollution abatement measures are identified for each KOC source and pollutant type. The abatement measures are wide ranging, from fuel switching or good international industry practice for stack height, to installation and operation of selective catalytic reduction (SCR). Each of these pollutant abatement measures has a cost and an assessment is conducted to determine whether the cost is warranted by the amount of pollution reduced. All sources of pollution are 'scored' based on emissions reduction potential and cost – to develop a prioritization schedule for emissions reduction. Sample of a prioritized schedule is shown in Fig. 4.

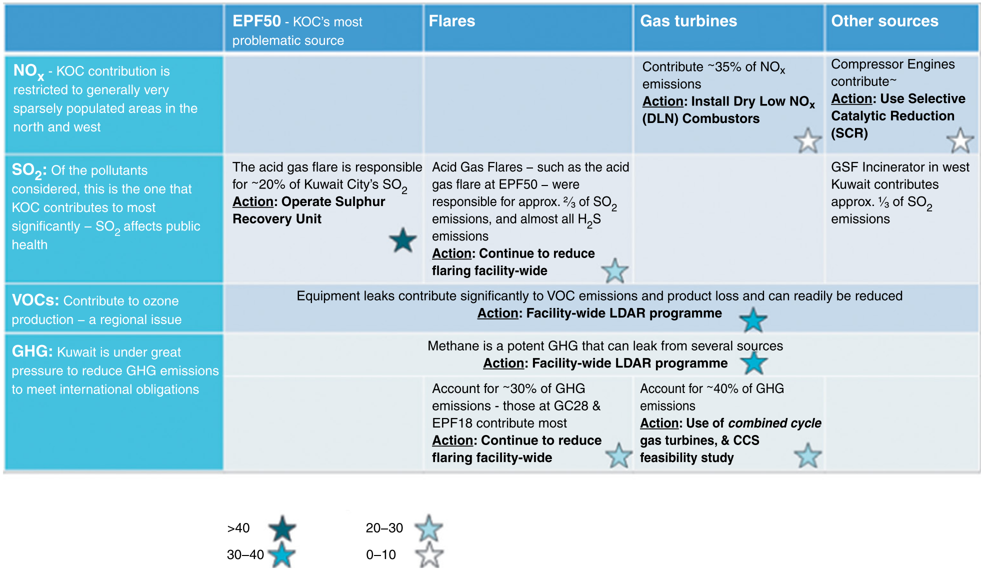

Figure 4: Sample prioritization schedule for emissions abatement for various pollutants.

2.5 Source apportionment study

The purpose of the source apportionment study was to map the spatial and temporal patterns of pollutant concentrations over whole of Kuwait and determine the contribution made by KOC activities. Methods were developed to estimate total concentrations of SO_2, NO_2, CO, PM_{10}, $PM_{2.5}$, benzene and formaldehyde (HCHO) across the country. These included developing a national emissions inventory (KNEI) of all sources in Kuwait. Regional dispersion modelling was carried out using AERMOD to predict pollutant concentrations throughout Kuwait. Ground-based monitoring data from the six existing KOC monitoring stations as well as ten KEPA monitoring stations was analysed. Satellite data was used to estimate ground-level concentrations in remote areas where monitoring data was not available. A method was developed to correlate the satellite-observed column amounts to ground-based concentration estimates that could be used to estimate concentrations in areas away from the monitoring stations. Ground-level concentrations of SO_2, NO_2, CO, PM_{10} and $PM_{2.5}$ were estimated using satellite data. However, concentrations of HCHO were found to be rarely above the satellite's limit of detection, so could not be used.

AERMOD was initially used to predict annual mean process contributions due to KNEI emission sources at the AQM stations. Contributions were modelled according to the emission sources in the KNEI which included KOC sources as well as other industrial and transport/residential sources. Estimates of background concentrations arising from sources not explicitly modelled were extracted from the MOZART (Model for Ozone and Related Chemical Tracers) [2] global modelled data and added to the KNEI emission source contributions to provide estimates of the total modelled pollutant concentrations.

The modelled values were then compared against monitored concentrations in order to assess model performance and to provide estimates of the potential percentage contributions of KOC operations to ambient pollutant concentrations. Maps were produced to show annual mean pollutant concentrations across Kuwait with breakdown of contributions from various

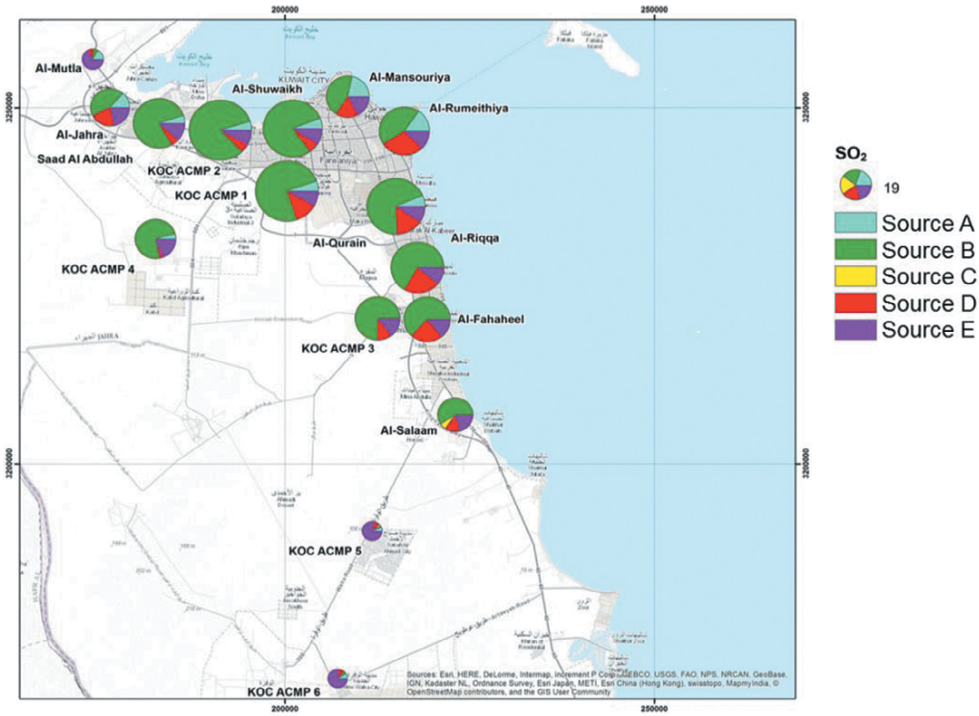

Figure 5: KOC SO_2 contribution to Kuwait ambient air quality.

entities including KOC. Figure 5 shows the contribution of various sources/entities towards SO_2 concentrations in Kuwait. Another outcome of the source apportionment study was the identification of highest contributing point sources within KOC itself and implementing strategies and plans to reduce emissions from these sources.

KOC is considered to make a small contribution to pollution in areas that are densely populated such as Kuwait city and south along the coast. However, the contribution from KOC activities to total modelled concentrations of SO_2, NO_2 and benzene in remote areas near KOC facilities can be significant.

2.6 Human health risk assessment

As part of the project, HHRA was performed to estimate the potential human health risks associated with the inhalation of ambient air in Kuwait. Evaluation included estimation of cancer risks, non-cancer hazard health effects and acute hazards based on exposure to both measured ambient air concentrations and modelled ground-level concentrations attributable to emissions from KOC operations. Results of this HHRA are intended to determine if the predicted inhalation risks in Kuwait exceed risk target levels and provide stakeholders with the information necessary to quantify the magnitude of potential health risks, and if warranted, develop appropriate risk management strategies.

The HHRA was performed following the US EPA 2005 Final Human Health Risk Assessment Protocol (HHRAP). The HHRAP provides guidance for developing an emission inventory, conducting air dispersion modelling, and completing a HHRA study including calculation of cancer risks and non-cancer health effects. The HHRAP covers emission inventory development, air dispersion modelling, and all steps involved in the risk assessment and risk characterization process. In addition, it further documents pollutant-specific fate, transport, and health benchmarks; equations for estimating media concentrations and cancer and non-cancer health effects; as well as details describing risk assessment methodologies including exposure, exposure scenarios, exposure pathway and pollutant-specific fate, transport, and toxicity parameters.

Relevant to this study, risk estimates include evaluation of cancer risk and non-cancer hazards. Cancer risk is the probability that a human receptor will develop cancer, based on the unique set of exposure pathways and toxicity factors applied. In contrast, hazard is the potential for developing non-cancer health effects as a result of exposure to pollutants. A hazard is not a probability but, rather, a comparison (calculated as a ratio) of a receptor's potential exposure relative to a standard exposure level. Inhalation risks were estimated by applying standard exposure levels including use of inhalation reference concentrations (RfC) and inhalation unit risk factors (URF).

Modelled KOC emissions were not estimated to cause adverse human health effects based on evaluation of the residential adult and child inhalation exposure scenarios. The results and risk analysis indicate that no chronic cancer risks, non-cancer hazards or acute exposures sufficiently exceed the established risk target levels to indicate unacceptable risk to the population of Kuwait.

3 CONCLUSION

This is the first-ever joint venture of its type between the industry and regulators, not only in Kuwait but across the region as well. The benefits of the project will be felt indefinitely and in the long term and will not all be realized at once. This is because the project will result in a permanent change in culture within Kuwait in general and KOC in specific whereby reducing emissions is engrained and at the heart of KOC operations. Nevertheless, the ACMP is already contributing to emissions reductions; for instance, in West Kuwait, the Gas Compression Project and Gas Reinjection Project became operational in March 2015 and these have resulted in huge reductions in emissions, of the order of 95% for the facilities involved. KOC also is discharging its commitment to communities by protecting their well-being and health and ensuring its operations do not affect the people living near its operations by conducting the HHRA.

The project is unique in its overarching aim and ambition and has been recognized with the following honours:

- First place at 26th Session of Council of Arab Ministers Responsible for the Environment
- HSE Initiative of the Year at the 2016 Middle East Oil & Gas Awards
- Project Merit in Air Quality by the Environmental Business Journal

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