CLEAN FUEL PROJECT
ENVIRONMENT IMPACT ASSESSMENT
AIR MODELING UPDATE REPORT

For

Kuwait National Petroleum Company

Kuwait

Prepared by

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1. INTRODUCTION

Kuwait's three domestic refineries have a combined capacity of roughly 936,000 bbl/d. The country's largest refinery is Mina Al Ahmadi, with a capacity of 466,000 bbl/d. The other refineries are Mina Al Abdullah (270,500 bbl/d) and Shuaiba (200,000 bbl/d). Kuwait National Petroleum Company (KNPC) continues to plan significant expansion of its production capacity aiming to reach a long-term total refining capacity of 1.4 million barrels/d.

KNPC, in its continuing commitment to meet changing (and more stringent) environmental requirements and to meet the increased need for clean fuels, is embarking upon an ambitious project, the Clean Fuels Project 2020 or CFP, to upgrade the three existing refineries.

CFP involves modifications at KNPC’s three (3) existing refineries: Mina Al Ahmadi (MAA), Mina Abdullah (MAB), and Shuaiba (SHU). The MAA and MAB refineries will undergo major upgrades while the processing facilities at SHU will be retired. The outcome of this will be the integration of the KNPC Refining System into one merchant Refining Complex with Full Conversion operation with highest Light Ends Products Yields and minimum Fuel Oil production.

CFP will result in a reduction in the overall refining capacity of the three refineries from the current operating levels of 936,000 bbl/d to 800,000 bbl/d. The changes are expected to reduce impact on the environment from the refinery activities. The CFP will integrate the new and existing process units along with storage, infrastructure, oil movement and shipping. A variety of new Utilities and Offsite (U&O) facilities will be provided.

In accordance with the regulatory requirement of Kuwait Environment Public Authority (K-EPA), an initial EIA was completed by Fluor (the CFP Project Management Consultant contractor) in August 2007. Later, Det Norske Veritas (DNV) conducted a full independent Environmental Impact Assessment (EIA) process for the proposed CFP during FEED in 2008.

Scope of work for this report is to update Air Dispersion modeling part i.e. Chapter-9 of Environmental Impact Statement report submitted in December, 2009.

2. LOCATION

Kuwait National Petroleum Company (KNPC), K.S.C is a state owned oil company that operates three refineries in Kuwait with combined refining capacity of 930,000 barrels per stream day. The three refineries Mina Al Ahmadi, Shuaiba and Mina Abdullah are located South of Kuwait city. Figure 1 below shows the location of the three refineries along with the surrounding residential and industrial areas.

FIGURE 1: LOCATION OF THREE REFINERIES OF KNPC

3. POLLUTANTS AND GUIDELINES

The model will predict the ground level concentration for principal pollutants SO_2 and NOx emanating from the refineries. The resulting ground level concentrations will be compared with the K-EPA Ambient Air Quality Standards (AAQS) mentioned in the tables below.

TABLE 1: AMBIENT AIR QUALITY STANDARDS FOR INDUSTRIAL AREAS IN KUWAIT (SOURCE: KUWAIT AL YOUM, APPENDIX OF ISSUE NO. – 553 – YEAR 47, 2001)

Pollutant	Hour*		8 hours		Day**		Year	
	ppb	µg/m³	ppb	µg/m³	ppb	µg/m³	ppb	µg/m³
Sulfur Dioxide (SO_2)	300	782.5	-	-	200	523.3	65	157
Hydrogen Sulphide (H_2S)	-	--	-	-	130	173.3	-	-
Nitrogen Dioxide (NO_2)	100	225	-	-	50	112	30	67
Carbon Monoxide (CO)	30000	34000	10000	11500	8000	9000	-	-
Ozone (O_3)	80	157	60	120	-	-	-	-
Ammonia (NH_3)	#800	850	-	-	-	-	140	148
Non-methane Hydrocarbons	1/10 from specified rate in works environment (TLV's) 0.240 ppm for three hours from 6:00 – 9:00 morning (a.m.)							
Suspended Particulate Matter(PM-10)	-	-	-	-	-	350	-	90
Lead	-	-	-	-	-	-	1.5 mg/m³	
Chlorine ##	30.0 (30 min.)	100	-	-	10.0	30	-	

TABLE 2: AMBIENT AIR QUALITY STANDARDS FOR INDUSTRIAL AREAS IN KUWAIT (SOURCE: KUWAIT AL YOUM, APPENDIX OF ISSUE NO. – 553 – YEAR 47, 2001)

Pollutant	Hour*		8 hours		Day**		Year	
	ppb	µg/m³	ppb	µg/m³	ppb	µg/m³	ppb	µg/m³
Sulfur Dioxide (SO_2)	170	444	-	-	60	157	30	80
Hydrogen Sulphide (H_2S)	140	200	-	-	30	40	6	8
Nitrogen Dioxide (NO_2)	100	225	-	-	50	112	30	67
Carbon Monoxide (CO)	30000	34000	10,000	11500	8000	9000	-	-
Ozone (O_3)	80	157	60	120	-	-	-	-
Ammonia (NH_3)	#800	850	-	-	-	-	140	148
Non Methane Hydrocarbons	1/10 from specified rate in works environment (TLV's) 0.24 ppm for three hours from 6:00 – 9:00 morning (a.m)							
Suspended Particulate Matter(PM-10)	-	-	-	-	-	350	-	90
Dust – Fall out Matter	-	-	-	-	-	-	7.5 ton /km²	
Lead	-	-	-	-	-	-	1.5 mg/m³	
Chlorine ##	30 (30 min.)	100	-	-	10	30	-	

** Average hour should not occur more than twice during the period of 30 days on the same site.*
*** Daily average (24 hours) should not occur more than once during the year.*
Should not occur more than once per year.

TABLE 3: MAXIMUM LIMITS ALLOWANCE FOR OCCUPATIONAL EXPOSURE TO CHEMICAL SUBSTANCE (SOURCE: KUWAIT AL YOUM, APPENDIX OF ISSUE NO. – 553 – YEAR 47, 2001)

Chemical Name	Exposure Level			
	Within 8 Hours		Within a short period	
	mg/m³	ppm	mg/m³	ppm
Sulphur Dioxide	5	2	13	5
Nitrogen Dioxide	1.8	1.0	-	-
Hydrogen Sulphide	14	10	21	15

Of the several species of NOx, only NO_2 is specified in the AAQS. Since most sources emit uncertain ratios of these species and these ratios change further in the atmosphere due to chemical reactions, a method for determining the amount of NO_2 in the plume must be used for calculating the NO_2 concentrations. The recommended method used in this modeling is *Ambient Ratio Method (ARM).* If there is at least one year of monitoring data available for NOx and NO_2, an empirical NO_2 /NOx relationship can be derived. The ratio used for this modeling is 0.75.

4. AIR DISPERSION MODELING METHODOLOGY

4.1 Modeling Approach

The assessment methodology for the air dispersion modeling exercise follows the guidance specified by the US-EPA guideline on Air Quality Models. The model selected is CALPUFF Air dispersion model.

CALPUFF is an advanced, integrated Gaussian puff modeling system for the simulation of atmospheric pollution dispersion. It is a multi-layer, multi-species non-steady-state puff dispersion model that simulates the effects of time and space-varying meteorological conditions on pollution transport, transformation and removal. CALPUFF can be applied on scales of tens to hundreds of kilometers. It includes algorithms for sub grid scale effects (such as terrain impingement), as well as, longer range effects (such as pollutant removal due to wet scavenging and dry deposition, chemical transformation, and visibility effects of particulate matter concentrations). The model has been adopted by the US-EPA in its Guideline on Air Quality Models as a preferred model for assessing long range transport of pollutants and their impacts on Federal Class I areas and on a case-by-case basis for certain near-field applications involving complex meteorological conditions.

CALPUFF View 5.0.1 (Interface for CALPUFF Model) by Lakes Environment was used for this modeling. CALPUFF modeling system includes three main components CALMET, CALPUFF and CALPOST. CALMET is a meteorological model that develops hourly wind and temperature field on a three dimensional gridded modeling domain. CALPUFF is a transport and dispersion model that advects puffs of material emitted from modeled sources, simulating dispersion and transformation process along the way. CALPOST is used for producing tabulations that summarize the results of the simulation, identifying the highest concentrations at each receptor.

4.2 Model Inputs

4.2.1 Meteorological Data

CALPUFF model requires hourly surface data values for wind speed, wind direction, temperature, cloud cover, and solar radiation. Hourly meteorological data for Ahmadi area were obtained from Lakes Environment and these were utilized to generate the required mixing heights for the CALPUFF model.

Both data files for the surface and mixing heights were then used to generate the meteorological file required by the CALPUFF dispersion model using the CALMET meteorological preprocessor program e. CALMET is a meteorological model which includes a diagnostic wind field generator containing objective analysis and parameterized treatments of slope flows, kinematic terrain effects, terrain blocking effects, and a divergence minimization procedure, and a micro-meteorological model for overland and overwater boundary layers. This CALMET program uses various programs to process the data. *METSCAN* extracts meteorological data and assesses data quality through a series of quality assessment checks. *READ62* extracts and process upper air wind and temperature data. *SMERGE* processes hourly surface observations.

The 2010 and 2011 meteorological preprocessed data was used to determine its corresponding Wind Rose plot (see Figure 2). The Wind rose shows that the most predominant wind direction blows from the northwest, with the secondary wind direction being from the east direction.

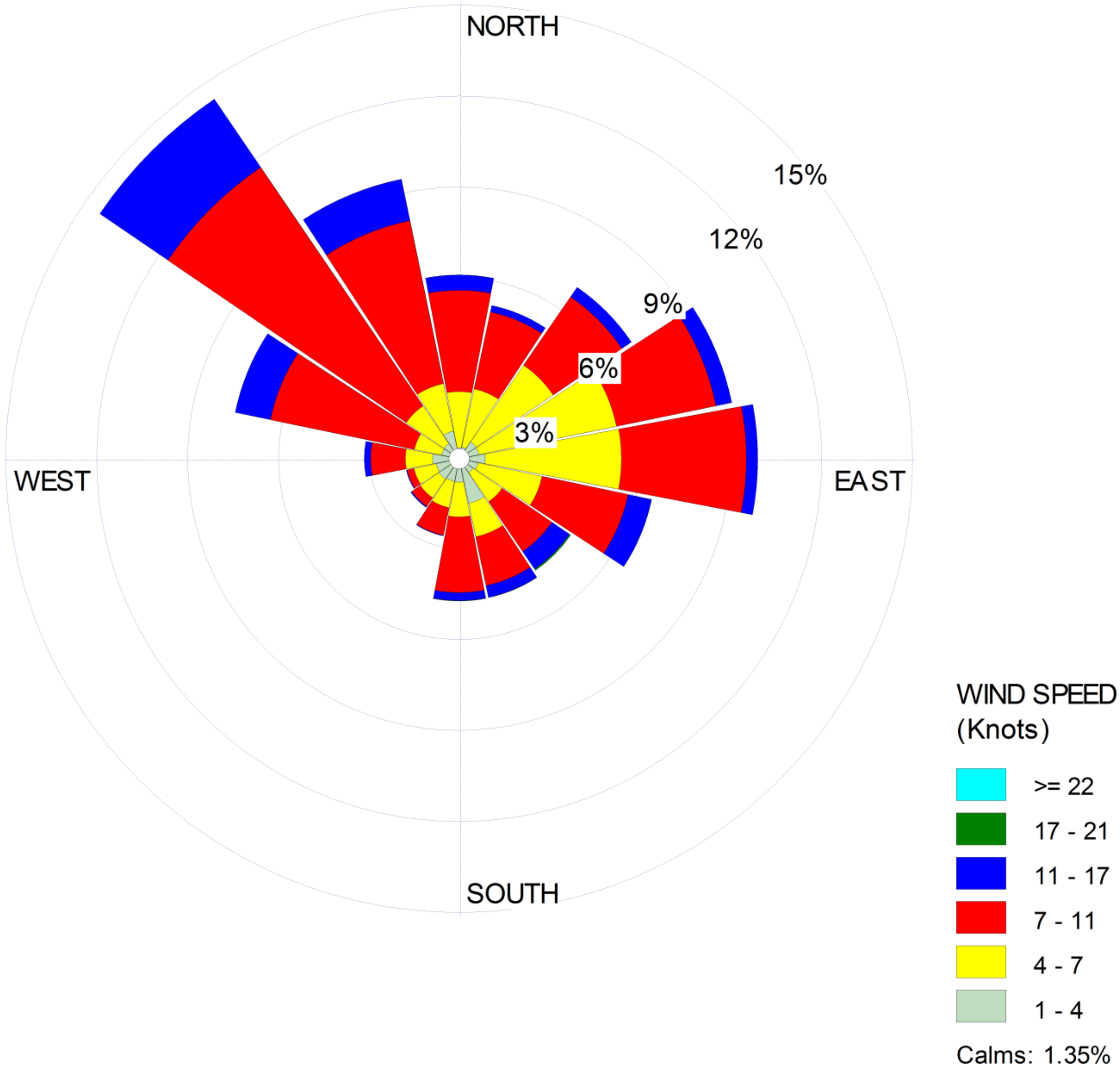

FIGURE 2: WIND ROSE PLOT (2010-2011)

4.2.2 Model Domain, Receptor network and Terrain considerations

The Extent of domain for the modeling starts from the residential area north of the MAA refinery and ends at the Ali Sabah Al Salem residential area south west of the refineries. The Domain covers all the residential area in close proximity of the refineries. The image below shows the extent of the site domain used for modeling. The selected model domain is 20 km in both the east-west and north-south directions, with the centre of the domain being the centre of all the three refineries, with coordinates 221654m UTME and 3215434 m UTMN. Figure 3 shows the model domain that was utilized in the project.

FIGURE 3: EXTENT OF MODELING DOMAIN

The selection and location of the receptor network are important in determining the maximum impact from a source and the area where there is significant air quality impact.

The entire receptor network locations include the following:

Uniform Cartesian Grid

A uniform Cartesian grid with uniform spacing was defined on the complete modeling domain. The figure below depicts the uniform Cartesian grid defined.

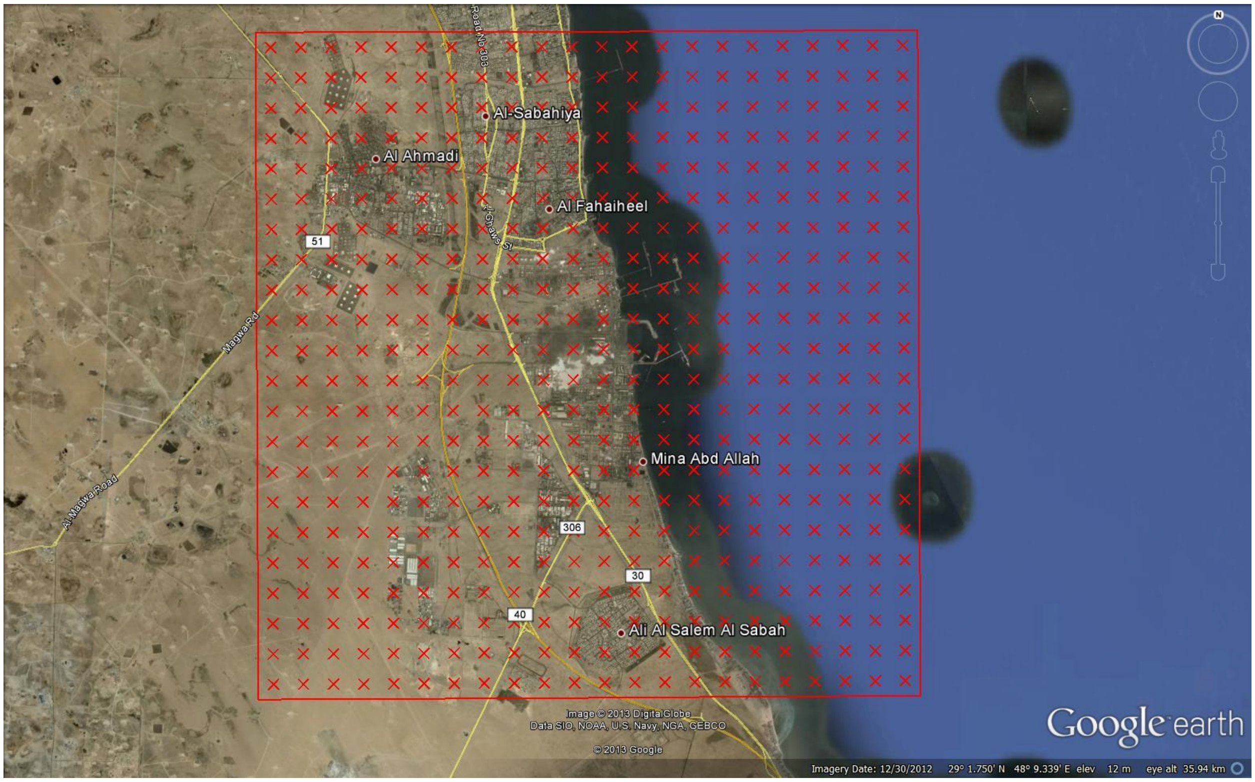

FIGURE 4: UNIFROM CARTESIAN GRID ON MODELED DOMAIN

Discrete receptors

Eight discrete receptors including the residential areas and industrial areas have been used in the modeling. The table below gives the list of discrete receptors used in modeling.

TABLE 4: DISCRETE RECEPTORS

Receptors	UTM Coordinates	
	Easting	Northing
Mina Al Ahmadi Refinery	220620.44	3217660.42
Shuaiba Refinery	221508.48	3215010.07
Mina Abdullah Refinery	222139.74	3212522.98
Fahaheel	220359.23	3221539.51
Mangaf	220207.07	3223382.49
Sabahiya	218291.95	3223647.81
Ahmadi	214637.33	3222235.65
Ali Sabah Al Salem	223080.96	3206919.61

4.2.3 Land Use Land Cover (LULC)

The classification of the land use in the vicinity of the refineries is needed because dispersion rates differ between urban and rural areas. In general, urban areas cause greater rates of dispersion because of increased turbulent and buoyancy-induced mixing. This is due to the combination of greater surface roughness caused by more buildings and structures and greater amounts of heat released from concrete and similar surfaces. The USEPA guidance provides two procedures to determine whether the character of an area is predominantly urban or rural. One procedure is based on land-use type, and the other is based on population density. The land-use methodology is considered to be more accurate than methodology based on population density. Hence, this method was applied and the land-use creator tool present in the CALPUFF view was used to create the Land Use and Land Cover (LULC) map. The Figure 5 below depicts the LULC.

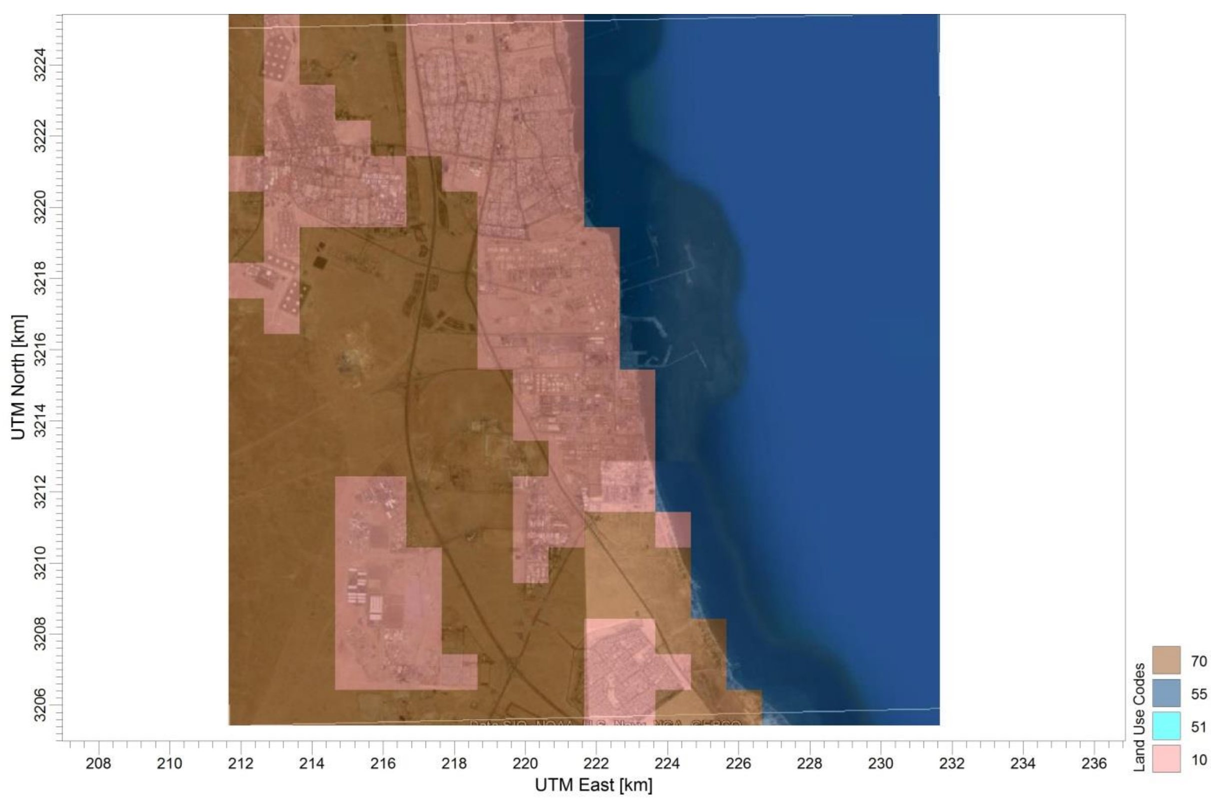

FIGURE 5 : LAND USE LAND COVER (LULC) MAP

The LULC map is in USGS Composite Theme Grid (CTG) format that uses codes for describing land use.

Code 70 is for Barren land.

Code 55 is for Oceans and seas.

Code 10 is for urban areas.

Code 51 is for Streams and canals.

Additionally, the topography in the region of the refineries defined as either simple terrain (terrain lying below the stack top elevation) or complex terrain (terrain above the top of the stack, coastal area). Measurements of the terrain in the area surrounding the refineries were made using terrain data obtained from WebGIS by Lakes Environment. It was determined that the topography on the western side of the domain have terrain elevations above 100 m (see Figure 6). The terrain on eastern side of the domain is mostly flat, and includes the marine environment.

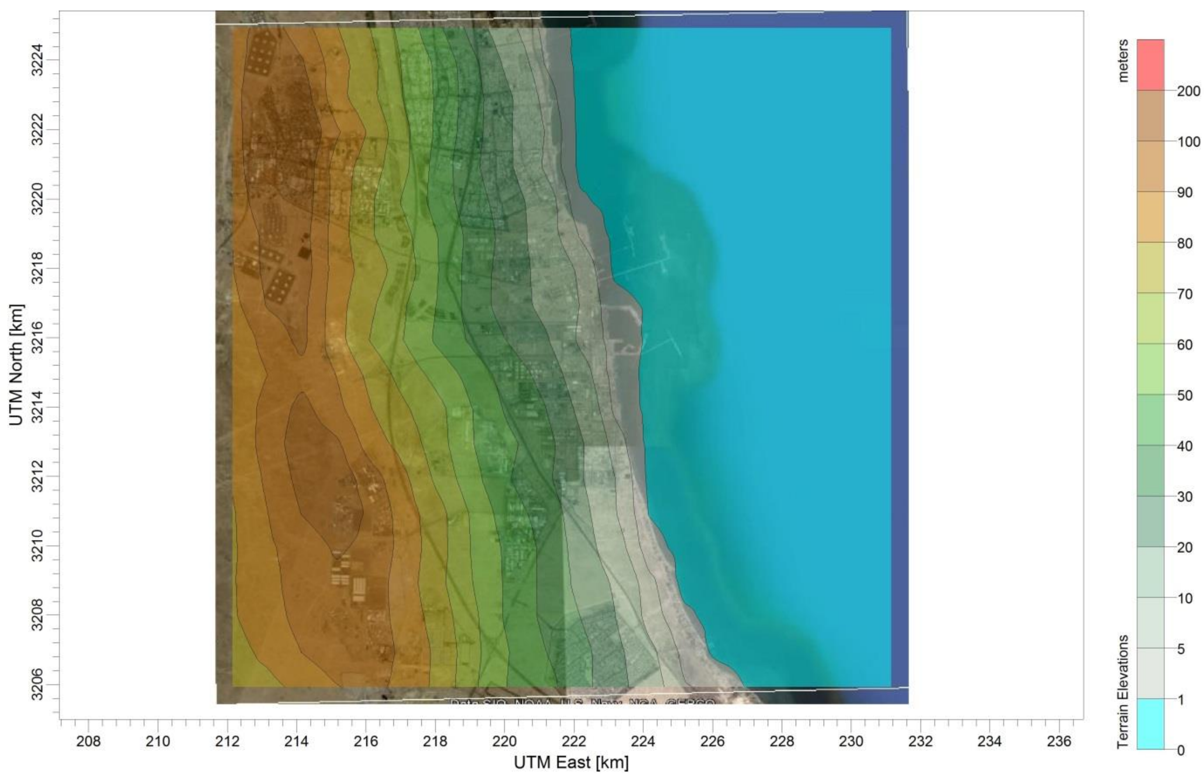

FIGURE 6: TERRAIN DATA

Therefore, since terrain elevations extend above the facility's highest top stack elevation and closeness to coastal conditions, CALPUFF was selected for the air dispersion modeling analysis.

4.2.4 Dispersion Modeling Scenarios

Scenario 1: Baseline

This scenario presents impact of air emissions from Mina Al Ahmadi, Shuaiba and Mina Abdullah refineries on ambient air quality. It is highlighted that all ongoing revamps and projects including LPG 4 & 5 have been considered in this scenario.

Table 5 below shows source information data used for this scenario.

TABLE 5: SOURCE INPUT FOR SCENARIO 1

Stack ID	Stack Height	Exit Diameter	Exit Velocity	Exit Temp.	NOx	SO_2	UTM Coordinates	
	[m]	[m]	[m/s]	[K]	g/s	g/s	Easting	Northing
Shuaiba Refinery (SHU)								
H0501W	24.69	3.05	14.67	1088.7	1.8105	0.00388	222175.5	3214818
H0501M	24.69	1.52	14.67	1088.71	1.8105	0.00388	222178.9	3214818
H0501E	24.69	1.83	14.67	1088.71	1.8105	0.00388	222184.3	3214818
H0601W	44.2	1.98	8.5	623.71	3.7938	0.00813	221924.9	3214905
H0601E	44.2	1.98	8.5	623.71	3.7938	0.00813	221932.6	3214905
H0602W	40.54	1.45	11.6	738.15	2.7447	0.005881	221923.6	3214889
H0602E	40.54	1.45	11.6	738.15	2.7447	0.005881	221933.7	3214889
H0603N	45.03	2.27	7.94	697.59	5.1708	0.01108	221909.3	3214953
H0603S	45.03	2.27	7.94	697.59	5.1708	0.01108	221909	3214945
H0604	26.09	1.71	9.3	798.15	0.6055	0.003633	221995.8	3214846
H0701A	27.43	1.3	11	970.37	0.4818	0.002891	222033.4	3214847
H0702AN	28.96	1.75	10.3	924.82	0.4818	0.002891	221987.5	3214846
H0702AS	28.96	1.75	10.3	924.82	0.4818	0.002891	221987.6	3214838
H0701B	27.43	1.3	10.9	966.48	0.4818	0.002891	222056.8	3214890
H0702BN	28.96	1.75	9.6	865.37	0.4818	0.002891	222041.7	3214846
H0702BS	28.96	1.75	9.6	865.37	0.4818	0.002891	222041.7	3214838
H0801	35.36	1.22	9.6	1009.26	0.04818	0.000289	221960	3214795
H0802	40.39	2.44	10.8	926.48	4.2716	0.009153	221924.3	3214802
H0901	40.39	2.44	11	960.93	2.8102	0.006022	222291.6	3214854
H1001	30.79	1.52	11	1022.04	0.3011	0.001807	222150.2	3214803
H1102	32.92	1.62	9.27	839.82	0.448	0.002688	222223.1	3214927
H1103	30.48	1.37	9.6	875.93	0.3011	0.001807	222221.4	3214917
H1104	33.83	1.68	12	1005.37	0.7026	0.004215	222221.5	3214908
H1105	35.05	1.98	10	1005.37	0.6022	0.003613	222221.2	3214898
H1106	31.39	1.37	9.29	830.93	0.4015	0.002409	222221	3214890
H1201	30.48	1.98	6	901.48	0.4143	0.002486	222221	3214800
H1203	28.5	1.37	8	899.82	0.2674	0.001604	222251.1	3214807
H1204	27.89	1.4	7.6	897.04	0.3677	0.002206	222251.4	3214799
H1301	30.48	1.22	12.7	897.04	0.5685	0.003411	222221.2	3214881
H1303	30.48	1.37	8.6	777.04	0.2674	0.001604	222221.3	3214873
H6301	66.45	1.75	5.84	505.37	0.9314	0.005588	221715.1	3214932

Stack ID	Stack Height	Exit Diameter	Exit Velocity	Exit Temp.	NOx	SO_2	UTM Coordinates	
	[m]	[m]	[m/s]	[K]	g/s	g/s	Easting	Northing
H6801W	33.83	1.52	5.52	741.48	0.281	0.001686	221711.1	3214824
H6801E	33.83	1.52	5.52	741.48	0.281	0.001686	221720.2	3214824
H6802W	49.07	1.75	5.88	644.26	0.07869	0.000169	221711.9	3214914
H6802E	49.07	1.75	5.88	644.26	0.07869	0.000169	221722	3214915
H0201N	52.21	3.66	8.87	699.82	11.7093	0.02509	221872.2	3214824
H0201S	52.21	3.66	8.87	699.82	11.7093	0.02509	221871.7	3214810
H0251N	52.21	3.66	8.87	699.82	11.7093	0.02509	221850.7	3214824
H0251S	52.21	3.66	8.87	699.82	11.7093	0.02509	221851.3	3214810
H6201N	52.21	3.66	8.87	699.82	11.7927	0.02527	221789.9	3214825
H6201S	52.21	3.66	8.87	699.82	11.7927	0.02527	221789.4	3214809
B2001A	18.29	2.97	16.18	680.37	7.494	0.01606	222189.8	3214930
B2001B	18.29	2.97	16.18	680.37	7.494	0.01606	222189.3	3214917
B2010C	18.29	2.97	16.18	680.37	7.494	0.01606	222189.2	3214905
B2001D	18.29	2.97	16.18	680.37	7.494	0.01606	222189.1	3214893
ST0402	60.96	2.74	6.97	849.82	0	93	222420.4	3215128
ST2901	73.45	0.91	0.29	348.71	0.1867	13.3187	222401.2	3215050
ST2902	73.45	0.91	0.29	348.71	0.1867	13.3187	222399.9	3214989
ST2903	101.2	1.07	0.05	348.71	0.07422	0.03274	221593	3214900
Mina Abdullah (MAB)								
H01101	20.95	1.52	8.53	755.37	0.3401	0.002041	222175.4	3212682
H01102	20.95	1.52	8.53	755.37	0.4163	0.002498	222175.6	3212688
H01104	20.95	1.52	8.53	755.37	0.3918	0.002351	222176.3	3212699
H01105	20.95	1.52	8.53	755.37	0.4341	0.002605	222176.6	3212705
H01106	20.95	1.52	8.53	727.59	0.2432	0.001459	222177.8	3212724
H01107	20.95	1.52	8.53	755.37	0.6528	0.003917	222178.9	3212730
H01108	20.95	1.52	8.53	755.37	0.6298	0.003779	222179.2	3212736
H01109	20.95	1.52	8.53	755.37	0.6898	0.004139	222179.7	3212742
H01110	20.95	1.52	8.53	755.37	0.6684	0.004011	222180.3	3212747
H020101A	19.81	2.29	0.95	783.15	0.4568	0.002741	222173.6	3212634
H02101B	19.81	2.29	0.95	783.15	0.4215	0.002529	222161.8	3212635
H02102	19.81	2.29	0.91	783.15	2.1349	0.004575	222195.7	3212633
H03101	43.1	2.74	2.13	560.92	10.3454	0.02217	222255.7	3212535
H11101	70.1	2.44	11.8	449.82	2.81	0.03245	222397.4	3211649
H121012	55.77	2.11	4.57	505.37	0.2973	0.003567	222685	3211667
H122012	55.77	2.11	4.57	505.37	0.367	0.004404	222702	3211666
H12103	36.57	1.07	5.18	677.59	0.1058	0.00127	222732.9	3211766
H13101	51.82	1.98	10.3	449.82	1.074	0.01065	222716.1	3211935
H13201	51.82	1.98	10.3	449.82	1.097	0.01009	222764.7	3211932
H14101	38.1	1.37	6.95	527.59	0.3779	0.004535	222507.4	3211682
H14102	38.1	1.37	6.95	527.59	0.3107	0.003728	222478.3	3211682
H14103	53.34	1.63	14.69	449.81	2.8215	0.01209	222557.9	3211677
H15101	38.1	1.22	7.62	647.59	0.1236	0.001483	222957.3	3211725
H16101	38.1	1.14	7.32	688.71	0.1197	0.001437	222890.2	3211723
H17101	30.48	0.91	4.27	455.37	0.09842	0.001181	222849.8	3211747
H18101	79.25	3.02	7.1	394.26	4.4673	0.01915	222505	3211950

Stack ID	Stack Height	Exit Diameter	Exit Velocity	Exit Temp.	NOx	SO_2	UTM Coordinates	
	[m]	[m]	[m/s]	[K]	g/s	g/s	Easting	Northing
H18201	79.25	3.02	7.1	394.26	4.7025	0.02015	222435	3211955
H18301	79.25	3.02	7.1	394.26	4.7025	0.02015	222355.6	3211959
H20101	60.96	1.88	5.18	449.82	0.5295	0.006354	222857.2	3211934
H20102	60.96	1.88	5.18	449.82	0.4836	0.005804	222858.7	3211958
H20201	60.96	1.88	5.18	449.82	0.5295	0.006354	222990.1	3211924
H20202	60.96	1.88	5.18	449.82	0.4836	0.005804	222991.3	3211949
B24104	110	2.13	7.68	538.71	0	6.735	222148.4	3211799
B24204	110	2.13	7.68	538.71	0	6.7351	222145.8	3211750
B06101	18.28	1.52	5.42	450	2.1412	0.0578	222378.8	3212728
B31101A	18.28	1.82	5.88	450	3.8464	0.054	222291.1	3212290
B31101B	18.28	1.82	6	450	4.0856	0.0578	222272.7	3212291
B31101C	18.28	1.82	5.94	450	7.1412	0.054	222254.3	3212292
B31102A	30.48	1.19	12.03	450	2.0717	0.0385	222279.5	3212206
B31102B	30.48	1.19	13.86	450	2.7391	0.0462	222262.5	3212207
FL49101	110.5	1.52	0.65	1644	0.1988	0.261	223276.9	3211463
FL49102	110.5	1.52	0.65	1644	0.1988	0.261	223267.6	3211277
FL01102	79.97	0.91	0.54	1644	0.1988	0.261	221857.4	3212699
FL01103	79.97	0.91	0.54	1644	0.1988	0.261	221851	3212599
FL23101	92.83	0.61	0.16	1644	0.00252	0.01406	222125.1	3211673
FL23102	92.89	0.61	0.16	1644	0.00252	0.01406	222178.8	3211674
Mina Al Ahmadi (MAA)								
312F101	58.83	3.07	4.24	533.15	1.9047	0.004082	221612.7	3217483
312F102	52.73	2.85	4.33	533.15	1.2843	0.002752	221614.3	3217468
312F103	58.83	2.41	3.88	533.15	0.5369	0.001151	221618.4	3217458
313F101	36.88	1.07	3.18	533.15	0.00205	0.0000123	221615.6	3217443
313F102	36.88	1.07	2.8	533.15	0.00457	0.0000274	221618	3217436
332F301	58.83	3.07	4.24	533.15	1.9513	0.004181	221686.7	3217273
332F302	52.73	2.85	4.33	533.15	1.3796	0.002956	221691.5	3217260
332F303	58.83	2.41	3.88	533.15	0.5519	0.001183	221695	3217249
333F301	36.88	1.07	3.18	533.15	0.00194	0.0000116	221691.9	3217235
333F302	36.88	1.07	2.8	533.15	0.00552	0.0000331	221692.7	3217226
H48001	79.25	3.58	3.62	394.26	11.2164	0.02404	220834	3218376
H49001	79.25	3.58	3.62	394.26	10.8108	0.02317	220789.7	3218373
H88001	79.25	3.58	3.62	394.26	10.56	0.02263	220343.2	3218336
H89001	79.25	3.58	3.62	394.26	9.0942	0.01949	220299.7	3218333
H83001	60.96	2.9	4.11	444.26	5.1555	0.01105	220080.4	3218305
H84320	60.96	2.39	6.24	433.15	4.9533	0.01061	219939.2	3218296
H84100	44.81	1.37	5.94	477.59	0.7296	0.004378	219995.2	3218073
H84200	44.81	1.37	5.94	477.59	0.6476	0.003885	219959.1	3218071
41H001	60.96	1.73	3.42	466.48	0.5517	0.00331	220938.2	3218209
41H002	62.48	2.13	4.38	466.48	1.8033	0.003864	220939.7	3218193
41H003	54.86	1.25	5.49	466.48	0.1791	0.001075	220909.3	3218385
42H001	60.96	1.73	3.42	466.48	0.526	0.003156	220793.5	3218197
42H002	62.48	2.13	4.38	466.48	1.9691	0.004219	220794.8	3218181
81H001	60.96	1.73	3.42	466.48	0.5183	0.00311	220419.9	3218344

Stack ID	Stack Height	Exit Diameter	Exit Velocity	Exit Temp.	NOx	SO_2	UTM Coordinates	
	[m]	[m]	[m/s]	[K]	g/s	g/s	Easting	Northing
81H002	62.48	2.13	4.38	466.48	1.9186	0.004111	220448.5	3218171
81H003	54.86	1.25	5.49	466.48	0.1711	0.001026	220449.6	3218153
82H001	60.96	1.73	3.42	466.48	0.4554	0.002732	220304.5	3218141
82H002	60.96	2.13	4.38	466.48	1.7656	0.003783	220302.9	3218158
H03070	62.48	3.05	7.42	533.15	5.2196	0.02237	221674	3218226
H40001	80.77	2.92	10.82	455.37	8.794	0.03769	221105.8	3218398
H80001	60.96	3.05	5.24	444.26	3.7577	0.0161	221242.2	3218186
H39001	60.96	2.39	2.56	488.71	0.1733	0.002079	222248.5	3218734
H12001	32	2.64	13.24	1033.15	0.2991	0.001795	222362	3218692
H43001	45.72	1.22	6.34	672.04	0.2305	0.001383	221033.4	3218331
H44001	60.96	1.78	6.3	455.37	0.2493	0.001496	220966	3218382
H58001	75.9	0.17	6.3	255.37	0.4792	0.002875	220757.3	3218375
B29011	45.72	2.29	20.04	472.04	5.51	0.02806	221346.9	3217216
B29012	45.72	2.29	20.04	472	10.9777	0.0235	221323.7	3217227
B29013	45.72	2.29	20.04	472.04	4.44	0.02393	221339.4	3217242
B29014	45.72	2.29	20.04	472.04	4.07	0.02745	221333.5	3217253
B29001	45.72	2.29	22.18	466.48	3.321	0.02038	221353.1	3217204
B29101	45.72	2.29	22.18	466.48	3.589	0.02331	221248	3217237
B29701	45.72	2.11	22.18	466.48	10.3247	0.02212	221171	3217223
ST86301	79.25	2.29	16.26	547.04	14.288	48.79	219828.5	3218028
ST93001	79.25	1.55	16.75	593.15	0	19.948	220603.2	3218264
ST54001	79.25	1.22	30.48	599.82	0	17.426	220621.9	3218130
ST20601	79.25	1.83	16.76	600	0	28.86	221732.4	3216730
ST62401	110.9	0.71	0.01	1273.15	0.00351	0.3162	220710.5	3217864
ST62001	88.82	1.02	84.2	1273.15	1.2902	1.2925	220672	3217722
ST62101	79.71	0.76	85.21	1273.15	0.2105	0.2076	219173.3	3218439
ST62102	79.77	0.76	85.21	1273.15	0.215	0.2121	219189.4	3218218
ST62301	80.23	0.76	85.21	1273.15	0.3472	0.1688	219153.6	3218655
ST119800	71.44	0.76	85.21	1273.15	0.8676	0.4485	221222.2	3217933
ST39001	85.7	0.56	96.28	1273.15	3.9798	2.903	222422.5	3218962
S10301	93.69	1.02	94.18	1273.15	0.02646	0.01323	221346.2	3216648
36F001A	94.03	1.22	75.63	1273.15	0.03441	0.2944	221284.2	3216885
36F001B	94.04	1.22	75.63	1273.15	0.03441	0.2944	221176.4	3216981
36F002A	62.83	1.22	13.75	1273.15	0.01744	0.1481	222410.2	3217328
36F002B	62.83	1.22	13.75	1273.15	0.01744	0.1481	222358	3217471
H231002	40	1.46	8.5	656	1.127	0.187	220569.2	3217334
H234001	40	1.46	8.5	656	0.736	0.187	220597.3	3217334
H231001A	40	3.4	14.7	448	0.578	0.702	220558.3	3217258
H231001B	40	3.4	14.7	448	0.578	0.702	220559	3217207
H235001A	40	3.4	14.7	448	0.578	0.702	220558.2	3217169
H235001B	40	3.4	14.7	448	0.578	0.702	220558.3	3217090
H331002	40	1.46	8.5	656	1.127	0.187	220581	3216972
H334001	40	1.46	8.5	656	0.736	0.187	220553	3216971
H331001A	40	3.4	14.7	448	0.578	0.702	220565	3216930
H331001B	40	3.4	14.7	448	0.578	0.702	220567	3216871

Stack ID	Stack Height	Exit Diameter	Exit Velocity	Exit Temp.	NOx	SO_2	UTM Coordinates	
	[m]	[m]	[m/s]	[K]	g/s	g/s	Easting	Northing
H335001A	40	3.4	14.7	448	0.578	0.702	220563	3216807
H335001B	40	3.4	14.7	448	0.578	0.702	220565	3216739
H25101	31.6	1.3	3.2	589	8.8	6.6	221364.6	3218106
H26101	31.6	1.3	3.2	589	8.8	6.6	221834.3	3218285

Table 6 summarizes maximum predicted Ground Level Concentrations (GLCs) and their comparison with K-EPA Ambient Air Quality Standards (AAQS). The result reveals that ground level concentrations for SO_2 exceed KEPA limit, however the number of exceeds are only 17 in two years period which satisfies the K-EPA's AAQS Appendix No. 17-1 & 17-2 stating "The hourly average should not occur more than twice during the period of 30 days at the same site". Hence, it meets the K-EPA's AAQS requirement.

However, maximum predicted ground level concentrations for NOx exceed K-EPA AAQS for hourly average period as well as for Maximum Number of Exceeds at a particular location.

TABLE 6: MODEL RESULTS FOR SCENARIO 1

Pollutant	Average Period	K-EPA AAQS (μg/m³)	Maximum predicted GLC (μg/m³)	Location		Maximum No. of Exceeds At a particular location
				UTME (Km)	UTMN (Km)	
SO_2	1 hr	782.5	1554.2	222.154	3214.934	17
	24 hr	523.3	220.65	222.154	3214.934	0
	Annual	157	58.86	222.154	3214.934	0
NO_2	1 hr	225	905.59	222.154	3214.934	81
	24 hr	112	107.42	222.154	3211.934	0
	Annual	67	27.01	222.154	3211.934	0

Figures 7 to 9 shows pollutant contour plot-files for SO_2. The plot files show most impacted areas based on predicted pollutant concentrations generated by the model run. Color coded scale in the figures indicates the various impact concentrations.

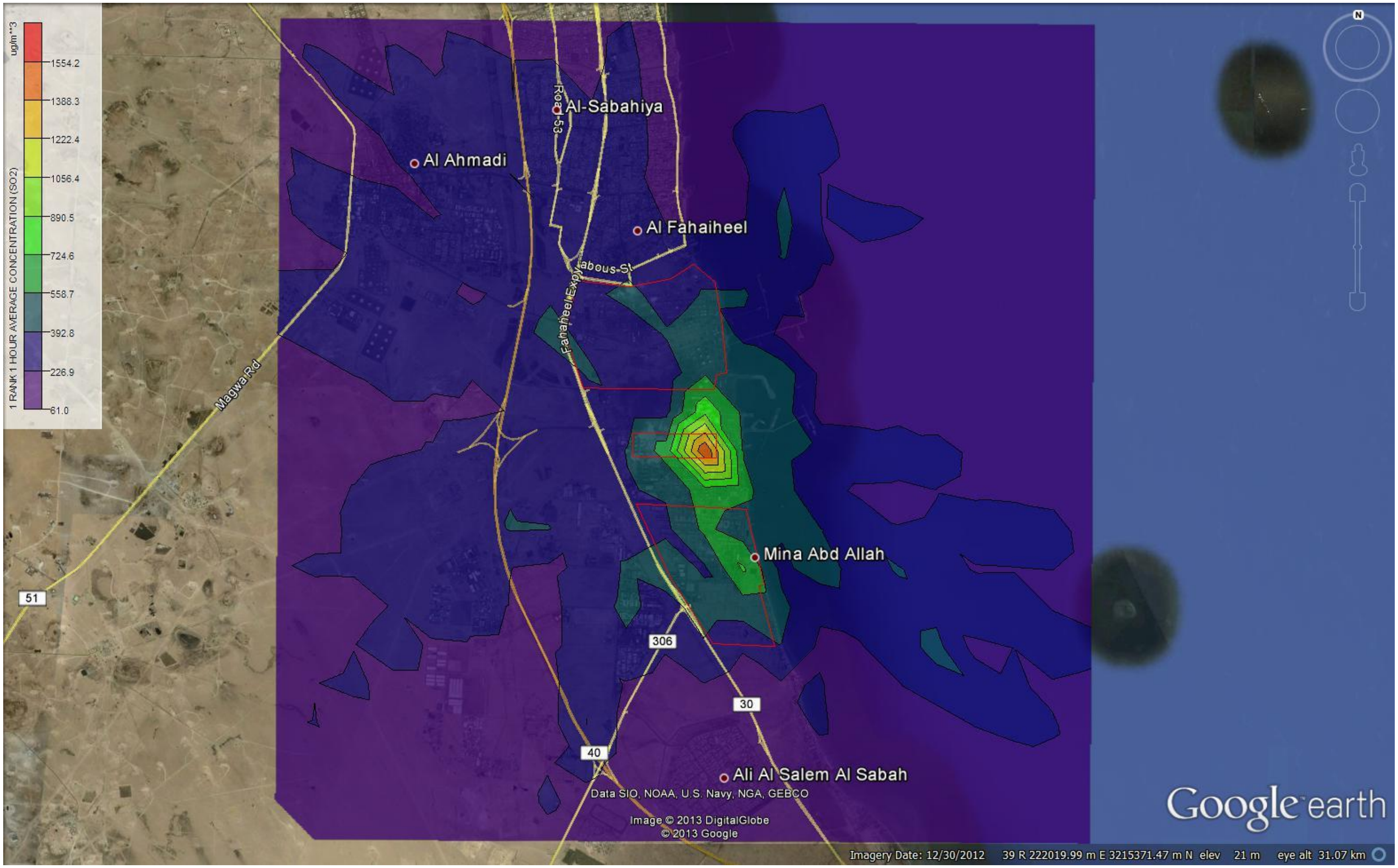

FIGURE 7: SO_2 ($\mu g/m^3$) HOURLY GLC'S FOR SCENARIO 1

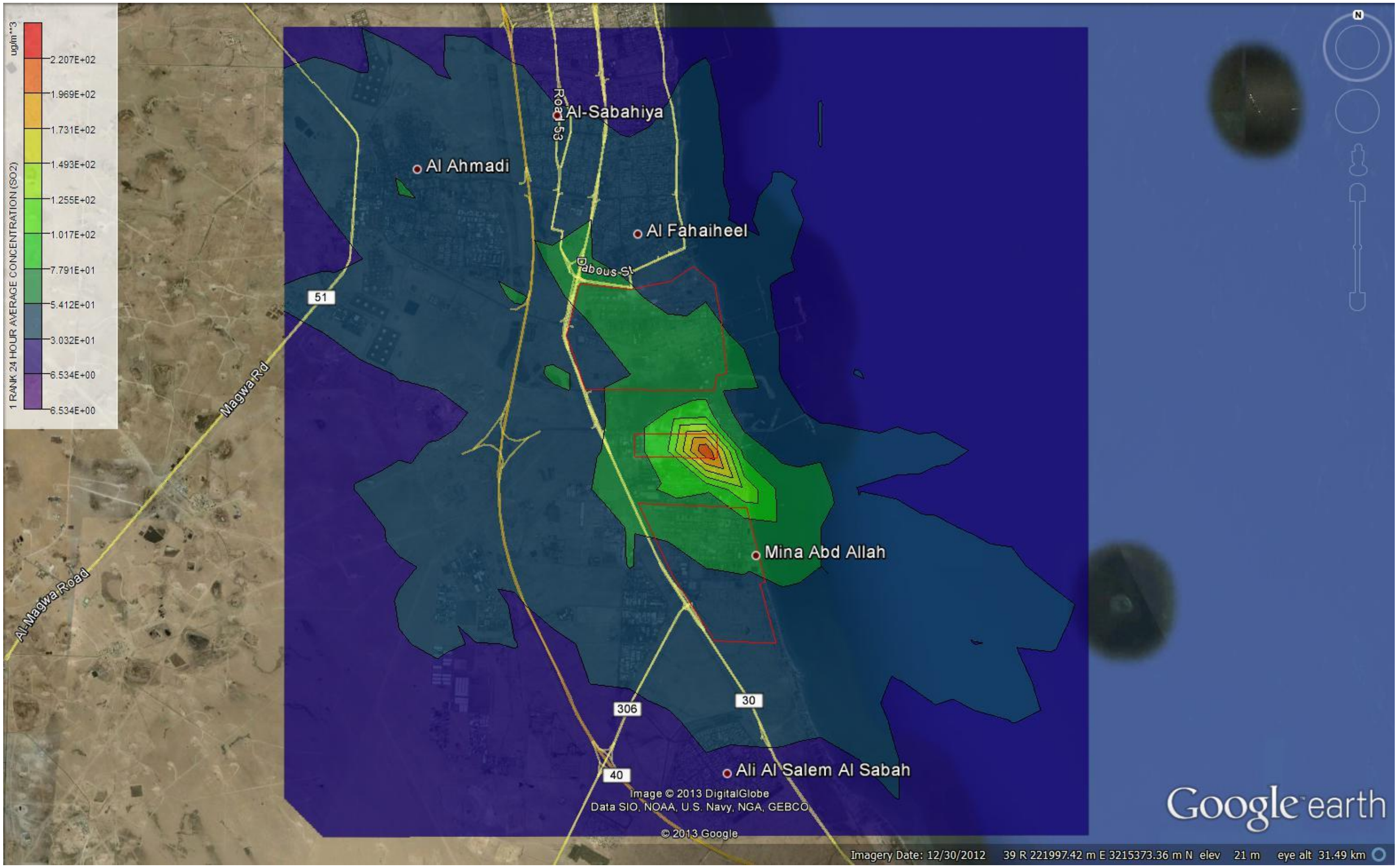

FIGURE 8: SO_2 ($\mu g/m^3$) DAILY GLC'S FOR SCENARIO 1

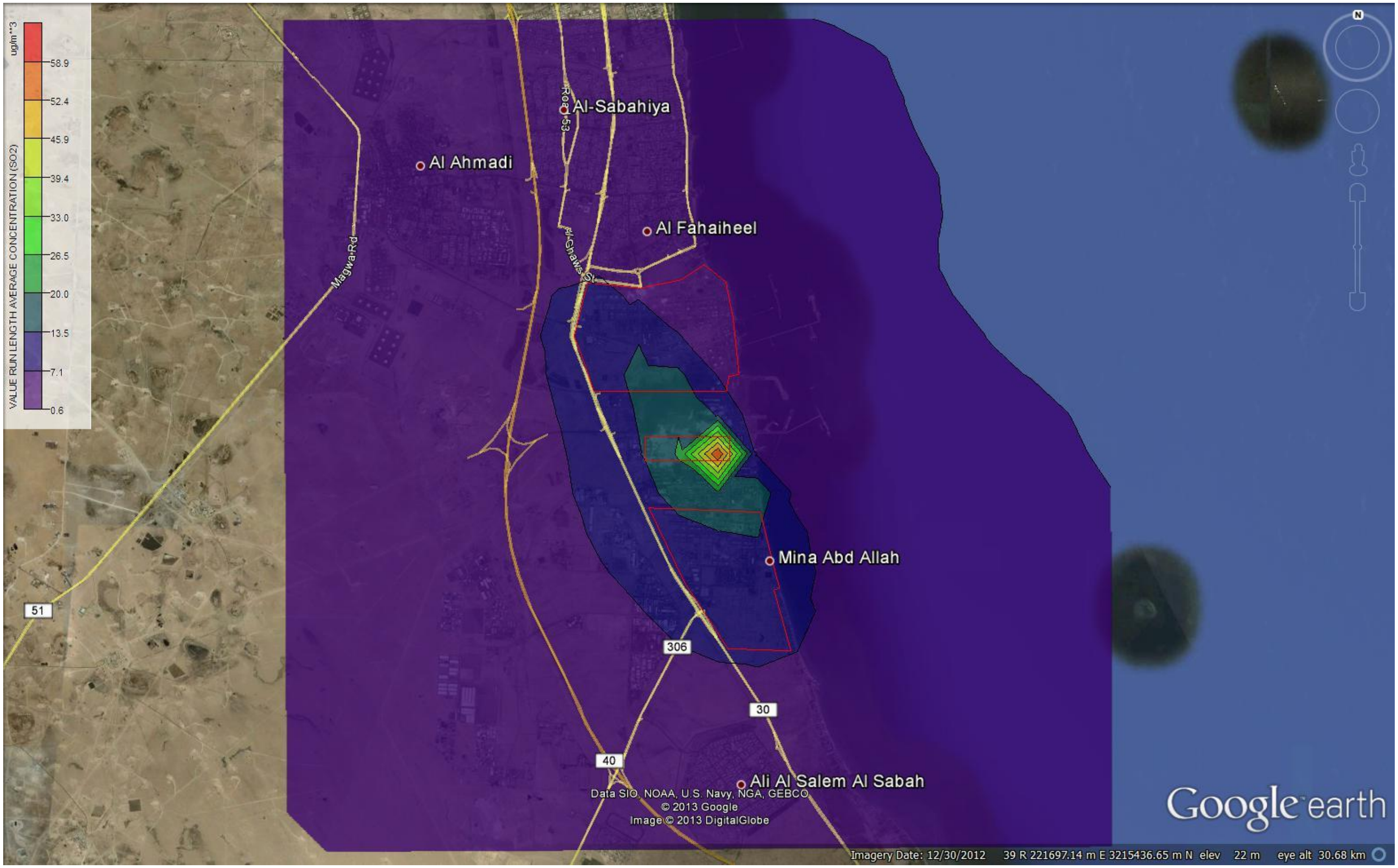

FIGURE 9: SO_2 ($\mu g/m^3$) ANNUAL GLC'S FOR SCENARIO 1

Table 7 lists the highest predicted hourly, daily and annual SO_2 G-LC's for three refineries complex.

TABLE 7: HIGHEST SO_2 GLC'S AT THE DISCRETE RECEPTORS FOR DIFFERENT AVERAGING PERIOD

Receptors	**Highest Average Concentration (µg/m³)**		
	Hourly	**Daily**	**Annual**
Mina Al Ahmadi Refinery	541.48	71.09	15.61
Shuaiba Refinery	1554.20	220.65	58.87
Mina Abdullah Refinery	747.12	68.74	13.95
K-EPA Limit	**782.5**	**523.3**	**157**

Table 8 lists the highest predicted hourly, daily and annual SO_2 GLC's at the residential area close to the refineries area

TABLE 8: HIGHEST SO_2 GLC'S FOR RESIDENTIAL AREAS

Receptor	**Highest Average Concentration(µg/m³)**		
	Hourly	**Daily**	**Annual**
Fahaheel	364.70	54.41	6.25
Ahmadi	378.09	54.64	4.76
Ali Sabah Al Salem	178.90	29.87	4.89
Sabahiya	329.02	43.96	4.10
Mangaf	277.44	31.82	2.94
K-EPA Limit	**444**	**157**	**80**

Findings:

On comparison of the above results to K-EPA AAQ standards mentioned in table 1 and table 2 average hourly, daily and annual GLC's of SO_2 meet K-EPA limit in residential and industrial areas.

Figures 10 to 12 shows pollutant contour plot-files for NO_2. The plot files show most impacted areas based on predicted pollutant concentrations generated by the model run. Color coded scale in the figures indicates the various impact concentrations.

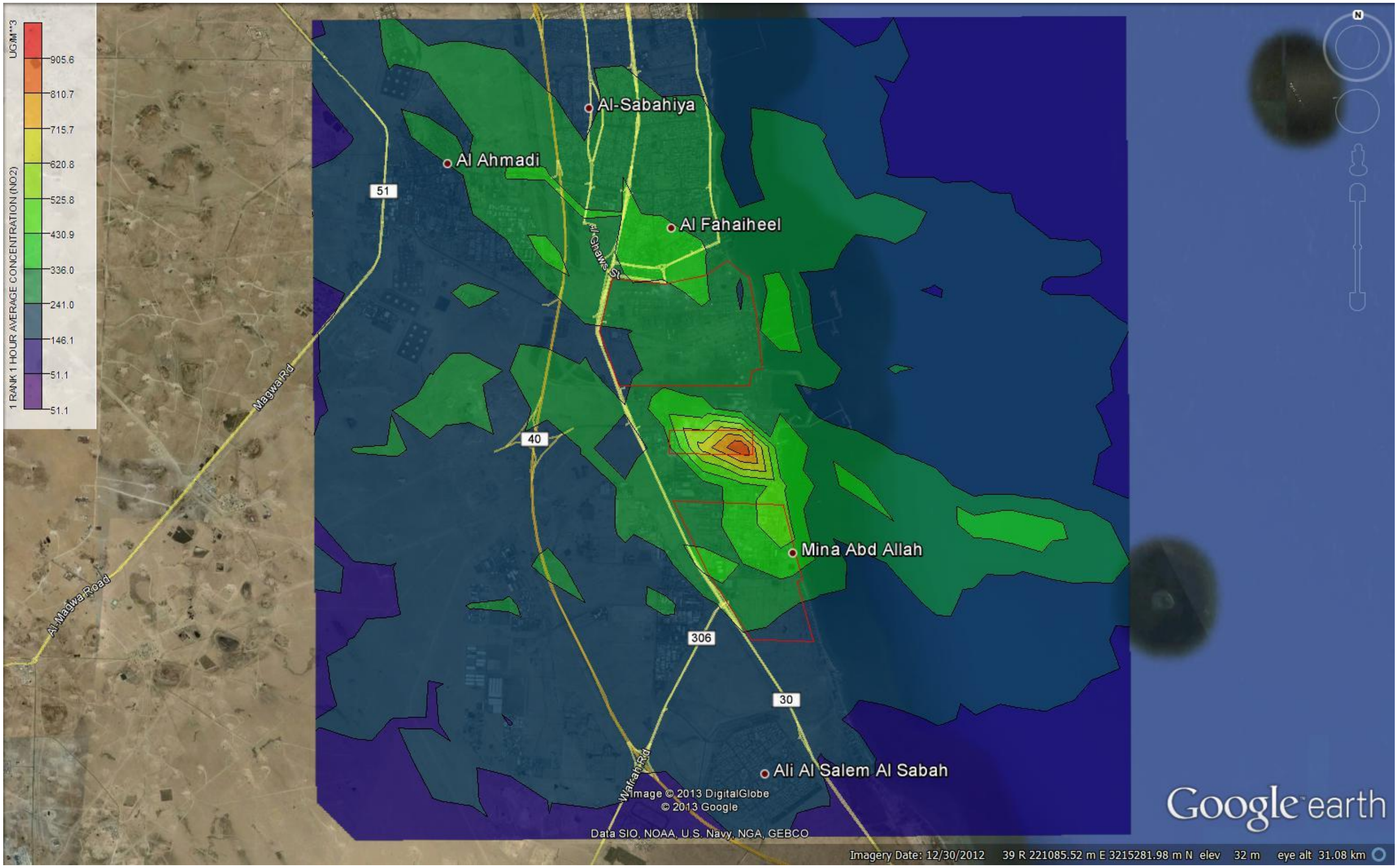

FIGURE 10: NO_2 (μg/m^3) HOURLY GLC'S FOR SCENARIO 1

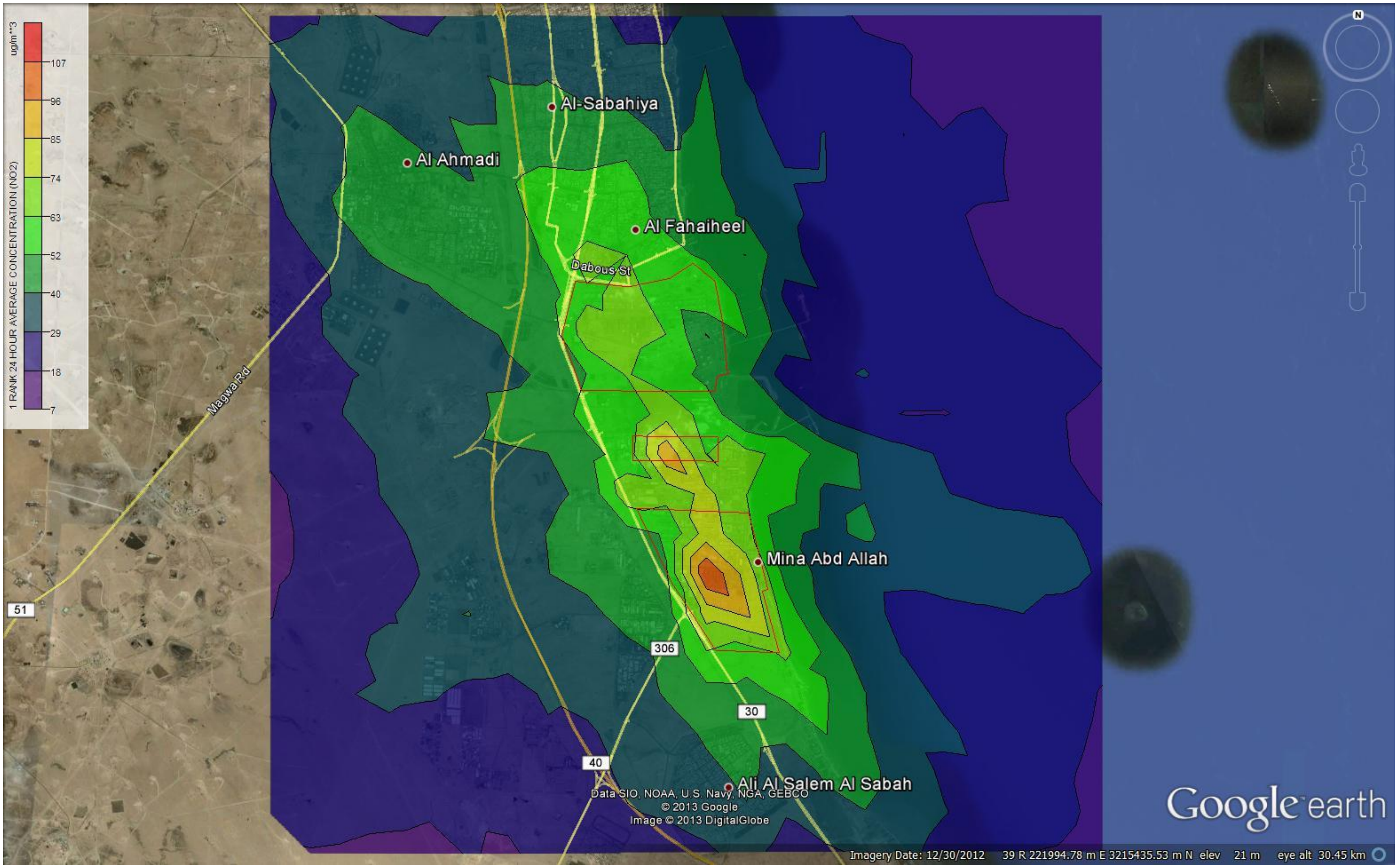

FIGURE 11: NO_2 ($\mu g/m^3$) DAILY GLC'S FOR SCENARIO 1

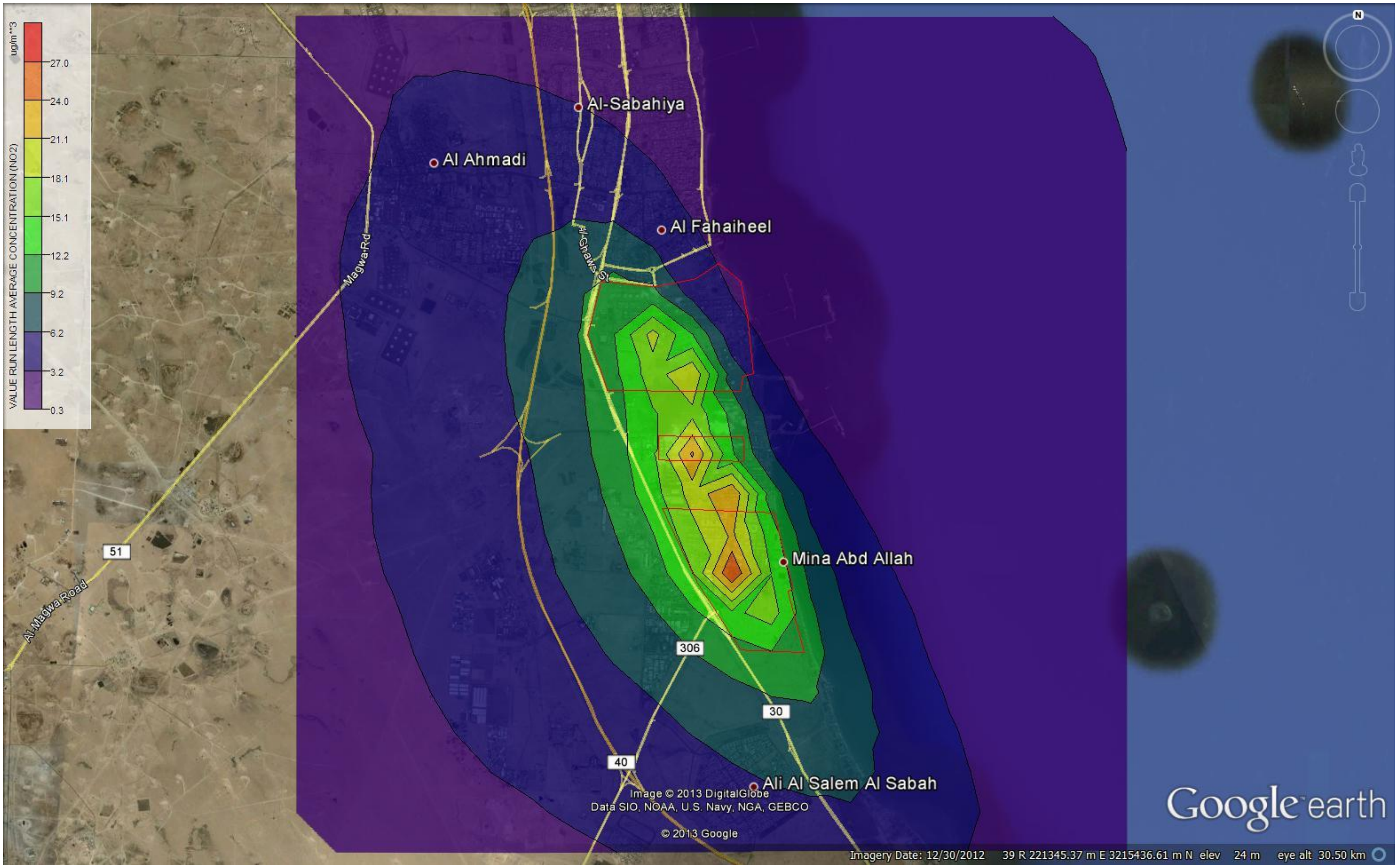

FIGURE 12: NO_2 ($\mu g/m^3$) ANNUAL GLC'S FOR SCENARIO 1

Table 9 lists the highest predicted hourly, daily and annual NO_2 G-LC's for entire three refineries complex.

TABLE 9: HIGHEST NO_2 GLC'S AT THE DISCRETE RECEPTORS FOR DIFFERENT AVERAGING PERIOD

Receptors	**Highest Average Concentration (µg/m³)**		
	Hourly	**Daily**	**Annual**
Mina Al Ahmadi Refinery	319.40	69.09	20.82
Shuaiba Refinery	905.59	93.34	24.46
Mina Abdullah Refinery	497.97	107.42	27.01
K-EPA Limit	**225**	**112**	**67**

Table 10 lists the highest predicted hourly, daily and annual NO_2 G-LC's at the residential area close to the refineries area

TABLE 10: HIGHEST NO_2 GLC'S FOR RESIDENTIAL AREA

Receptor	**Highest Average Concentration (µg/m³)**		
	Hourly	**Daily**	**Annual**
Fahaheel	390.31	67.98	8.09
Ahmadi	340.52	48.44	5.33
Ali Sabah Al Salem	177.28	43.16	6.55
Sabahiya	335.75	53.76	4.92
Mangaf	326.13	54.54	3.53
K-EPA Limit	**225**	**112**	**67**

Findings:

Average hourly of NO_2 exceeds the K-EPA limit within the industrial complex and the residential areas except Ali Sabah Al Salem. Daily and annual averages for NO_2 are within K-EPA limit.

Scenario 2: CFP Normal Emissions

This modeling run is for the base case after completion of project which reflects post CFP scenario after retirement/decommissioning of all SHU process units and some process units at MAA and MAB.

Table 11 below lists out the source data used for modeling

TABLE 11: INPUT FOR SCENARIOS 2

Stack ID	Stack Height	Exit Diameter	Exit Velocity	Exit Temp.	NOx	SO_2	UTM Coordinates	
	[m]	[m]	[m/s]	[K]	g/s	g/s	Easting	Northing
Mina Abdullah								
H121012	55.77	2.11	4.57	505.37	0.2973	0.003567	222685	3211667
H122012	55.77	2.11	4.57	505.37	0.367	0.004404	222702	3211666
H12103	36.57	1.07	5.18	677.59	0.1058	0.00127	222732.9	3211766
H13101	51.82	1.98	10.3	449.82	1.074	0.01065	222716.1	3211935
H13201	51.82	1.98	10.3	449.82	1.097	0.01009	222764.7	3211932
H14101	38.1	1.37	6.95	527.59	0.3779	0.004535	222507.4	3211682
H14102	38.1	1.37	6.95	527.59	0.3107	0.003728	222478.3	3211682
H14103	53.34	1.63	14.69	449.81	2.8215	0.01209	222557.9	3211677
H15101	38.1	1.22	7.62	647.59	0.1236	0.001483	222957.3	3211725
H16101	38.1	1.14	7.32	688.71	0.1197	0.001437	222890.2	3211723
H17101	30.48	0.91	4.27	455.37	0.09842	0.001181	222849.8	3211747
H18101	79.25	3.02	7.1	394.26	4.4673	0.01915	222505	3211950
H18201	79.25	3.02	7.1	394.26	4.7025	0.02015	222435	3211955
H18301	79.25	3.02	7.1	394.26	4.7025	0.02015	222355.6	3211959
H20101	60.96	1.88	5.18	449.82	0.5295	0.006354	222857.2	3211934
H20102	60.96	1.88	5.18	449.82	0.4836	0.005804	222858.7	3211958
H20201	60.96	1.88	5.18	449.82	0.5295	0.006354	222990.1	3211924
H20202	60.96	1.88	5.18	449.82	0.4836	0.005804	222991.3	3211949
B24104	110	2.13	7.68	538.71	0	6.735	222148.4	3211799
B24204	110	2.13	7.68	538.71	0	6.7351	222145.8	3211750
B06101	18.28	1.52	5.42	450	2.1412	0.0578	222378.8	3212728
B31101A	18.28	1.82	5.88	450	3.8464	0.054	222291.1	3212290
B31101B	18.28	1.82	6	450	4.0856	0.0578	222272.7	3212291
B31101C	18.28	1.82	5.94	450	7.1412	0.054	222254.3	3212292
B31102A	30.48	1.19	12.03	450	2.0717	0.0385	222279.5	3212206
B31102B	30.48	1.19	13.86	450	2.7391	0.0462	222262.5	3212207
FL01102	79.97	0.91	0.54	1644	0.1988	0.261	221857.4	3212699
FL01103	79.97	0.91	0.54	1644	0.1988	0.261	221851	3212599
FL23101	92.83	0.61	0.16	1644	0.00252	0.01406	222125.1	3211673
FL23102	92.89	0.61	0.16	1644	0.00252	0.01406	222178.8	3211674
Mina Abdullah - CFP Sources								
111F0101	61	4.5	4.4	450	4.9285	0.43	222196.2	3211177
112F0101	65	1.5	7.6	423	0.723	0.16	222303.1	3211014

Stack ID	Stack Height	Exit Diameter	Exit Velocity	Exit Temp.	NOx	SO_2	UTM Coordinates	
	[m]	[m]	[m/s]	[K]	g/s	g/s	Easting	Northing
112F0201	65	1.5	7.6	423	0.723	0.16	222309.1	3211151
112F0401	65	2.2	7.4	423	1.6917	0.31	222319.9	3211330
212F0101	65	1.5	7.6	423	0.722	0.16	222490.3	3210998
212F0401	65	1.6	7.3	423	0.8464	0.17	222498.6	3211213
114F0101	61	1.6	5.1	432	0.27	0.05	222382.1	3210672
114F0102	61	1.7	5.2	432	0.37	0.06	222390.4	3210782
114F0103	61	4	10.1	432	3.2052	0.28	222398.3	3210879
115F0101	61	1.3	7.6	686	0.09	0.02	222205	3210851
116F0101	61	1.8	10	489	0.49	0.09	222299.8	3210854
117F0101	61	0.5	7.6	670	0.03	0.01	222694.6	3210985
118F0101	61	5	9.7	428	10.09	1.19	222866.4	3211001
118F0201	61	5	9.7	428	10.09	1.19	223005.9	3210996
123F0132	61	1.7	15	543	1.67	1.47	223195.2	3210805
123F0232	61	1.7	15	543	1.67	1.47	223328.8	3210810
123F0332	61	1.7	15	543	0.5154	1.47	223261.8	3210737
127F0101	61	2.6	10.8	466	1.14	0.2	222663.4	3210826
127F0105	61	0.9	10.5	556	0.1	0.02	222668.1	3210880
213F0101	61	2.2	5.7	477	1.4145	0.12	222615.8	3211001
H11101	70	2.5	13	458	4.1211	1.8	222397.4	3211649
131F201A	65	2.2	5.3	448	2.0121	0.18	222684.8	3211144
131F201B	65	2.2	5.3	448	2.0121	0.18	222685.8	3211185
131F201C	65	2.2	5.3	448	2.0121	0.18	222689.9	3211240
131F201D	65	2.2	5.3	448	2.0121	0.18	222692.6	3211290
131F201E	65	2.2	5.3	448	2.0121	0.18	222692	3211325
131F201F	65	2.2	5.3	448	2.0121	0.18	222652	3211255
156A0209	20	0.9	6.8	1223	0.06	0.01	223302.1	3212080
214F0101	61	3.7	4.3	409	3.417	0.36	222476.4	3210775
216F0101	61	1.6	6.9	450	0.59	0.1	221951.9	3211753
118F0301	61	4.9	10.2	428	10.09	1.19	222953	3211068
Mina Al Ahmadi								
312F101	58.83	3.07	4.24	533.15	1.9047	0.004082	221612.7	3217483
312F102	52.73	2.85	4.33	533.15	1.2843	0.002752	221614.3	3217468
312F103	58.83	2.41	3.88	533.15	0.5369	0.001151	221618.4	3217458
313F101	36.88	1.07	3.18	533.15	0.00205	0.0000123	221615.6	3217443
313F102	36.88	1.07	2.8	533.15	0.00457	0.0000274	221618	3217436
332F301	58.83	3.07	4.24	533.15	1.9513	0.004181	221686.7	3217273
332F302	52.73	2.85	4.33	533.15	1.3796	0.002956	221691.5	3217260
332F303	58.83	2.41	3.88	533.15	0.5519	0.001183	221695	3217249
333F301	36.88	1.07	3.18	533.15	0.00194	0.0000116	221691.9	3217235
333F302	36.88	1.07	2.8	533.15	0.00552	0.0000331	221692.7	3217226
H48001	79.25	3.58	3.62	394.26	11.2164	0.02404	220834	3218376
H49001	79.25	3.58	3.62	394.26	10.8108	0.02317	220789.7	3218373
H88001	79.25	3.58	3.62	394.26	10.56	0.02263	220343.2	3218336
H89001	79.25	3.58	3.62	394.26	9.0942	0.01949	220299.7	3218333
H83001	60.96	2.9	4.11	444.26	5.1555	0.01105	220080.4	3218305

Stack ID	Stack Height	Exit Diameter	Exit Velocity	Exit Temp.	NOx	SO_2	UTM Coordinates	
	[m]	[m]	[m/s]	[K]	g/s	g/s	Easting	Northing
H84320	60.96	2.39	6.24	433.15	4.9533	0.01061	219939.2	3218296
H84100	44.81	1.37	5.94	477.59	0.7296	0.004378	219995.2	3218073
H84200	44.81	1.37	5.94	477.59	0.6476	0.003885	219959.1	3218071
41H001	60.96	1.73	3.42	466.48	0.5517	0.00331	220938.2	3218209
41H002	62.48	2.13	4.38	466.48	1.8033	0.003864	220939.7	3218193
41H003	54.86	1.25	5.49	466.48	0.1791	0.001075	220909.3	3218385
42H001	60.96	1.73	3.42	466.48	0.526	0.003156	220793.5	3218197
42H002	62.48	2.13	4.38	466.48	1.9691	0.004219	220794.8	3218181
81H001	60.96	1.73	3.42	466.48	0.5183	0.00311	220419.9	3218344
81H002	62.48	2.13	4.38	466.48	1.9186	0.004111	220448.5	3218171
81H003	54.86	1.25	5.49	466.48	0.1711	0.001026	220449.6	3218153
82H001	60.96	1.73	3.42	466.48	0.4554	0.002732	220304.5	3218141
82H002	60.96	2.13	4.38	466.48	1.7656	0.003783	220302.9	3218158
H40001	80.77	2.92	10.82	455.37	8.794	0.03769	221105.8	3218398
H80001	60.96	3.05	5.24	444.26	3.7577	0.0161	221242.2	3218186
H39001	60.96	2.39	2.56	488.71	0.1733	0.002079	222248.5	3218734
H12001	32	2.64	13.24	1033.15	0.2991	0.001795	222362	3218692
H43001	45.72	1.22	6.34	672.04	0.2305	0.001383	221033.4	3218331
H44001	60.96	1.78	6.3	455.37	0.2493	0.001496	220966	3218382
H58001	75.9	0.17	6.3	255.37	0.4792	0.002875	220757.3	3218375
B29011	45.72	2.29	20.04	472.04	5.51	0.02806	221346.9	3217216
B29013	45.72	2.29	20.04	472.04	4.44	0.02393	221339.4	3217242
B29014	45.72	2.29	20.04	472.04	4.07	0.02745	221333.5	3217253
B29001	45.72	2.29	22.18	466.48	3.321	0.02038	221353.1	3217204
B29101	45.72	2.29	22.18	466.48	3.589	0.02331	221248	3217237
B29701	45.72	2.11	22.18	466.48	10.3247	0.02212	221171	3217223
ST86301	79.25	2.29	16.26	547.04	14.288	48.79	219828.5	3218028
ST93001	79.25	1.55	16.75	593.15	0	19.948	220603.2	3218264
ST54001	79.25	1.22	30.48	599.82	0	17.426	220621.9	3218130
ST20601	79.25	1.83	16.76	600	0	28.86	221732.4	3216730
ST62401	110.9	0.71	0.01	1273.15	0.00351	0.3162	220710.5	3217864
ST62301	80.23	0.76	85.21	1273.15	0.3472	0.1688	219153.6	3218655
ST119800	71.44	0.76	85.21	1273.15	0.8676	0.4485	221222.2	3217933
ST39001	85.7	0.56	96.28	1273.15	3.9798	2.903	222422.5	3218962
S10301	93.69	1.02	94.18	1273.15	0.02646	0.01323	221346.2	3216648
36F001A	94.03	1.22	75.63	1273.15	0.03441	0.2944	221284.2	3216885
36F001B	94.04	1.22	75.63	1273.15	0.03441	0.2944	221176.4	3216981
36F002A	62.83	1.22	13.75	1273.15	0.01744	0.1481	222410.2	3217328
36F002B	62.83	1.22	13.75	1273.15	0.01744	0.1481	222358	3217471
B29012	45.72	2.29	20.04	472	10.9777	0.0235	221323.7	3217227
H231002	40	1.46	8.5	656	1.127	0.187	220569.2	3217334
H234001	40	1.46	8.5	656	0.736	0.187	220597.3	3217334
H231001A	40	3.4	14.7	448	0.578	0.702	220558.3	3217258
H231001B	40	3.4	14.7	448	0.578	0.702	220559	3217207
H235001A	40	3.4	14.7	448	0.578	0.702	220558.2	3217169

Stack ID	Stack Height	Exit Diameter	Exit Velocity	Exit Temp.	NOx	SO_2	UTM Coordinates	
	[m]	[m]	[m/s]	[K]	g/s	g/s	Easting	Northing
H235001B	40	3.4	14.7	448	0.578	0.702	220558.3	3217090
H331002	40	1.46	8.5	656	1.127	0.187	220581	3216972
H334001	40	1.46	8.5	656	0.736	0.187	220553	3216971
H331001A	40	3.4	14.7	448	0.578	0.702	220565	3216930
H331001B	40	3.4	14.7	448	0.578	0.702	220567	3216871
H335001A	40	3.4	14.7	448	0.578	0.702	220563	3216807
H335001B	40	3.4	14.7	448	0.578	0.702	220565	3216739
H25101	31.6	1.3	3.2	589	0.305	0.18	221364.6	3218106
H26101	31.6	1.3	3.2	589	0.305	0.18	221834.3	3218285
Mina Al Ahmadi – CFP Sources								
135F0101	61	0.5	7.6	594	0.1054	0.01	219762.7	3216930
136F0201	61	3.3	4.7	423	2.6887	0.28	219747.3	3216825
137F0101	61	2.3	6.8	455	1.875	0.17	221711.4	3217075
141F0201	65	1.5	7.4	423	0.5797	0.13	219766.3	3217036
141F0401	65	1.5	7.4	423	0.8	0.17	219746.2	3217238
148F0301	61	2.8	10.3	427	3.51	0.03	219656	3217062
129F201A	65	4.1	5.3	566	3.8186	0.3	219307.5	3216798
129F201B	65	4.1	5.3	566	3.8186	0.3	219301.1	3216843
129F201C	65	4.1	5.3	566	3.8186	0.3	219293.4	3216895
151F0132	61	1.4	14	543	0.76	0.67	219438	3217048
152F0132	61	1.4	14	543	0.76	0.67	219532.6	3217050
183F0101	61	2.1	5.7	477	1.7918	0.16	219878.6	3217067
186F0201	65	1	6.3	636	0.1	0.02	219502.5	3218006
186F0202	65	1.1	6.3	645	0.13	0.02	219491.4	3218113
107F0101	61	1.8	4.2	566	0.37	0.06	221449.3	3218091
107F0102	61	3.5	4.3	461	2.7372	0.29	221536.3	3218101
144F0101	61	1.2	7	602	0.24	0.04	221505.8	3218269

Table 12 summarizes maximum predicted Ground Level Concentrations (GLCs) and their comparison with K-EPA Ambient Air Quality Standards (AAQS). The result reveals that ground level concentrations for NO_2 exceed KEPA limit, however the number of exceeds are only 13 in two years period which satisfies the K-EPA's AAQS Appendix No. 17-1 & 17-2 stating "The hourly average should not occur more than twice during the period of 30 days at the same site". Hence, it meets the K-EPA's AAQS requirement.

However, maximum predicted ground level concentrations for SO_2 meet K-EPA AAQS.

TABLE 12: MODEL RESULTS

Pollutant	Average Period	K-EPA AAQS ($\mu g/m^3$)	Maximum predicted GLC ($\mu g/m^3$)	Location		Maximum No. of Exceeds At a particular location
				UTME (Km)	UTMN (Km)	
SO_2	1 hr	782.5	485.42	221.154	3214.934	0
	24 hr	523.3	41.93	219.154	3217.934	0
	Annual	157	9.98	220.154	3216.934	0
NO_2	1 hr	225	430.48	222.154	3214.934	13
	24 hr	112	67.54	222.154	3212.934	0
	Annual	67	18.68	222.154	3211.934	0

Figures 13 to 15 show pollutant contour plot-files for SO_2. The plot files show most impacted areas based on predicted pollutant concentrations generated by the model run. Color coded scale in the figures indicated the various impact concentrations.

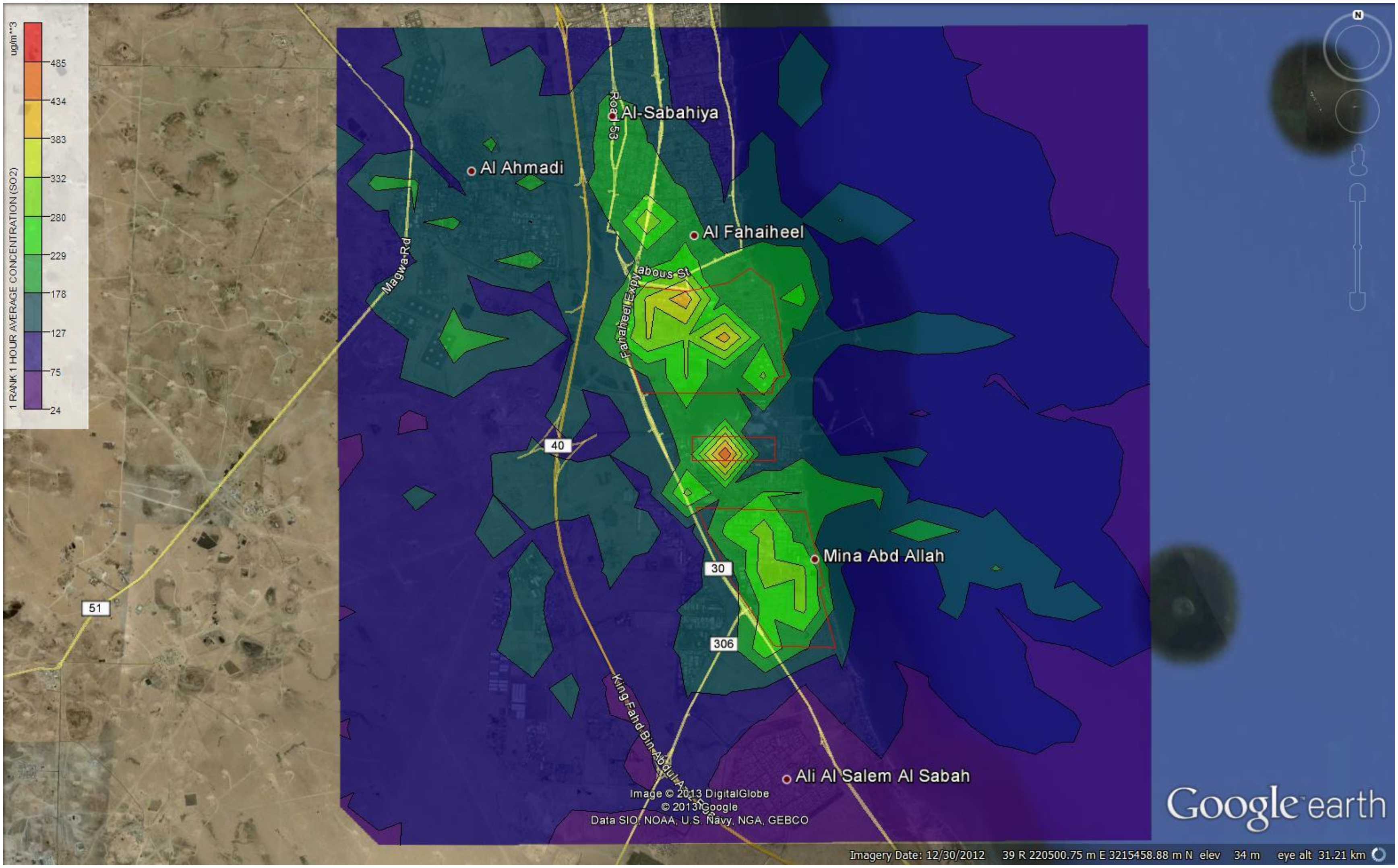

FIGURE 13 : SO_2 ($\mu g/m^3$) HOURLY GLC'S FOR SCENARIO 2

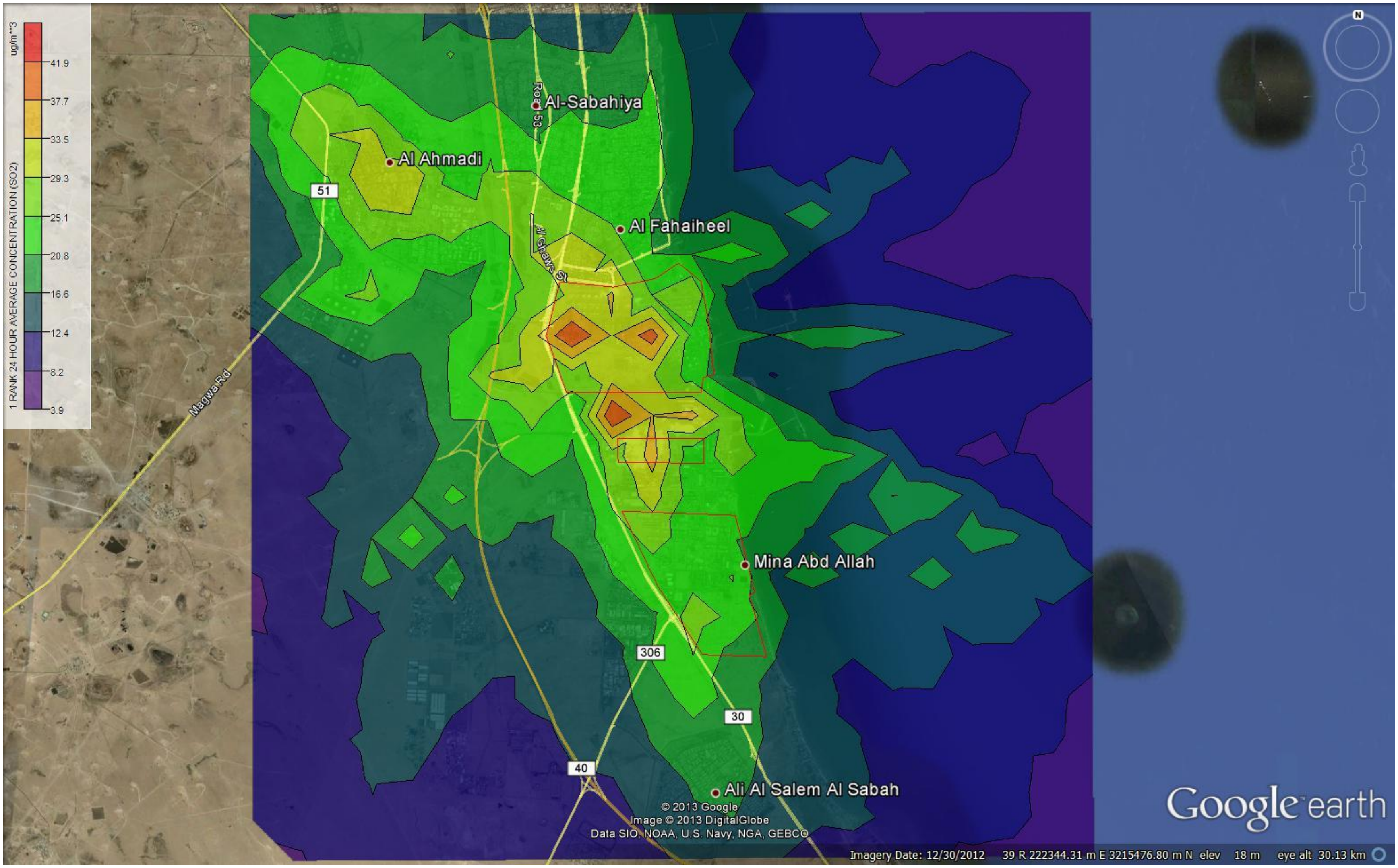

FIGURE 14: SO_2 ($\mu g/m^3$) DAILY GLC'S FOR SCENARIO 2

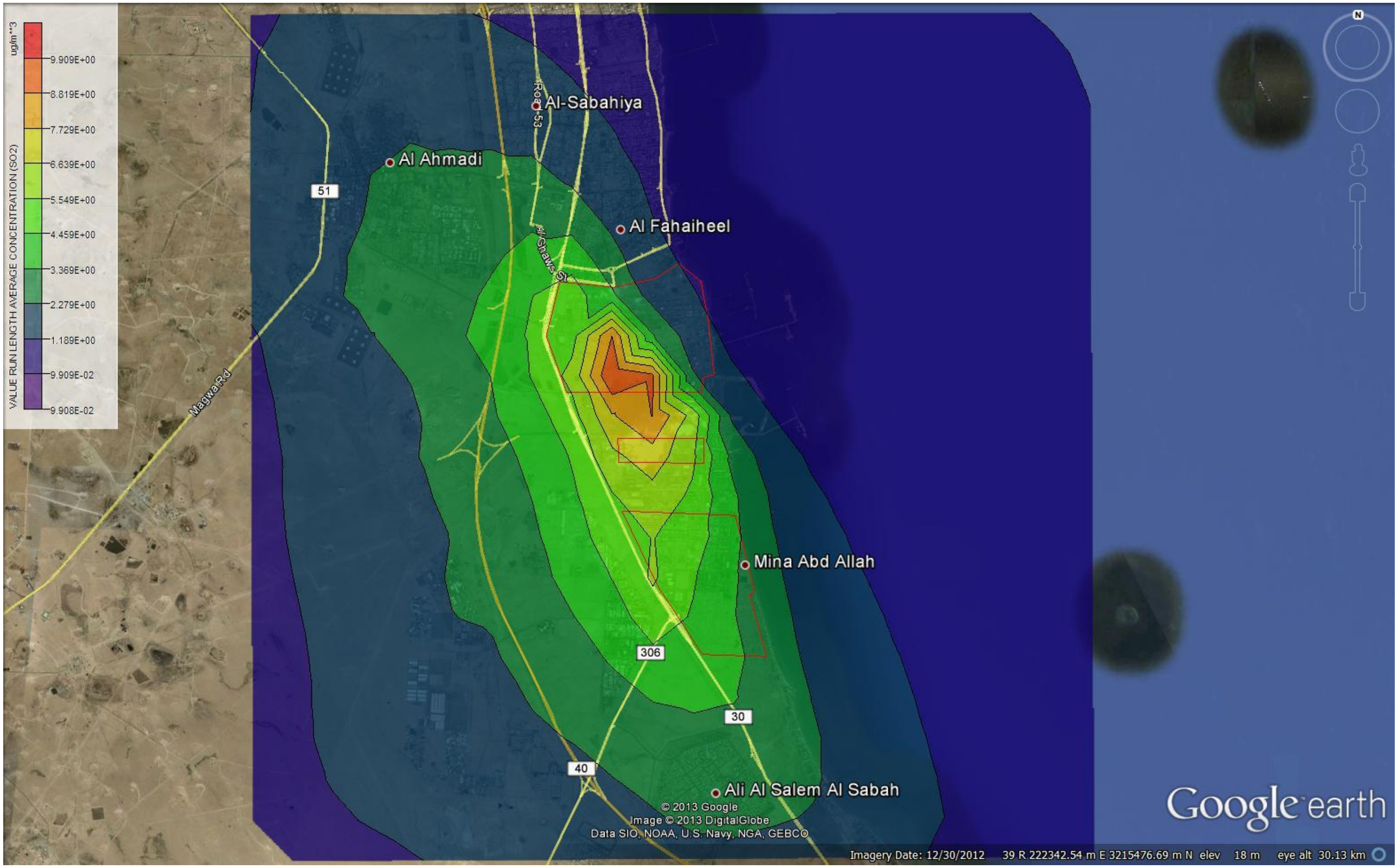

FIGURE 15: SO_2 ($\mu g/m^3$) ANNUAL GLC'S FOR SCENARIO 2

Table 13 lists the highest predicted hourly, daily and annual SO_2 G-LC's for three refineries complex.

TABLE 13: HIGHEST SO_2 GLC'S AT THE DISCRETE RECEPTORS FOR DIFFERENT AVERAGING PERIOD

Receptors	Highest Average Concentration (µg/m³)		
	Hourly	**Daily**	**Annual**
Mina Al Ahmadi Refinery	414.78	33.89	9.91
Shuaiba Refinery	485.42	35.17	7.24
Mina Abdullah Refinery	311.55	27.10	5.60
K-EPA Limit	**782.5**	**523.3**	**157**

Table 14 lists the highest predicted hourly, daily and annual SO_2 GLC's at the residential area close to the refineries area

TABLE 14: HIGHEST SO_2 GLC'S FOR RESIDENTIAL AREAS

Receptor	Highest Average Concentration(µg/m³)		
	Hourly	**Daily**	**Annual**
Fahaheel	248.78	32.47	3.97
Ahmadi	195.58	33.34	2.83
Ali Sabah Al Salem	68.61	17.95	2.77
Sabahiya	204.59	25.50	2.53
Mangaf	172.79	23.46	1.53
K-EPA Limit	**444**	**157**	**80**

Findings:

On comparison of the above results to K-EPA AAQ standards mentioned in table 1 and table 2 hourly, daily and annual average GLC's of SO_2 meet K-EPA limit in industrial as well as residential areas.

Figures 16 to 18 show pollutant contour plot-files for NO_2. The plot files show most impacted areas based on predicted pollutant concentrations generated by the model run. Color coded scale in the figures indicated the various impact concentrations.

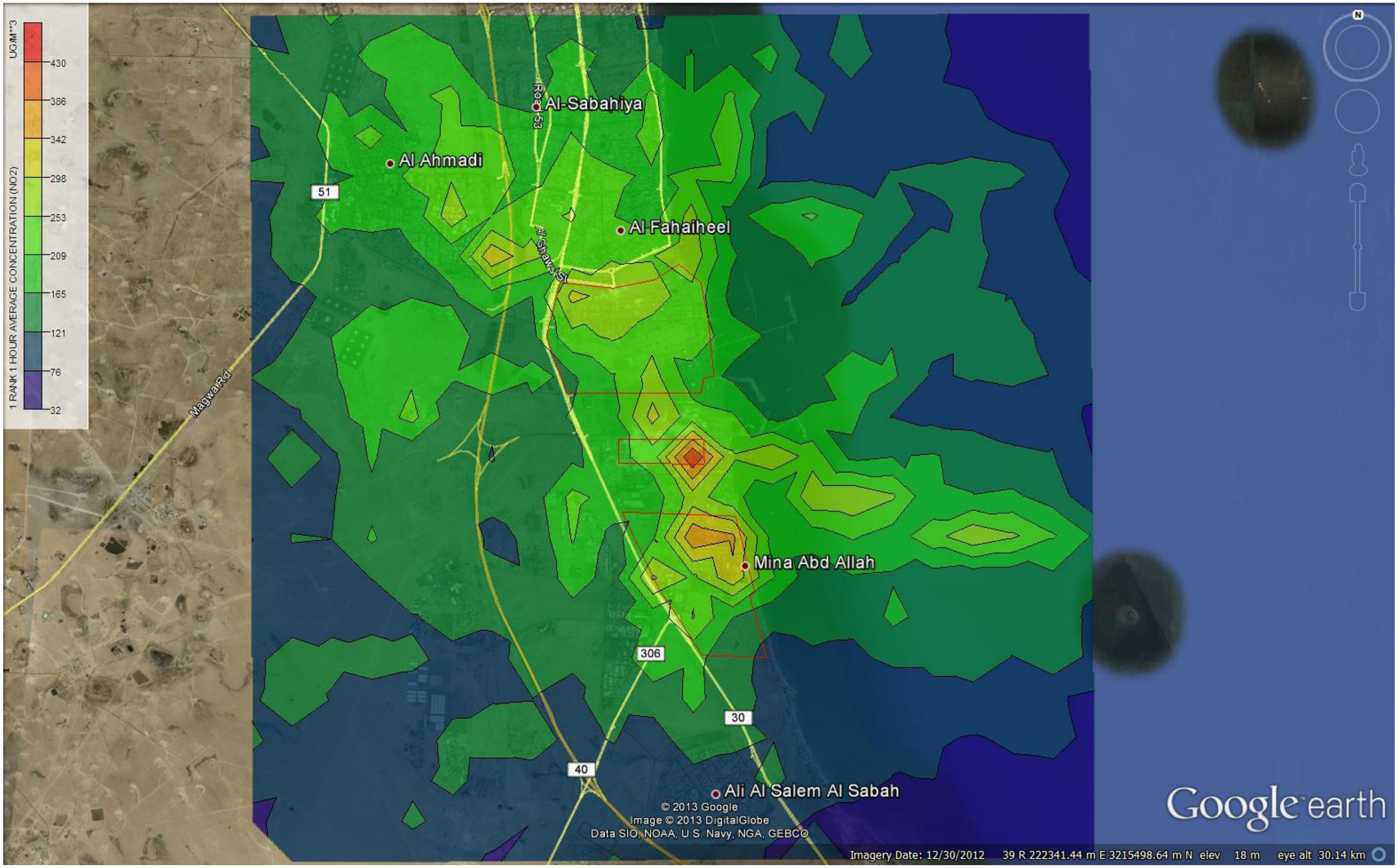

FIGURE 16: NO_2 (μg/m^3) HOURLY GLC'S FOR SCENARIO 2

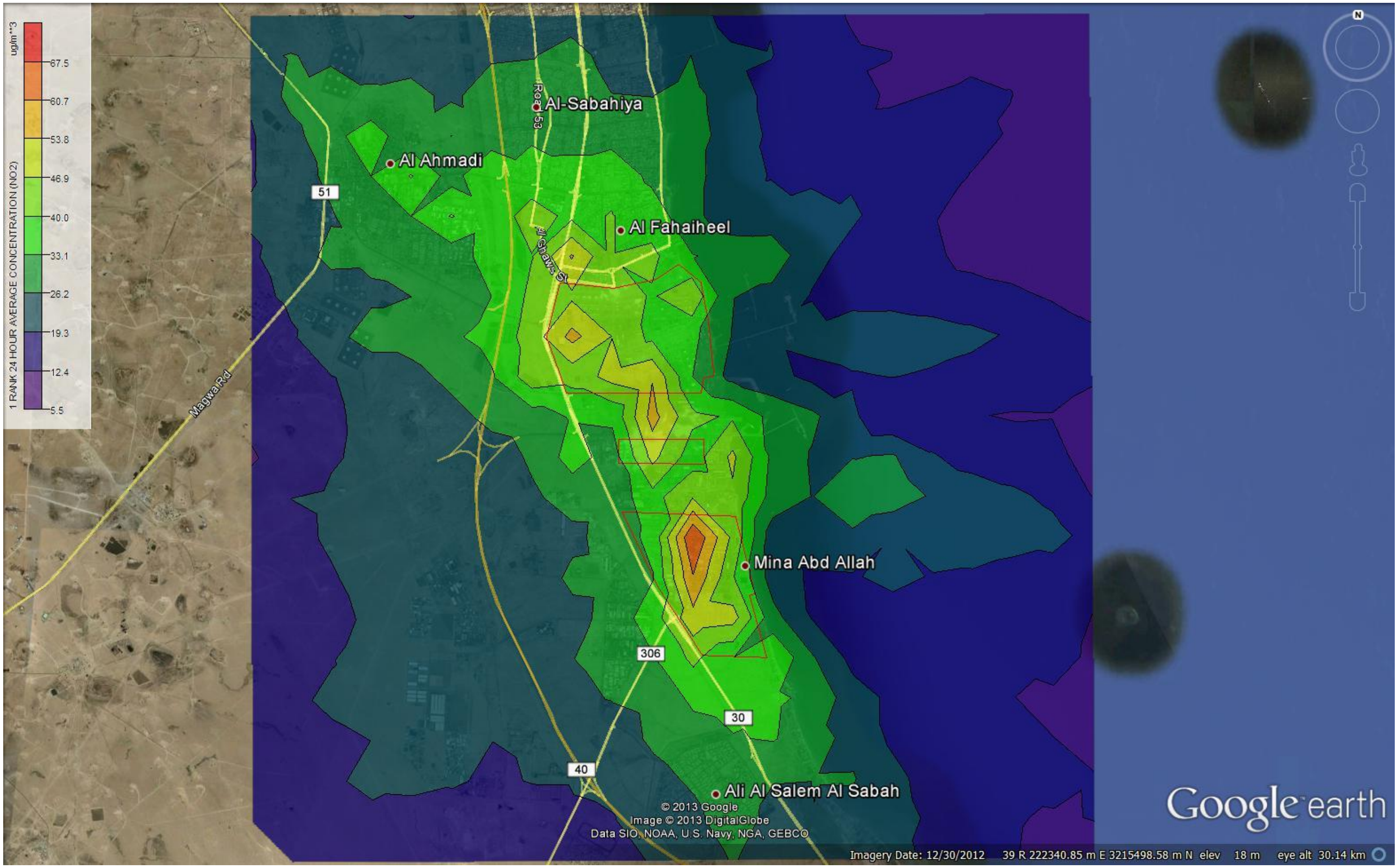

FIGURE 17: NO_2 ($\mu g/m^3$) DAILY GLC'S FOR SCENARIO 2

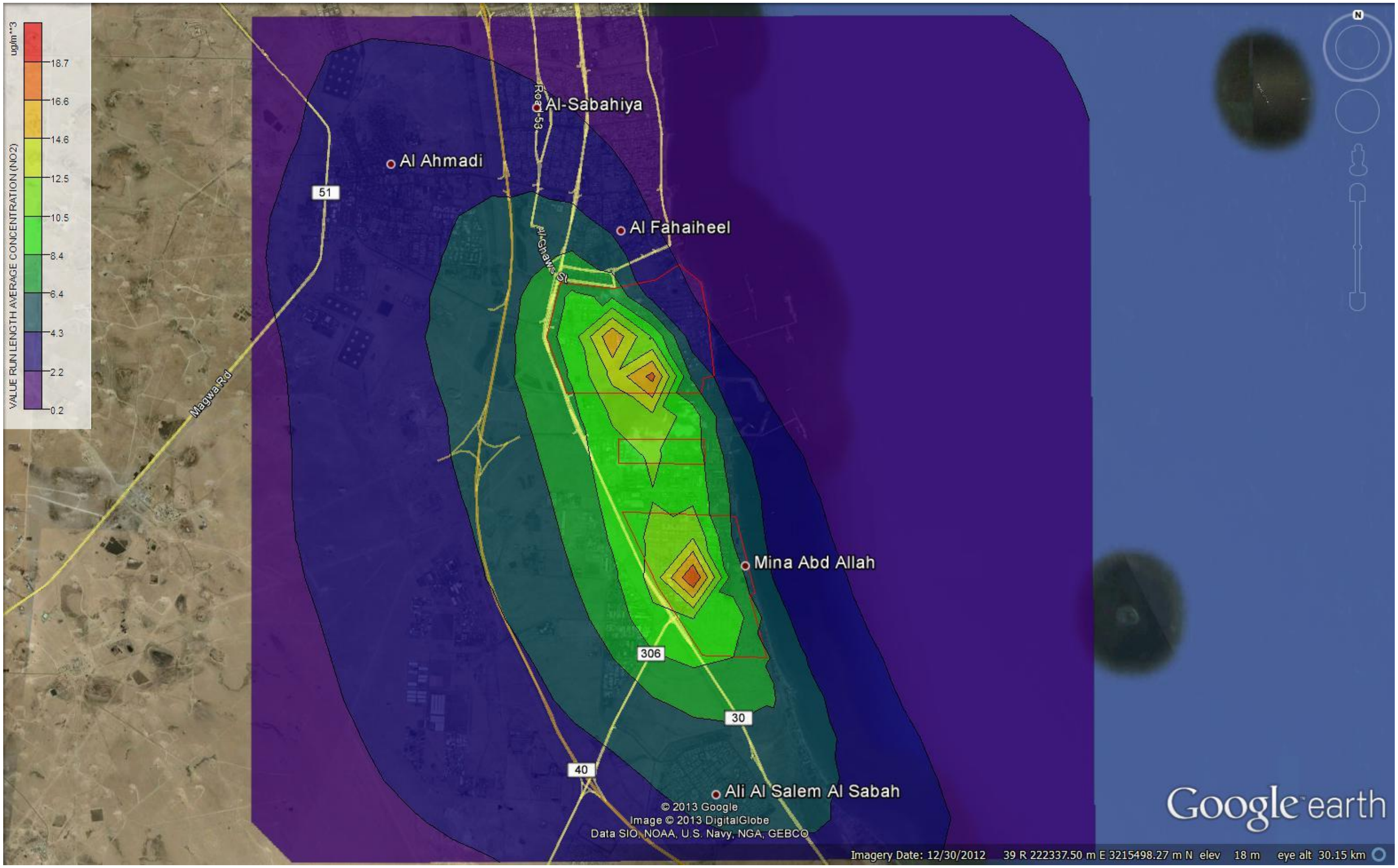

FIGURE 18: NO_2 ($\mu g/m^3$) ANNUAL GLC'S FOR SCENARIO 2

Table 15 lists the highest predicted hourly, daily and annual NO_2 G-LC's for entire three refineries complex.

TABLE 15: HIGHEST NO_2 GLC'S AT THE DISCRETE RECEPTORS FOR DIFFERENT AVERAGING PERIOD

Receptors	Highest Average Concentration (μg/m³)			Maximum No. of Exceeds
	Hourly	Daily	Annual	
Mina Al Ahmadi Refinery	309.66	56.01	16.36	3
Shuaiba Refinery	430.48	48.93	10.71	2
Mina Abdullah Refinery	378.12	67.54	18.68	13
K-EPA Limit	**225**	**112**	**67**	**48**

Table 16 lists the highest predicted hourly, daily and annual NO_2 G-LC's at the residential area close to the refineries area

TABLE 16: HIGHEST NO_2 GLC'S FOR RESIDENTIAL AREA

Receptor	Highest Average Concentration (μg/m³)			Maximum No. of Exceeds
	Hourly	Daily	Annual	
Fahaheel	251.12	54.42	6.60	1
Ahmadi	281.48	40.44	4.40	1
Ali Sabah Al Salem	119.61	32.05	5.21	0
Sabahiya	235.06	35.76	3.94	1
Mangaf	217.30	37.83	2.67	1
K-EPA Limit	**225**	**112**	**67**	**48**

Findings:

The result reveals that average hourly ground level concentrations for NO_2 exceed KEPA limit in industrial as well as residential areas.

In industrial area Mina Abdullah has maximum number of exceeds with 13 in two years period which satisfies the K-EPA's AAQS Appendix No. 17-1 & 17-2 stating "The hourly average should not occur more than twice during the period of 30 days at the same site". Hence, it meets the K-EPA's AAQS requirement.

Exceedances in residential areas also satisfy K-EPA's AAQS Appendix No. 17-1 & 17-2 stating "The hourly average should not occur more than twice during the period of 30 days at the same site". Hence, it meets the K-EPA's AAQS requirement.

Scenario 3: CFP maximum Emissions

In this scenario designed unit specification has been considered. In general emissions are significantly less for normal scenario.

TABLE 17: MODEL INPUT FOR SCENARIO 3

Stack ID	Stack Height	Exit Diameter	Exit Velocity	Exit Temp.	NOx	SO_2	UTM Coordinates	
	[m]	[m]	[m/s]	[K]	g/s	g/s	Easting	Northing
Mina Abdullah								
H121012	55.77	2.11	4.57	505.37	0.2973	0.003567	222685	3211667
H122012	55.77	2.11	4.57	505.37	0.367	0.004404	222702	3211666
H12103	36.57	1.07	5.18	677.59	0.1058	0.00127	222732.9	3211766
H13101	51.82	1.98	10.3	449.82	1.074	0.01065	222716.1	3211935
H13201	51.82	1.98	10.3	449.82	1.097	0.01009	222764.7	3211932
H14101	38.1	1.37	6.95	527.59	0.3779	0.004535	222507.4	3211682
H14102	38.1	1.37	6.95	527.59	0.3107	0.003728	222478.3	3211682
H14103	53.34	1.63	14.69	449.81	2.8215	0.01209	222557.9	3211677
H15101	38.1	1.22	7.62	647.59	0.1236	0.001483	222957.3	3211725
H16101	38.1	1.14	7.32	688.71	0.1197	0.001437	222890.2	3211723
H17101	30.48	0.91	4.27	455.37	0.09842	0.001181	222849.8	3211747
H18101	79.25	3.02	7.1	394.26	4.4673	0.01915	222505	3211950
H18201	79.25	3.02	7.1	394.26	4.7025	0.02015	222435	3211955
H18301	79.25	3.02	7.1	394.26	4.7025	0.02015	222355.6	3211959
H20101	60.96	1.88	5.18	449.82	0.5295	0.006354	222857.2	3211934
H20102	60.96	1.88	5.18	449.82	0.4836	0.005804	222858.7	3211958
H20201	60.96	1.88	5.18	449.82	0.5295	0.006354	222990.1	3211924
H20202	60.96	1.88	5.18	449.82	0.4836	0.005804	222991.3	3211949
B24104	110	2.13	7.68	538.71	0	6.735	222148.4	3211799
B24204	110	2.13	7.68	538.71	0	6.7351	222145.8	3211750
B06101	18.28	1.52	5.42	450	2.1412	0.0578	222378.8	3212728
B31101A	18.28	1.82	5.88	450	3.8464	0.054	222291.1	3212290
B31101B	18.28	1.82	6	450	4.0856	0.0578	222272.7	3212291
B31101C	18.28	1.82	5.94	450	7.1412	0.054	222254.3	3212292
B31102A	30.48	1.19	12.03	450	2.0717	0.0385	222279.5	3212206
B31102B	30.48	1.19	13.86	450	2.7391	0.0462	222262.5	3212207
FL01102	79.97	0.91	0.54	1644	0.1988	0.261	221857.4	3212699
FL01103	79.97	0.91	0.54	1644	0.1988	0.261	221851	3212599
FL23101	92.83	0.61	0.16	1644	0.00252	0.01406	222125.1	3211673
FL23102	92.89	0.61	0.16	1644	0.00252	0.01406	222178.8	3211674
Mina Abdullah – CFP Sources								
111F0101	61	4.5	4.4	450	7.8913	11.3	222196.2	3211177
112F0101	65	1.5	7.6	423	0.9114	0.2	222303.1	3211014
112F0201	65	1.5	7.6	423	0.9114	0.2	222309.1	3211151
112F0401	65	2.2	7.4	423	2.7452	3.8	222319.9	3211330
212F0101	65	1.5	7.6	423	0.9101	0.2	222490.3	3210998
212F0401	65	1.6	7.3	423	0.8167	1.9	222498.6	3211213

Stack ID	Stack Height	Exit Diameter	Exit Velocity	Exit Temp.	NOx	SO_2	UTM Coordinates	
	[m]	[m]	[m/s]	[K]	g/s	g/s	Easting	Northing
114F0101	61	1.6	5.1	432	0.3	0.1	222382.1	3210672
114F0102	61	1.7	5.2	432	0.4	0.1	222390.4	3210782
114F0103	61	4	10.1	432	3.872	0.3	222398.3	3210879
115F0101	61	1.3	7.6	686	0.1	0.03	222205	3210851
116F0101	61	1.8	10	489	1.7	0.1	222299.8	3210854
117F0101	61	0.5	7.6	670	0.03	0.00001	222694.6	3210985
118F0101	61	5	9.7	428	12.1	1.4	222866.4	3211001
118F0201	61	5	9.7	428	12.1	1.4	223005.9	3210996
123F0132	61	1.7	15	543	2.4	7.08	223195.2	3210805
123F0232	61	1.7	15	543	2.4	7.08	223328.8	3210810
123F0332	61	1.7	15	543	2.4	7.08	223261.8	3210737
127F0101	61	2.6	10.8	466	1.4	0.2	222663.4	3210826
127F0105	61	0.9	10.5	556	0.1	0.03	222668.1	3210880
213F0101	61	2.2	5.7	477	1.7232	0.1	222615.8	3211001
H11101	70	2.5	13	458	15.8569	59.9	222397.4	3211649
131F201A	65	2.2	5.3	448	2.8744	4.1	222684.8	3211144
131F201B	65	2.2	5.3	448	2.8744	4.1	222685.8	3211185
131F201C	65	2.2	5.3	448	2.8744	4.1	222689.9	3211240
131F201D	65	2.2	5.3	448	2.8744	4.1	222692.6	3211290
131F201E	65	2.2	5.3	448	2.8744	4.1	222692	3211325
131F201F	65	2.2	5.3	448	2.8744	4.1	222652	3211255
156A0209	20	0.9	6.8	1223	0.1	0	223302.1	3212080
214F0101	61	3.7	4.3	409	4.0888	0.4	222476.4	3210775
216F0101	61	1.6	6.9	450	2	0.1	221951.9	3211753
118F0301	61	4.9	10.2	428	12.1	1.4	222953	3211068
Mina Al Ahmadi								
312F101	58.83	3.07	4.24	533.15	1.9047	0.004082	221612.7	3217483
312F102	52.73	2.85	4.33	533.15	1.2843	0.002752	221614.3	3217468
312F103	58.83	2.41	3.88	533.15	0.5369	0.001151	221618.4	3217458
313F101	36.88	1.07	3.18	533.15	0.00205	0.0000123	221615.6	3217443
313F102	36.88	1.07	2.8	533.15	0.00457	0.0000274	221618	3217436
332F301	58.83	3.07	4.24	533.15	1.9513	0.004181	221686.7	3217273
332F302	52.73	2.85	4.33	533.15	1.3796	0.002956	221691.5	3217260
332F303	58.83	2.41	3.88	533.15	0.5519	0.001183	221695	3217249
333F301	36.88	1.07	3.18	533.15	0.00194	0.0000116	221691.9	3217235
333F302	36.88	1.07	2.8	533.15	0.00552	0.0000331	221692.7	3217226
H48001	79.25	3.58	3.62	394.26	11.2164	0.02404	220834	3218376
H49001	79.25	3.58	3.62	394.26	10.8108	0.02317	220789.7	3218373
H88001	79.25	3.58	3.62	394.26	10.56	0.02263	220343.2	3218336
H89001	79.25	3.58	3.62	394.26	9.0942	0.01949	220299.7	3218333
H83001	60.96	2.9	4.11	444.26	5.1555	0.01105	220080.4	3218305
H84320	60.96	2.39	6.24	433.15	4.9533	0.01061	219939.2	3218296
H84100	44.81	1.37	5.94	477.59	0.7296	0.004378	219995.2	3218073
H84200	44.81	1.37	5.94	477.59	0.6476	0.003885	219959.1	3218071
41H001	60.96	1.73	3.42	466.48	0.5517	0.00331	220938.2	3218209

Stack ID	Stack Height	Exit Diameter	Exit Velocity	Exit Temp.	NOx	SO_2	UTM Coordinates	
	[m]	[m]	[m/s]	[K]	g/s	g/s	Easting	Northing
41H002	62.48	2.13	4.38	466.48	1.8033	0.003864	220939.7	3218193
41H003	54.86	1.25	5.49	466.48	0.1791	0.001075	220909.3	3218385
42H001	60.96	1.73	3.42	466.48	0.526	0.003156	220793.5	3218197
42H002	62.48	2.13	4.38	466.48	1.9691	0.004219	220794.8	3218181
81H001	60.96	1.73	3.42	466.48	0.5183	0.00311	220419.9	3218344
81H002	62.48	2.13	4.38	466.48	1.9186	0.004111	220448.5	3218171
81H003	54.86	1.25	5.49	466.48	0.1711	0.001026	220449.6	3218153
82H001	60.96	1.73	3.42	466.48	0.4554	0.002732	220304.5	3218141
82H002	60.96	2.13	4.38	466.48	1.7656	0.003783	220302.9	3218158
H40001	80.77	2.92	10.82	455.37	8.794	0.03769	221105.8	3218398
H80001	60.96	3.05	5.24	444.26	3.7577	0.0161	221242.2	3218186
H39001	60.96	2.39	2.56	488.71	0.1733	0.002079	222248.5	3218734
H12001	32	2.64	13.24	1033.15	0.2991	0.001795	222362	3218692
H43001	45.72	1.22	6.34	672.04	0.2305	0.001383	221033.4	3218331
H44001	60.96	1.78	6.3	455.37	0.2493	0.001496	220966	3218382
H58001	75.9	0.17	6.3	255.37	0.4792	0.002875	220757.3	3218375
B29011	45.72	2.29	20.04	472.04	5.51	0.02806	221346.9	3217216
B29013	45.72	2.29	20.04	472.04	4.44	0.02393	221339.4	3217242
B29014	45.72	2.29	20.04	472.04	4.07	0.02745	221333.5	3217253
B29001	45.72	2.29	22.18	466.48	3.321	0.02038	221353.1	3217204
B29101	45.72	2.29	22.18	466.48	3.589	0.02331	221248	3217237
B29701	45.72	2.11	22.18	466.48	10.3247	0.02212	221171	3217223
ST86301	79.25	2.29	16.26	547.04	14.288	48.79	219828.5	3218028
ST93001	79.25	1.55	16.75	593.15	0	19.948	220603.2	3218264
ST54001	79.25	1.22	30.48	599.82	0	17.426	220621.9	3218130
ST20601	79.25	1.83	16.76	600	0	28.86	221732.4	3216730
ST62401	110.9	0.71	0.01	1273.15	0.00351	0.3162	220710.5	3217864
ST62301	80.23	0.76	85.21	1273.15	0.3472	0.1688	219153.6	3218655
ST119800	71.44	0.76	85.21	1273.15	0.8676	0.4485	221222.2	3217933
ST39001	85.7	0.56	96.28	1273.15	3.9798	2.903	222422.5	3218962
S10301	93.69	1.02	94.18	1273.15	0.02646	0.01323	221346.2	3216648
36F001A	94.03	1.22	75.63	1273.15	0.03441	0.2944	221284.2	3216885
36F001B	94.04	1.22	75.63	1273.15	0.03441	0.2944	221176.4	3216981
36F002A	62.83	1.22	13.75	1273.15	0.01744	0.1481	222410.2	3217328
36F002B	62.83	1.22	13.75	1273.15	0.01744	0.1481	222358	3217471
B29012	45.72	2.29	20.04	472	10.9777	0.0235	221323.7	3217227
H231002	40	1.46	8.5	656	1.127	0.187	220523.6	3217305
H234001	40	1.46	8.5	656	0.736	0.187	220547.5	3217309
H231001A	40	3.4	14.7	448	0.578	0.702	220511.8	3217244
H231001B	40	3.4	14.7	448	0.578	0.702	220516.3	3217188
H235001A	40	3.4	14.7	448	0.578	0.702	220520.6	3217139
H235001B	40	3.4	14.7	448	0.578	0.702	220525.7	3217074
H331002	40	1.46	8.5	656	1.127	0.187	220581	3216972
H334001	40	1.46	8.5	656	0.736	0.187	220553	3216971
H331001A	40	3.4	14.7	448	0.578	0.702	220565	3216930

Stack ID	Stack Height	Exit Diameter	Exit Velocity	Exit Temp.	NOx	SO_2	UTM Coordinates	
	[m]	[m]	[m/s]	[K]	g/s	g/s	Easting	Northing
H331001B	40	3.4	14.7	448	0.578	0.702	220567	3216871
H335001A	40	3.4	14.7	448	0.578	0.702	220563	3216807
H335001B	40	3.4	14.7	448	0.578	0.702	220565	3216739
H25101	31.6	1.3	3.2	589	0.2	0	221364.6	3218106
H26101	31.6	1.3	3.2	589	0.2	0	221834.3	3218285
Mina Al Ahmadi – CFP Sources								
135F0101	61	0.5	7.6	594	0.1	0.00001	219762.7	3216930
136F0201	61	3.3	4.7	423	3.2193	0.3	219747.3	3216825
137F0101	61	2.3	6.8	455	2.2642	0.2	221711.4	3217075
141F0201	65	1.5	7.4	423	0.8017	0.2	219766.3	3217036
141F0401	65	1.5	7.4	423	1.009	0.2	219746.2	3217238
148F0301	61	2.8	10.3	427	13.3815	0.04	219656	3217062
129F201A	65	4.1	5.3	566	5.4451	0.48	219307.5	3216798
129F201B	65	4.1	5.3	566	5.4451	0.48	219301.1	3216843
129F201C	65	4.1	5.3	566	5.4451	0.48	219293.4	3216895
151F0132	61	1.4	14	543	1.2	3.2	219438	3217048
152F0132	61	1.4	14	543	1.2	3.2	219532.6	3217050
183F0101	61	2.1	5.7	477	2.1246	0.2	219878.6	3217067
186F0201	65	1	6.3	636	0.1	0.03	219502.5	3218006
186F0202	65	1.1	6.3	645	0.2	0.03	219491.4	3218113
107F0101	61	1.8	4.2	566	0.6586	0.1	221449.3	3218091
107F0102	61	3.5	4.3	461	0.2157	0.3	221536.3	3218101
144F0101	61	1.2	7	602	0.4625	0.1	221505.8	3218269

Table 18 summarizes maximum predicted Ground Level Concentrations (GLCs) and their comparison with K-EPA Ambient Air Quality Standards (AAQS). The result reveals that ground level concentrations for NO_2 exceed KEPA limit, however the number of exceeds are only 18 in two years period which satisfies the K-EPA's AAQS Appendix No. 17-1 & 17-2 stating "The hourly average should not occur more than twice during the period of 30 days at the same site". Hence, it meets the K-EPA's AAQS requirement.

However, maximum predicted ground level concentrations for SO_2 meet K-EPA AAQS.

TABLE 18 : MODEL RESULTS

Pollutant	Average Period	K-EPA AAQS (µg/m³)	Maximum predicted GLC (µg/m³)	Location		Maximum Number of exceeds at a particular location
				UTME (Km)	UTMN (Km)	
SO_2	1 hr	782.5	493.77	223.154	3211.934	0
	24 hr	523.3	87.80	222.154	3211.934	0
	Annual	157	13.85	221.154	3211.934	0
NO_2	1 hr	225	439.61	222.154	3214.934	18
	24 hr	112	73.24	222.154	3212.934	0
	Annual	67	19.83	222.154	3211.934	0

Figures 19 to 21 show pollutant contour plot-files for SO_2. The plot files show most impacted areas based on predicted pollutant concentrations generated by the model run. Color coded scale in the figures indicated the various impact concentrations.

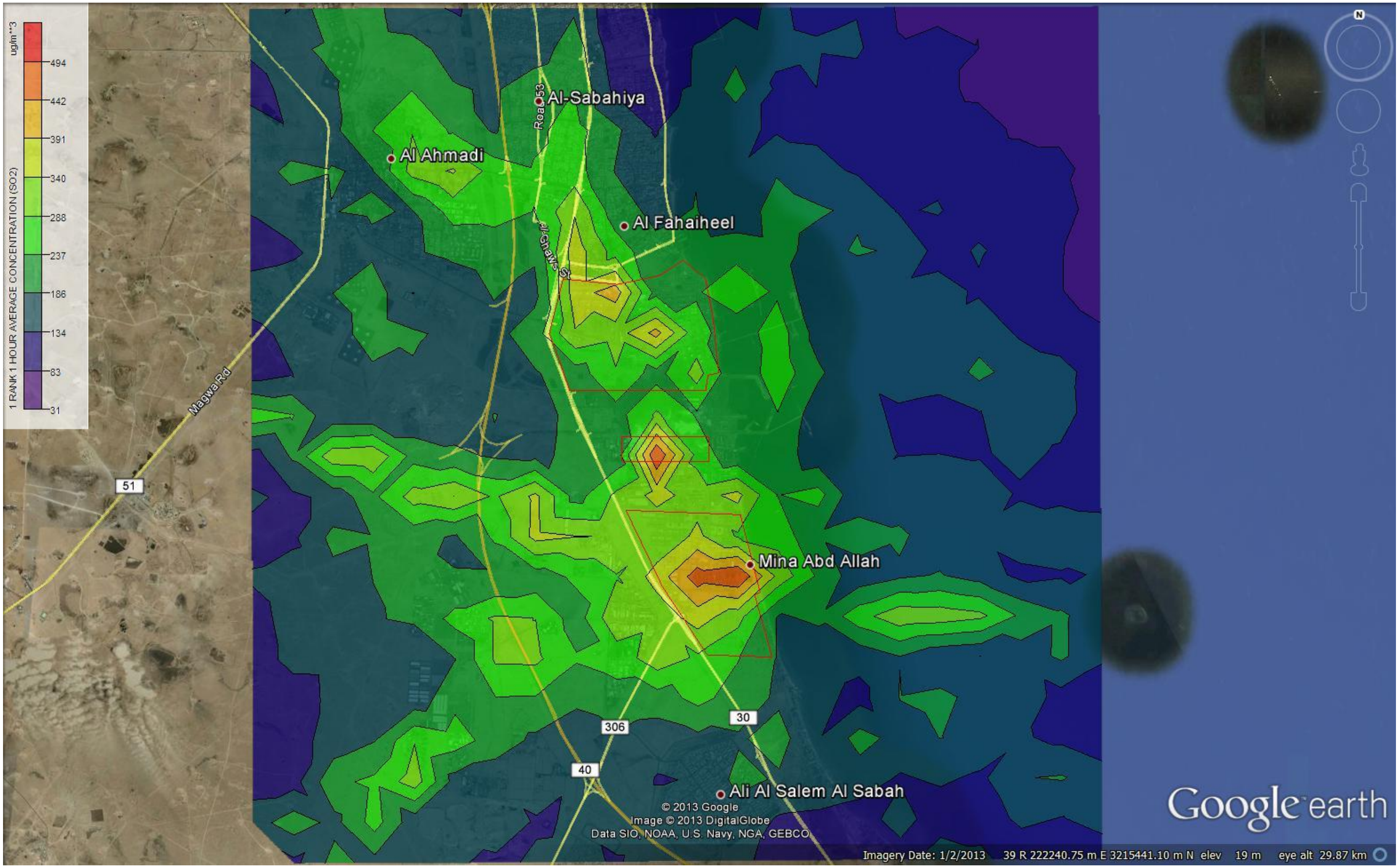

FIGURE 19: SO_2 (μg/m^3) HOURLY GLC'S FOR SCENARIO 3

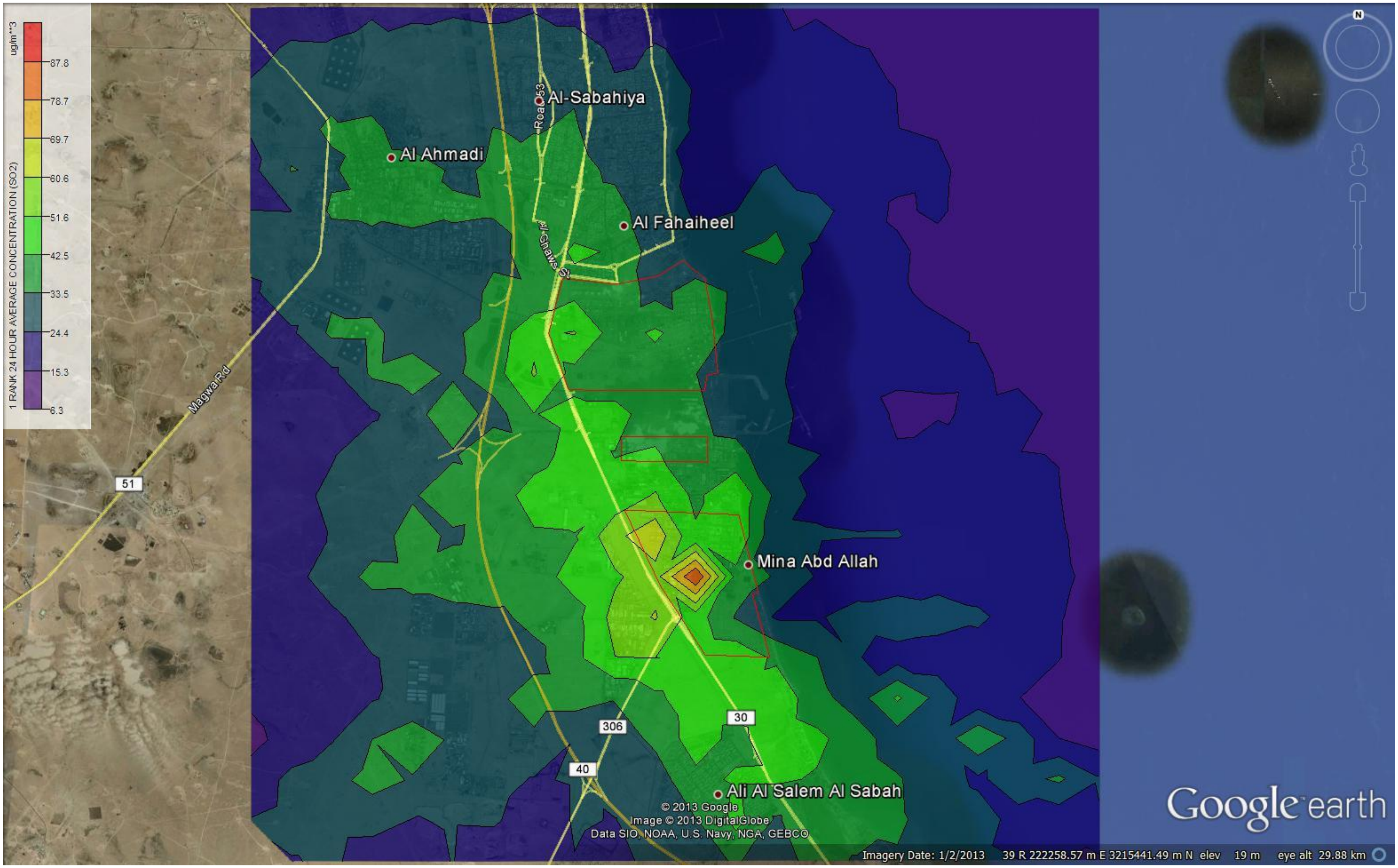

FIGURE 20: SO_2 ($\mu g/m^3$) DAILY GLC'S FOR SCENARIO 3

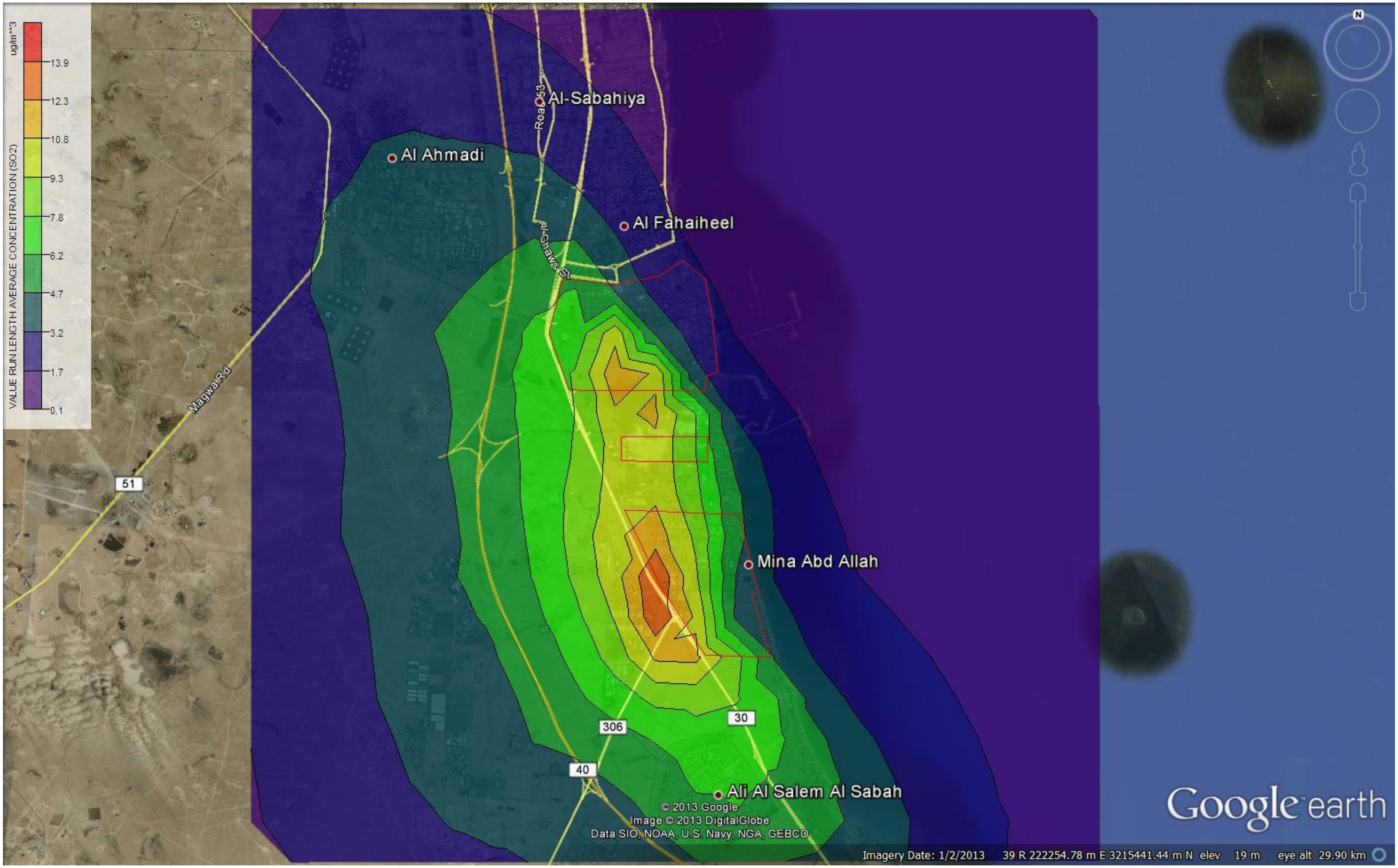

FIGURE 21: SO_2 (μg/m^3) ANNUAL GLC'S FOR SCENARIO 3

Table 19 lists the highest predicted hourly, daily and annual SO_2 G-LC's for three refineries complex.

TABLE 19: HIGHEST SO_2 GLC'S AT THE DISCRETE RECEPTORS FOR DIFFERENT AVERAGING PERIOD

Receptors	Highest Average Concentration (μg/m³)		
	Hourly	**Daily**	**Annual**
Mina Al Ahmadi Refinery	418.10	52.22	11.88
Shuaiba Refinery	491.73	43.36	10.41
Mina Abdullah Refinery	493.77	87.81	13.85
K-EPA Limit	**782.5**	**523.3**	**157**

Table 20 lists the highest predicted hourly, daily and annual SO_2 GLC's at the residential area close to the refineries area

TABLE 20: HIGHEST SO_2 GLC'S FOR RESIDENTIAL AREAS

Receptor	Highest Average Concentration(μg/m³)		
	Hourly	**Daily**	**Annual**
Fahaheel	368.82	43.62	5.14
Ahmadi	346.05	39.92	4.20
Ali Sabah Al Salem	201.91	45.36	6.56
Sabahiya	258.77	38.38	3.46
Mangaf	197.17	31.47	2.19
K-EPA Limit	**444**	**157**	**80**

Findings:

On comparison of the above results to K-EPA AAQ standards mentioned in table 1 and table 2 average hourly GLC's of SO_2 meet K-EPA limit in industrial as well as residential areas.

Figures 22 to 24 show pollutant contour plot-files for NO_2. The plot files show most impacted areas based on predicted pollutant concentrations generated by the model run. Color coded scale in the figures indicated the various impact concentrations.

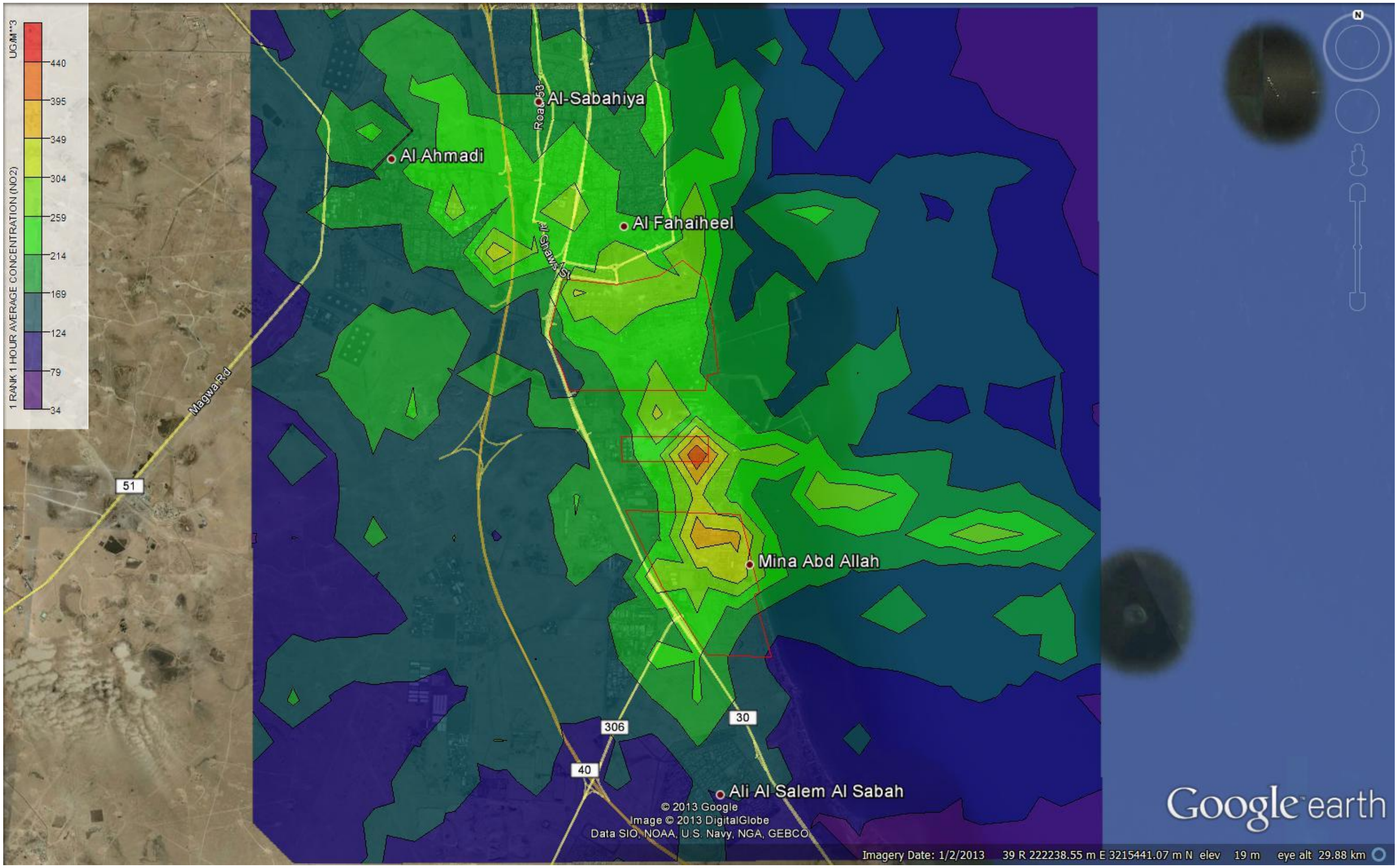

FIGURE 22: NO_2 ($\mu g/m^3$) HOURLY GLC'S FOR SCENARIO 3

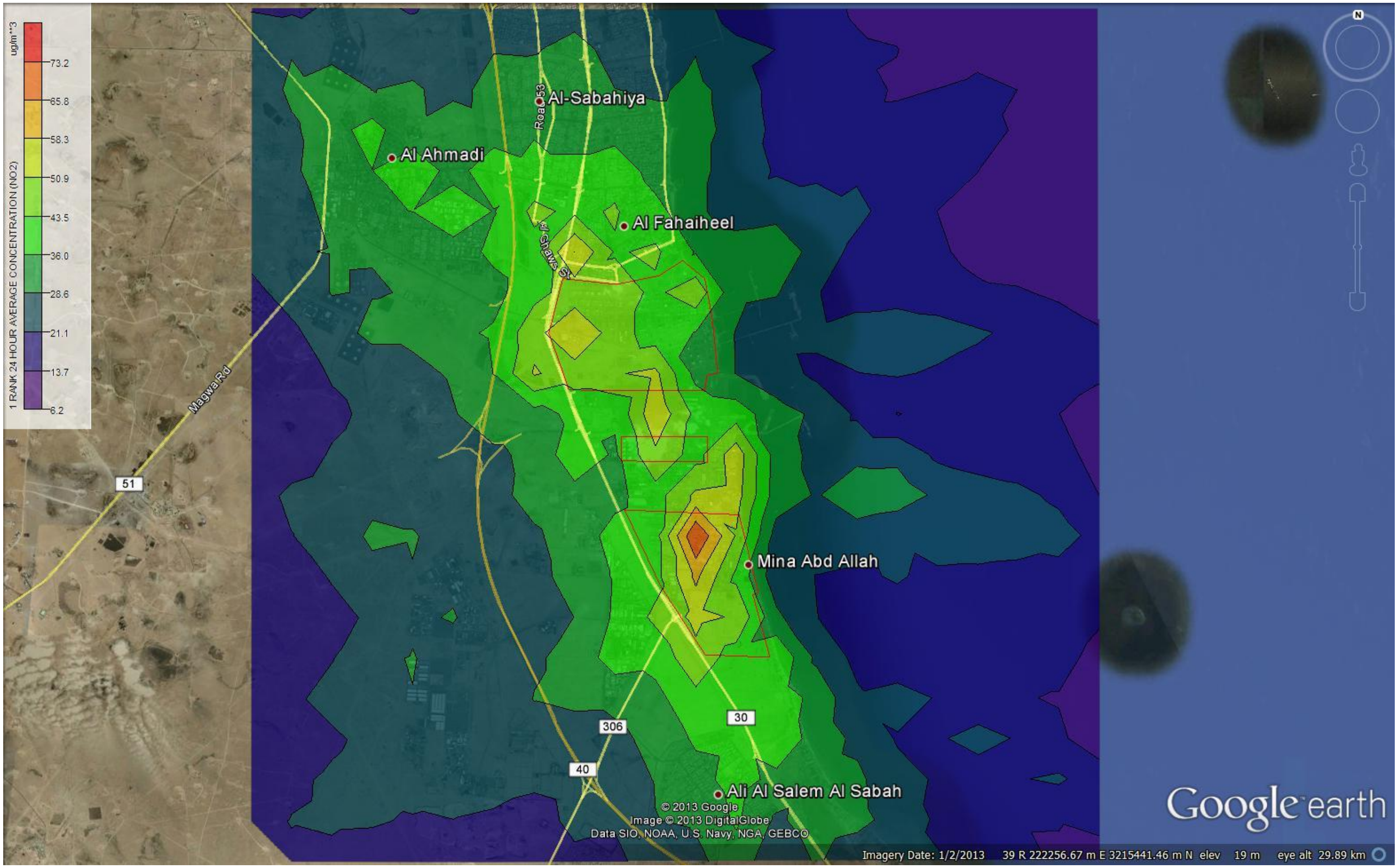

FIGURE 23: NO_2 ($\mu g/m^3$) DAILY GLC'S FOR SCENARIO 3

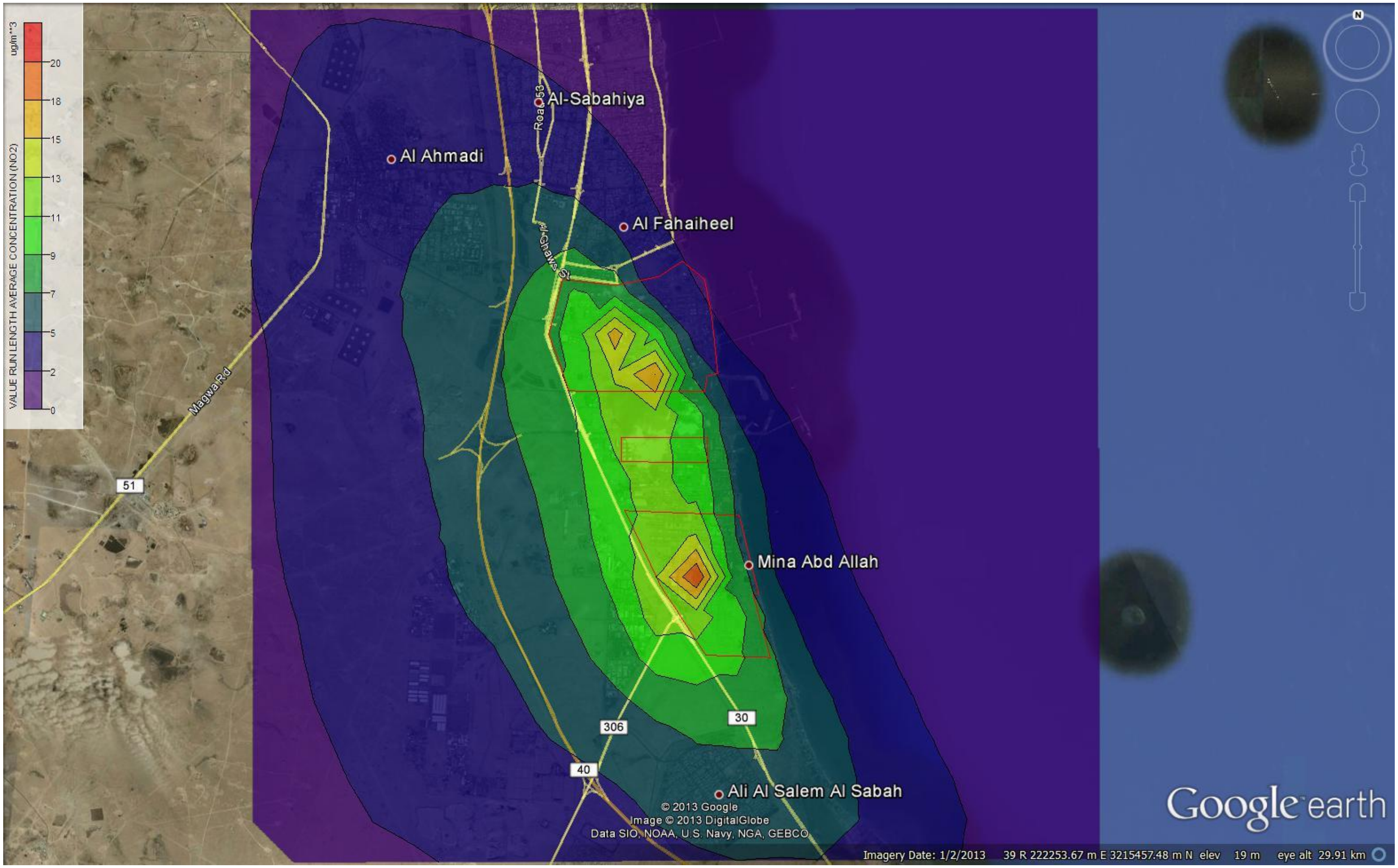

FIGURE 24: NO_2 ($\mu g/m^3$) ANNUAL GLC'S FOR SCENARIO 3

Table 21 lists the highest predicted hourly, daily and annual NO_2 G-LC's at the monitoring locations identified in the model as discrete receptors and for the entire three refineries complex.

TABLE 21: HIGHEST NO_2 GLC'S AT THE DISCRETE RECEPTORS FOR DIFFERENT AVERAGING PERIOD

Receptors	Highest Average Concentration (μg/m³)			Maximum Number of exceeds
	Hourly	Daily	Annual	
Mina Al Ahmadi Refinery	310.86	58.29	17.68	3
Shuaiba Refinery	439.61	49.40	11.79	2
Mina Abdullah Refinery	378.12	73.24	19.84	18
K-EPA Limit	**225**	**112**	**67**	**48**

Table 22 lists the highest predicted hourly, daily and annual NO_2 G-LC's at the residential area close to the refineries area

TABLE 22: HIGHEST NO_2 GLC'S FOR RESIDENTIAL AREA

Receptor	Highest Average Concentration (μg/m³)			Maximum Number of Exceeds
	Hourly	Daily	Annual	
Fahaheel	277	58.38	6.95	2
Ahmadi	280.19	42.90	4.93	1
Ali Sabah Al Salem	146.79	38.82	6.18	0
Sabahiya	248.58	38.18	4.24	2
Mangaf	215.99	40.97	2.84	0
K-EPA Limit	**225**	**112**	**67**	**48**

Findings:

The result reveals that average hourly ground level concentrations for NO_2 exceed KEPA limit in industrial as well as residential areas except Ali Sabah Al Salem.

In industrial area Mina Abdullah has maximum number of exceeds with 13 in two years period which satisfies the K-EPA's AAQS Appendix No. 17-1 & 17-2 stating "The hourly average should not occur more than twice during the period of 30 days at the same site". Hence, it meets the K-EPA's AAQS requirement.

Exceedances in residential areas also satisfy K-EPA's AAQS Appendix No. 17-1 & 17-2 stating "The hourly average should not occur more than twice during the period of 30 days at the same site". Hence, it meets the K-EPA's AAQS requirement.

Scenario 4: SRU Upset cases

Following two SRU upset conditions have been modeled with "Normal Emission" scenario

1. SRU operating while SCOT sections are bypassed.
2. SRU operating while SCOT sections are bypassed, and the tail gas incinerator is also not operating.

Four (4) cases have been modeled in total, as it has been assumed that upset events will not occur simultaneously at the two refineries (MAA and MAB):

- For SRU Upset 1 at MAA, one of the two trains at MAA (Units 151 and 152) is modeled under emergency conditions.
- For SRU Upset 1 at MAB, one of the three trains at MAB (Unit 123) is modeled assuming under emergency conditions.
- Similarly, for SRUs Upset 2 at MAA, only one of the two trains at MAA (Units 151 and 152) is modeled under emergency conditions.
- For SRU Upset 2 at MAB one of the three trains at MAB (Unit 123) is modeled under emergency conditions.

TABLE 23: MODEL INPUT FOR SRU UPSET CONDITIONS

Upset Condition	Name	SO_2	H_2S	Stack Height (m)	Exit Velocity (m/s)	Exit Temp. (°C)	Exit Diameter (m)
		g/s	g/s				
Upset 1	Unit 151 MAA	204.72	0.11	61	14	270	1.4
		0.68	0.06	61	14	270	1.4
	Unit 123 MAB	461.7	0.25	61	15	270	1.7
		1.472	0.25	61	15	270	1.7
		1.472	0.25	61	15	270	1.7
Upset 2	Unit 151 MAA	80.56	86.39	61	14	150	1.4
		0.68	0.06	61	14	150	1.4
	Unit 123 MAB	178.67	190.92	61	15	150	1.7
		1.472	0.25	61	15	150	1.7
		1.472	0.25	61	15	150	1.7

Table 24 below shows predicted ground level concentrations for upset case 1. With initial Stack height of 60m the ground level concentrations for MAA exceeds KEPA limits but meets AAQS. Ground level concentrations resulting from Upset in MAB doesn't meets KEPA standards.

TABLE 24: MODEL RESULTS FOR UPSET CASE 1

SO_2	Average Period	K-EPA AAQS (µg/m³)	Maximum predicted GLC (µg/m³)	
			With Stack Height 60m	Maximum Number of exceeds at a particular location
MAA	1 hr	782.5	1638	9
MAB	1 hr	782.5	3196	178
MAA+MAB	1 hr	782.5	-	-

A sensitivity analysis on stack height was performed for both MAA and MAB SRU stacks. The results of sensitivity analysis are mentioned in table 25 below.

Ground level concentrations resulting from upset in MAB meets KEPA AAQS with 90 and 110 m stack heights.

A model run was also done assuming upset case to occur simultaneously in MAA and MAB refinery with stack height 110m. The resulting ground level concentrations meet KEPA AAQS.

TABLE 25: RESULTS FOR SENSITIVITY ANALYSIS FOR UPSET CASE 1

SO_2	Average Period	K-EPA AAQS (µg/m³)	Maximum predicted GLC (µg/m³)			
			With Stack Height 90m	Maximum Number of exceeds at a particular location	With Stack Height 110m	Maximum Number of exceeds at a particular location
MAA	1 hr	782.5	1272	3	981	2
MAB	1 hr	782.5	1945	41	1799	28
MAA+MAB	1 hr	782.5	1944	42	1800	28

Table 26 below shows predicted ground level concentrations for upset case 2. Since upset case 1 in MAB meets KEPA limit with a stack height of 90m, Upset case 2 in MAB was done with Stack height of 90m instead of present 60m height.

TABLE 26: MODEL RESULTS FOR UPSET CASE 2

Refinery	Pollutant	Average Period	K-EPA AAQS (µg/m³)	Maximum predicted GLC (µg/m³)					
				With Stack Height 60m	Maximum Number of exceeds at a particular location	With Stack Height 90m	Maximum Number of exceeds at a particular location	With Stack Height 110m	Maximum Number of exceeds at a particular location
MAA	SO_2	1 hr	782.5	660.10	0	-	-	-	-
	H_2S	Daily	173.3	85	0	-	-	-	-
MAB	SO_2	1 hr	782.5			766	0	713.9	0
	H_2S	Daily	173.3			106	0	82.36	0

Findings:

With initial Stack height of 60m the ground level concentrations for MAA meets KEPA limits in Upset case 1 and Case 2.

Ground level concentrations resulting from upset case 1 and case 2 in MAB meets KEPA AAQS with 90 and 110 m stack heights.

Hence, a minimum stack height of 90m is recommended for SRU stacks.

Scenario 5: Emergency Flaring

Significant flare emissions only take place during emergencies or upset conditions such as power failure or upset scenarios at specific units which are rare occurrences. Emissions from emergency flaring have been modeled for both the new MAA and MAB acid and hydrocarbon gas flares, as well as the revamped flare systems at the MAA refinery. The flare systems considered in the scope of this study are summarized in Table 27 below.

Key assumptions for deriving the necessary emission parameters are:

- Total combustion of the released stream (including 20% excess air)
- An exit velocity of 40 m/s (consistent with flare modeling guidelines)
- Calculating the flame height, which is included in the effective release height

The emergency flaring scenarios do not include the normal emissions from sources that will continue to operate during the emergency flaring event. The pollutant contributions from these sources will be negligible in comparison to the emissions from the emergency flaring event.

TABLE 27: FLARING SCENARIOS INPUT

Refinery / Flare	Emergency Scenario/ Governing Case	SO_2 (g/s)	Height above ground (m)	Effective Height (m)	Exit Velocity (m/sec)	Exit Temp. (°C)	Effective Exit Diameter (m)
MAA Unit 162	Case 2	2061	108	118	40	1000	1.06
MAA Unit 167	Case 2	8163	91	108	40	1000	2.04
MAA Unit 25/26	Case 2	420	144	269.2	40	1000	22.18
MAA Unit 39	Case 1	522	67.1	108.7	40	1000	5.34
	Case 2	433	67.1	77.1	40	1000	0.85
	Case 4	1.25	67.1	110.3	40	1000	5.51
	Case 5	44	67.1	69.6	40	1000	0.22
MAB Unit 146	Case 2	28247	36.6	64.1	40	1000	3.84
MAB Unit 149 HP HC	Case 2	1237	61	69.3	40	1000	0.85
MAB Unit 149 LP HC	Case 2	1774	64	141.7	40	1000	11.74
MAB Unit 249	Case 2	10293	77	162.7	40	1000	14.08
MAB Unit 314 HP HCR	Case 3	439	85	131.2	40	1000	6.37

In the event of an upset condition in a facility, flaring of large volumes of gas can occur in a short period of time. Design of emergency flare stacks to K-EPA's AAQS considers parameters such as duration and flow rates which will vary depending on the nature of the emergency or upset flaring event.

Further, the shortest averaging time that most models predict for GLCs is 1-hour, while often; emergencies or flaring events can be much shorter in duration. Hence, Alberta's modeling guidelines for Emergency/Process Upset Flaring Management which appropriately describes methodology for normalization of averaging times for intermittent flaring. It states that "*If the flaring period is more than 1-hour the flare will be modeled as a continuous source and the model predictions are directly compared with Ambient Air Quality Guidelines. However, if the flare duration is less than 1-hour the predicted ground level concentrations must be first converted to 1-hour equivalent and then compared to Ambient Air Quality Standards*".

With practical refinery experience, it is estimated that total emergency flaring release occurs over 15- minute. As per Alberta guidelines, the emission rate was divided by 4, and modeled for an entire hour, and the resulting prediction were directly compared with a 1 – Hour standard. Table 28 below shows emission rates modeled according to above methodology.

TABLE 28: FLARING SCENARIO MODELING INPUT

Refinery/ Flare	Stack ID	Emergency Scenario/ Governing Case	Actual SO_2 emission (g/s)	Equivalent 1-hour predicted SO_2 emission (g/s)
MAA Unit 162	162A0101	case 2	2061	515.25
MAA Unit 167	167A0101	case 2	8163	2040.75
MAA Unit 25/26	MAA25/26	case 2	420	105
MAA Unit 39	ST39001	case 1	522	130.5
		case 2	433	108.25
		case 4	1.25	0.3125
		case 5	44	11
MAB Unit 146	146A0101A	case 2	28247	7061.75
MAB Unit 149 HP HC	149A0112A	case 2	1237	309.25
MAB Unit 149 LP HC	149A0102A	case 2	1774	443.5
MAB Unit 249	249A0101	case 2	10293	2573.25
MAB Unit 314 HP HCR	314A0112A	case 3	439	109.75

Table 29 below summarizes maximum predicted ground level concentrations and their comparison with hourly K-EPA Ambient Air Quality Standards (AAQS) mentioned in Table 1 & Table 2. The resulting GLC's exceed K-EPA limits.

TABLE 29: MODEL RESULTS FOR FLARING SCENARIOS

Refinery / Flare	Stack ID	Emergency Scenario/ Governing Case	Pollutant	Maximum predicted GLC ($\mu g/m^3$)
MAA Unit 162	162-A-0101	Case 2	SO_2	1990.1
MAA Unit 167	167-A-0101	Case 2	SO_2	5398.4
MAA Unit 25/26	-	Case 2	SO_2	13.36
MAA Unit 39	ST-39-001	Case 1	SO_2	171.12
		Case 2	SO_2	851.57
		Case 4	SO_2	Insignificant Impact
		Case 5	SO_2	Insignificant Impact
MAB Unit 146	146-A-0101A	Case 2	SO_2	18094
MAB Unit 149 HP HC	149-A-0112A	Case 2	SO_2	1607.4
MAB Unit 149 LP HC	149-A-0102A	Case 2	SO_2	369.47
MAB Unit 249	249-A-0101	Case 2	SO_2	1287.4
MAB Unit 314 HP HCR	314-A-0112A	Case 3	SO_2	114.29
KEPA Limit	**-**	**-**	**-**	**782.5**
KEPA STEL	**-**	**-**	**-**	**13000**

A sensitivity analysis was performed on stack heights to determine ideal stack height to meet KEPA Ambient Air standards.

TABLE 30: SENSIVITY ANALYSIS ON STACK HEIGHTS FOR FLARING SCENARIOS

Refinery / Flare	Stack ID	Original Stack height (m)	Sensitivity Stack height (m)
MAA Unit 162	162-A-0101	108	140
MAA Unit 167	167-A-0101	91	140
MAA Unit 39	ST-39-001	67.1	90
MAB Unit 146	146-A-0101A	36.6	110
MAB Unit 149 HP HC	149-A-0112A	61	140
MAB Unit 249	249-A-0101	77	140

Table 31 below summarizes maximum predicted ground level concentrations and their comparison with hourly K-EPA Ambient Air Quality Standards (AAQS) mentioned in Table 1 & Table 2. Increasing Stack height reduces ground level concentration from flaring emissions but it still exceeds KEPA limits.

TABLE 31: SENSIVITY ANALYSIS RESULTS

Refinery / Flare	Stack ID	Emergency Scenario/ Governing Case	Pollutant	Maximum predicted GLC (µg/m³)
MAA Unit 162	162-A-0101	Case 2	SO_2	1875
MAA Unit 167	167-A-0101	Case 2	SO_2	4852
MAA Unit 39	ST-39-001	Case 2	SO_2	663.66
MAB Unit 146	146-A-0101A	Case 2	SO_2	7844
MAB Unit 149 HP HC	149-A-0112A	Case 2	SO_2	864
MAB Unit 249	249-A-0101	Case 2	SO_2	1100
KEPA Limit	**-**	**-**	**-**	**782.5**
KEPA STEL	**-**	**-**	**-**	**13000**

Total Power Failure case

Total power failure scenario was also done in combination of all flares. Table 32 below summarizes model input used for total flaring scenario.

TABLE 32: TPF SCENARIO INPUTS

Refinery / Flare	Stack ID	SO_2 g/s	Height above ground (m)	Effective Height (m)	Exit Velocity (m/sec)	Exit Temp. (°C)	Effective Exit Diameter (m)
MAA Unit 162	162-A-0101	985	140	248.2	40	1000	16.4
MAA Unit 167	167-A-0101	628	140	189	40	1000	0.89
MAA Unit 25/26	-	219	144	244.9	40	1000	16.57
MAA Unit 39	ST-39-001	523	90	112.9	40	1000	5.15
MAA Unit 62	ST-62-201N	27074	110	140.2	40	1000	4.57
MAB Unit 146	146-A-0101A	2112	110	119.4	40	1000	1.64
MAB Unit 149 HP HC	149-A-0112A	20849	140	246.4	40	1000	18.63
MAB Unit 249	249-A-0101	412	140	173.7	40	1000	4.06
MAB Unit 314 HP HCR	314-A-0112A	14754	85	217.7	40	1000	23.41

Table 33 below summarizes maximum predicted ground level concentration and its comparison with hourly K-EPA Ambient Air Quality Standards (AAQS) mentioned in Table 1 & Table 2.

TABLE 33: TPF SCENARIO RESULTS

Refinery / Flare	Stack ID	Emergency Scenario/ Governing Case	Pollutant	Maximum predicted GLC (μg/m³)
MAA & MAB	All Flares	TPF combination	SO_2	11495
KEPA Limit	**-**	**-**	**-**	**782.5**
KEPA STEL	**-**	**-**	**-**	**13000**

Findings:

GLC's resulting from emergency flaring emissions in MAA and MAB do not meet KEPA AAQS mentioned in table 1&2. However, it satisfies Short Term Exposure Limit (STEL) mentioned in table 3 except MAB Acid flare unit 146.

After sensitivity run on stack height of Unit 146, flaring from this unit also meets STEL limits.

Resulting ground level concentrations during total power failure exceeds KEPA limit but meets STEL limits. It should be noted that scenario of Total Power failure is a rare occurrence event.

Scenario 6: Maintenance Shutdown

The following two maintenance events scenarios for MAA have been modeled

Maintenance 1: Shutdown of RMP Block would result in only sour fuel gas to be available to MAA Isomerization Unit 107 (two fired heaters). Consequently there would be an increase in SO_2 emissions during operation of CFP 2020 facilities. However, fired equipment within the RMP block will not operate, partially offsetting the increased SO_2 emissions from Unit 107.

Maintenance 2: Shutdown of CFP Block would result in only sour fuel gas to be available to MAA Deisopentanizer Unit 137 (one fired heater) that would result in increased SO_2 emissions. Fired equipment within the CFP block will not operate partially offsetting the increased SO_2 emissions from Unit 137.

TABLE 34: MODEL INPUTS USED FOR MAINTENANCE SCENARIO

Maintenance Scenario	Refinery	Status	Name	Unit	SO_2
					g/s
Maintenance 1	MAA CFP	Running	Unit 107	107-F-0101	1.2777
				107-F-0102	5.7222
RMP Block Shutdown	MAA CFP	Shutdown	Unit 144	144-F-0101	0.04
	MAA Existing	Shutdown	KD Unit	H-40-001	0.3801
	MAA Existing	Shutdown		H-43-001	0.0194
	MAA Existing	Shutdown	ARDS 1	41-H001	0.0210
	MAA Existing	Shutdown		41-H-002	0.0410
	MAA Existing	Shutdown		41-H-003	0.0175
	MAA Existing	Shutdown	ARDS2	42-H001	0.000
	MAA Existing	Shutdown		42-H001	0.0410
	MAA Existing	Shutdown	HP-1	H-48-001	0.0957
	MAA Existing	Shutdown	HP-2	H-49-001	0.0957
	MAA Existing	Shutdown	SR/TGT	ST-54-001	48
Maintenance 2	MAA CFP	Running	Unit 137	137-F-0101	3.3055
CFP Block Shutdown	MAA CFP	Shutdown	Unit 129	129-F-0201A	0.3
	MAA CFP	Shutdown		129-F-0201B	0.3
	MAA CFP	Shutdown		129-F-0201C	0.3
	MAA CFP	Shutdown	Unit 135	135F-0101	0.01
	MAA CFP	Shutdown	Unit 136	136-F-0201A/B/C	0.28
	MAA CFP	Shutdown	Unit 141	141-F-0201	0.13
	MAA CFP	Shutdown		141-F-0301	0.17
	MAA CFP	Shutdown	Unit 148	148-F-0301	0.03
	MAA CFP	Shutdown	Unit 151	151-F-0132	0.67
	MAA CFP	Shutdown	Unit 152	152-F-0132	0.67
	MAA CFP	Shutdown	Unit 183	183-F-0101	0.16

Both these events are anticipated to last for up to 30 days, and occur once every four to five years. During the maintenance period, the concentration of H_2S in the fuel gas being consumed by the fired equipment in either Unit 107 or Unit 137 (approximately 1500 mg/dry m^3 at normal conditions) will exceed K-EPA Appendix 20 criteria (230 mg/dry m^3) However, the SO_2 emission rate will still be well below the applicable K-EPA limit (512 ng/J). The potential impacts of the 'above normal' SO_2 emissions for the two maintenance cases were evaluated by air dispersion modeling analysis in consideration of the applicable K-EPA. Although, It is unlikely that the two maintenance events will occur simultaneously, for air dispersion modeling it is modeled as together with CFP maximum emissions.

Table 35 below summarizes maximum predicted concentrations and their comparison with K-EPA Ambient Air Quality Standards (AAQS). The results reveal that maximum predicted ground level concentration for SO_2 meets KEPA limits.

TABLE 35: MODEL RESULTS FOR SCENARIO 6

Pollutant	Average Period	K-EPA AAQS (µg/m³)	Maximum predicted GLC (µg/m³)	Location		Maximum Number of exceeds per location
				UTME (Km)	UTMN (Km)	
SO_2	1 hr	782.5	713.66	221.154	3214.934	0
	24 hr	523.3	87.80	222.154	3211.934	0
	Annual	157	15.86	220.154	3217.934	0

Figures 25 shows pollutant contour plot-files for SO_2. The plot files show most impacted areas based on predicted pollutant concentrations generated by the model run. Color coded scale in the figure indicated the various impact concentrations.

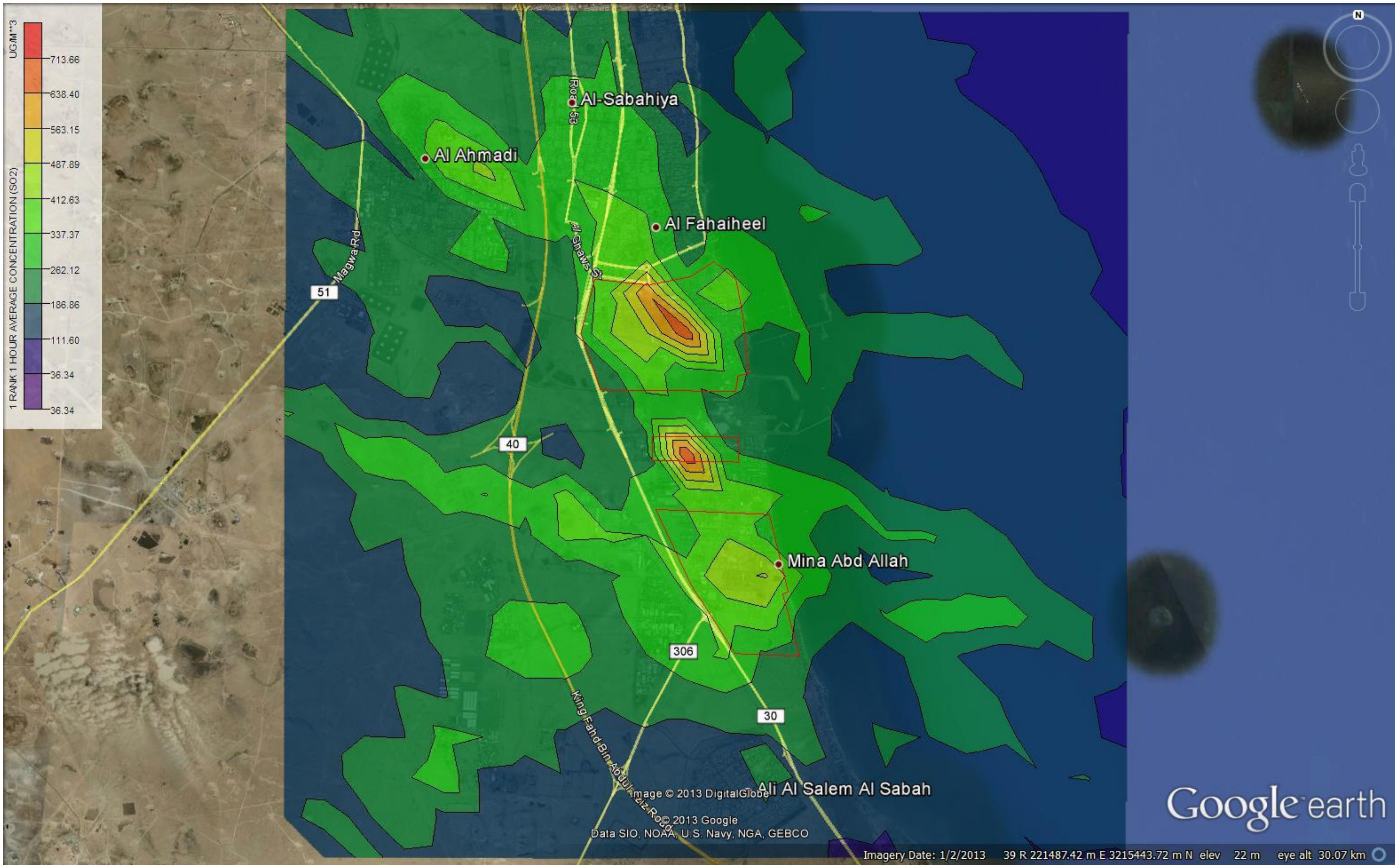

FIGURE 25: SO_2 ($\mu g/m^3$) ANNUAL GLC'S FOR SCENARIO 6

5. CONCLUSIONS

1. Existing baseline scenario represents impact of air emissions from existing Mina Al Ahmadi, Shuaiba and Mina Abdullah refineries with all ongoing revamps and projects including LPG 4 & 5.

    - Baseline Ground Level Concentrations (GLCs) resulting from SO_2 emissions from all three existing refineries exceeds KEPA limit, however it satisfies KEPA's criteria of number of allowable exceedances in a month.

    - Baseline Ground Level Concentrations (GLCs) resulting from NOx emissions from all three existing refineries exceeds KEPA limit.

2. Ground level concentrations resulting from SO_2 emissions of post CFP operation meets KEPA limit.

3. Ground level concentrations resulting from NOx emissions of post CFP operation exceeds KEPA limit, however it satisfies KEPA's criteria of number of allowable exceedances in a month.

4. SRU upset (Case 1 - SCOT sections are bypassed, Case 2- SCOT sections are bypassed with tail gas incinerator also not operating) for MAA refinery meets KEPA limits with present Stack height of 60m.

5. SRU upset (Case 1 - SCOT sections are bypassed, Case 2- SCOT sections are bypassed with tail gas incinerator also not operating) for MAB refinery meets KEPA limits with present Stack height of 90m.

6. Emergency flaring from Flare units 162 & 167 of MAA and units 146, 149 & 249 of MAB exceeds KEPA limit. However, emergency flaring emissions meets the KEPA's Short Term Exposure Limit (STEL).

7. Emergency flaring during Total Power Failure scenario (All flares combined) also exceeds KEPA limits. However, it also meets the KEPA's Short Term Exposure Limit (STEL).

8. Maintenance & Shutdown scenario meets KEPA limit. Further, RMP & CFP shutdown together also meets KEPA limit.

6. RECOMMENDATIONS

1. It is recommended to:
   - Provide ultra-low NOx burners for the Hydrogen and Crude distillation units in MAA refinery.
   - Increase stack heights of Unit 31 boilers (4 nos.) of MAB refinery to 30m from existing 18.28m.
   - Increase stack heights of SRUs at MAA Unit 151 and MAB Unit 123 to a minimum height of 90m.
   - Increase stack height of the following Flaring units

TABLE 36: RECOMENDED STACK HEIGHTS FOR FLARE UNITS

Refinery / Flare	Stack ID	Original Stack height (m)	Recommended Stack height (m)
MAA Unit 162	162-A-0101	108	140
MAA Unit 167	167-A-0101	91	140
MAA Unit 25/26	-	144	144
MAA Unit 39	ST-39-001	67.1	90
MAA Unit 62	ST-62-201N	110	110
MAB Unit 146	146-A-0101A	36.6	110
MAB Unit 149 HP HC	149-A-0112A	61	140
MAB Unit 149 LP HC	149-A-0102A	64	64
MAB Unit 249	249-A-0101	77	140
MAB Unit 314 HP HCR	314-A-0112A	85	85

2. Though GLCs during Total Power Failure case do not meet KEPA limit, however being a rare event, no recommendations are suggested.

7. REFERENCES

USEPA, 2006a. *Guideline on Air Quality Models*, Appendix W of 40 CFR Part 51, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina.

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