Proceedings World Geothermal Congress 2020+1
Reykjavik, Iceland, April - October 2021

Update of Air Quality Dispersion Model for Geothermal Power Plants and Wellhead Generation Units at Olkaria in Kenya

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Keywords: Air quality assessment, Calmet/Calpuff dispersion model, Olkaria geothermal Project, hydrogen sulphide effects

ABSTRACT

The Kenya Electricity Generating Company (KenGen) PLC is the leading producer of electricity in Kenya, generating 1631MWe of electricity as at 31st December 2018. The Company uses various power generation mix ranging from hydro (50%), geothermal (32%), thermal (16%) and wind (2%). Due to the increasing demand for electricity and in line with Kenya's Vision 2030, KenGen has embarked on an ambitious strategy to inject into the national grid an additional 721MWe by 2025, mainly from geothermal resource. Kenya is endowed with geothermal resource in excess of 10,000MWe and only 677MWe has been harnessed for power generation.

The Olkaria Geothermal Field has a potential of over 1,200MWe, out of which 531.1MWe has been developed by KenGen PLC. The power is harnessed from 14 wellhead generation units and four power plants (45MWe Olkaria I Units 1-3, 105 MWe Olkaria II Units 1-3, 140MWe Olkaria I AU 4 & 5 and 140MWe Olkaria IV) located within/near Hell's Gate National Park, which is an ecologically sensitive area. In additional, there exists a commercial flower farm about 1km to the North West of Olkaria II and Lake Naivasha, a ramsar site, is about 5 km to the North. Hydrogen sulphide gas is one of the bye-products of geothermal exploitation. The gas is a nuisance at detectable levels due to the rotten-egg odor and toxic at high concentrations.

This paper seeks to assess air quality dispersion model due to the operations of the existing Olkaria power plants including the well head generation units, and the potential impact associated with the proposed geothermal development. The study uses Calmet and Calpuff computer-based dispersion model to investigate the air quality effects due to the existing 531.1MWe power installations, and anticipated effects from the proposed 140MWe Olkaria VI PPP, 140MWe Olkaria VII and the 61MWe Modular Geothermal power plant at Olkaria geothermal field. Three modelling scenarios have been considered in the assessment.

1. INTRODUCTION

Geothermal resources are a clean, reliable and abundant source of energy, with great potential to meet an increasing share of the world´s expanding energy needs (Rybach, 2003). Such energy is inexorably gaining momentum in many parts of the world endowed with the resource, due to burgeoning populations and escalating economies. It is presently being utilised in 78 countries worldwide for both direct and indirect uses (Lund et al., 2010).

Kenya is the first country in Sub-Sahara Africa to tap power from the Earth's crust in a significant fashion (Karekezi and Kithyoma, 2003). The country has plentiful geothermal resources that have not been exploited to full potential. The resources are located in the Kenyan Rift (Figure 1), and recent studies of geothermal explorations reveal that geothermal potential in the rift exceeds 10,000 megawatts of electricity (MWe). The Least Cost Power Development Plan (2017-2037) prepared by the Government of Kenya indicates that geothermal plants have the lowest unit cost and therefore are suitable for base load and are thus, recommended for additional expansion (Republic of Kenya, 2018). Geothermal energy in Kenya is primarily utilized for electricity production, and this currently stands at 677 MWe. Direct uses of geothermal energy in the country include greenhouses, drying agricultural products, swimming, therapeutic bathing, and aquaculture. More than 23 geothermal sites have been identified in the Kenyan Rift (Figure 1). It's only at Olkaria and Eburru geothermal fields where geothermal steam has been harnessed for power generation. The other geothermal prospects are at various reconnaissance and surface exploration stages.

The main environmental concerns arising from geothermal operations are associated with discharge of non-condensable gases and such as hydrogen sulphide (H_2S), carbon dioxide and methane into the atmosphere. Hydrogen sulphide has the greatest environmental concern not only because of its noxious smell in low concentrations but also due to its toxicity and health impacts at high concentrations, and its tendency to concentrate in hollows and low-lying areas due to its high density (Kristmannsdóttir et al., 2000). The current geothermal energy generation at Greater Olkaria and Eburru geothermal fields is 677 MWe. Kenya Electricity Generating Company (KenGen) PLC, is the leading power generating company in Kenya, and uses various generation mix ranging from hydro (819MWe), thermal (253.5MWe), wind (25.5MWe) and geothermal (534MWe). Due to impacts of climate change which are affecting hydro power generation in Kenya, the Country has embarking on geothermal resource development which is clean, renewable and resilient to climate change. Hydrogen sulphide gas is one of the bye-products of geothermal power exploitation. The gas is a nuisance at low concentrations due to its rotten-egg odor and toxic at high concentrations. In order to determine cumulative environmental impacts associated with hydrogen sulphide, various modeling techniques have been employed in distinct parts of the world. This study uses CALMET/CALPUFF computer-based dispersion model to investigate the air quality effects of three stages in the proposed development of the Olkaria geothermal field. The assessment has been confined to the potential effects of hydrogen sulphide.

2. STUDY AREA

The study focuses on the Olkaria geothermal area (Figure 2) in Kenya located on the floor of the Kenyan rift.

3. METHODS USED IN THE ASSESSMENT

The assessment has been undertaken using the CALMET/CALPUFF modeling system to predict the ground level concentrations of hydrogen sulphide expected as a result of emissions from existing and yet to be developed geothermal power stations at Olkaria. The CALMET/CALPUFF modeling system is an advanced wind-field based dispersion model designed to simulate pollutant dispersal on both small and large scale modeling domains. The CALMET model prepares the meteorological data into an hourly four-dimensional database required by CALPUFF. CALPUFF is then used to simulate the transport and diffusion of the emissions and to predict the concentrations of emissions at a user-specified grid of receptors for nominated averaging periods.

The CALMET/CALPUFF suite of models is approved by the United States Environmental Protection Agency (US EPA) for air quality assessments. The models require meteorological data, topographical data and data on land-use to simulate the wind fields and other dispersion information generated by CALMET. This information is also needed by CALPUFF.

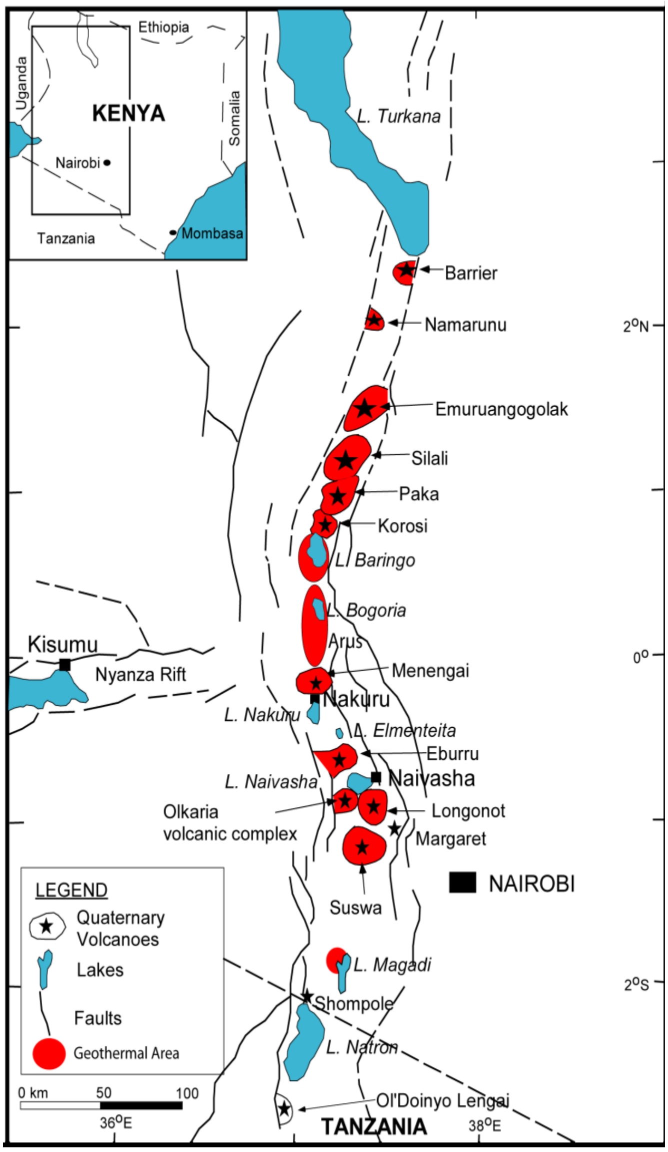

Figure 1: Kenya geothermal fields and prospects

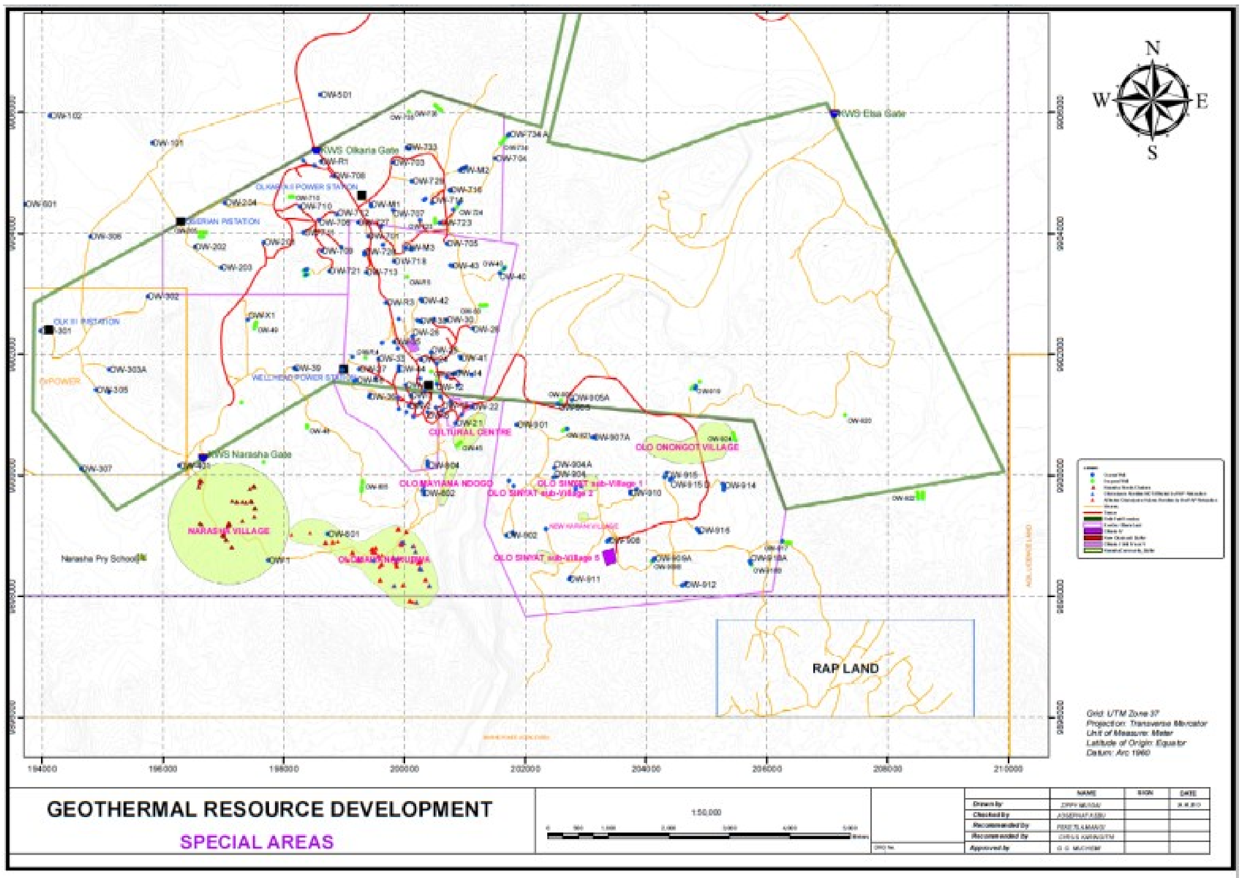

Figure 2: Olkaria geothermal development area and surrounds

4. AIR QUALITY ASSESSMENT CRITERIA

Hydrogen sulphide odour detection limit of 0.0046 ppm (7 µg/m ^{3}) has been used as per the study by Nagy (1991). At this concentration, no harmful effects to human health are known. At higher concentrations, where hydrogen sulphide is extremely toxic, it produces complete fatigue of the olfactory nerve and its presence cannot be detected. Its odour therefore serves as an important warning of its presence well before the concentrations reach dangerous levels.

The Kenya Environmental Management and Coordination (Air Quality) Regulations 2014 (Schedule 1) sets air quality tolerance limits for hydrogen sulphide. These area: 150µg/m^3 (0.1ppm) for 24-hour time weighted average for industrial areas and 50 50µg/m^3 (0.03ppm) for 24-hour time weighted average at the property boundaries for industries in residential areas. The WHO specify a 24-hour average guideline value of 0.1 ppm, which is consistent with the 2014 Kenya air quality regulations.

Thompson and Kats (Thompson & Kats, 1978) found that concentrations of 0.3 to 3 ppm could cause vegetation damage that was correlated with dose, but concentrations of 0.03 to 0.1 ppm appeared to stimulate growth in some rapidly growing species. An annual average concentration of 0.03 ppm has been suggested as a value that would be adequate to protect commercial crops or culturally or scientifically important vegetation.

The protection of workers within the power station is beyond the scope of an Environmental Assessment, but it is suggested that the United States threshold limit values (TLVs) for work-place exposure and the Factories and Other Places of Work (Hazardous Substances) Rules 2007 long term occupational exposure limit, namely 10 ppm (15 mg/m^3) 8-hour time weighted average, be used for this purpose.

5. MODELING CASES AND EMISSIONS

Five development cases (Cases 1 to 5) have been modeled for Olkaria. These show the expected air pollution effects of each case for 1-hour, 24-hour and one-year averaging periods. Each case represents the cumulative effects of all power stations expected to be operating for the particular case. The emission scenarios are summarized in Table 1 below:

Table 1: Modeling cases and emission scenarios

Modeling Cases	Description of installations	Installed capacity	Total associated H_2S emission rate	Number of emission points
Case 1	Existing power plants and well head generating units {50.7MWe Olkaria I (Units 1, 2 & 3), 140MWe Olkaria I AU 4 & 5, 105MWe Olkaria II (Units 1, 2 & 3), 81.1MWe wellhead generating units (OW-37,39,43,905,919,915 and 914)}	516.8 MWe	209.8 g/s	69
Case 2	Includes Case 1 above plus 70MW Olkaria I AU 6 and 140MW Olkaria V Power Plants which are currently under construction	726.8 MWe	295.1 g/s	93
Case 3	Include all Case 2 above plus 140MWe Olkaria VI (units 1 & 2) PPP Power Plant, 140MWe Olkaria VII (units 1 & 2) Power Plant and 61MWe Modular Power Plant (one unit of 31MWe at OW-733 being binary and the other unit of 30MWe being at OW-R5 being conventional)	1,067.8 MWe	420.9 g/s	129

6. RESULTS AND ANALYSIS

The prediction results for each of the five cases for 1-hour, 24-hour and annual average hydrogen sulphide concentrations (in ppm) are illustrated below.

6.1 Annual and seasonal wind roses

Figure 3 shows seasonal and annual wind roses derived from the modeling file produced by CALMET for a location close to the Olkaria II Power Station. Note the seasons have been taken to be southern hemisphere summer (December, January and February), autumn (March, April and May) etc. seasons. The predominant wind directions over the year are from the south and south-southeast.

6.2 Case 1

Figures 4, 5 & 6 show the predicted maximum 1-hour and 24-hour and annual average hydrogen sulphide concentrations for Case 1 operations. The operating power plants and well head generating units include 50.7MWe Olkaria I (Units 1, 2 & 3), 140MWe Olkaria I AU 4 & 5, 105MWe Olkaria II (Units 1, 2 & 3) and 81.1MWe wellhead generating units (15.5MWe OW-37, 5MWe OW-39,12.8MWe OW-43, 5MWe OW-905, 5MWe OW-919,10MWe OW-915 and 27.8MWe OW-914). The total installed capacity for Case 1 is 516.8MWe.

Figure 4 shows that the highest 1-hour average concentrations are predicted to occur near OW-914. The reason is that the emissions from plants using gas ejectors are dispersed far less effectively than those released in either wet or dry cooling towers, where the additional plume-rise (generated by the buoyant cooling tower warm air flow) gives rise to much lower ground level concentrations. The predictions indicate that odours could be detected (at least for some hours in the year) over all of the prediction grid.

Figure 5 shows the area where the Kenya 24-hour tolerance limits may be exceeded. It should be noted that the Kenyan tolerance limit of 0.1 ppm allows seven non-consecutive 24-hour exceedances per year. The contours in the figure are the highest 24-hour concentrations.

Figure 6 shows the area where annual average concentrations are predicted to exceed the 0.03 ppm concentration values selected to protect commercial crops and vegetation. The red (0.03 ppm) contours are contained within the geothermal license area.

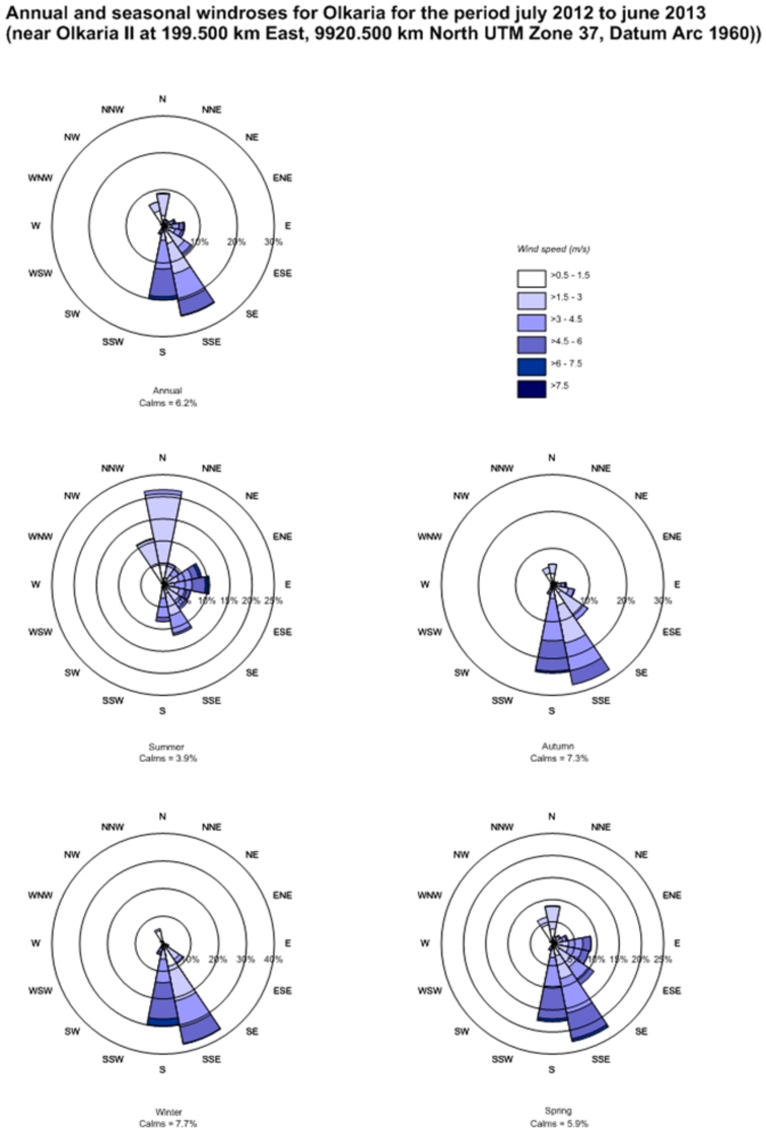

Figure 3: Olkaria wind roses derived from Calmet Model at 10m above ground level

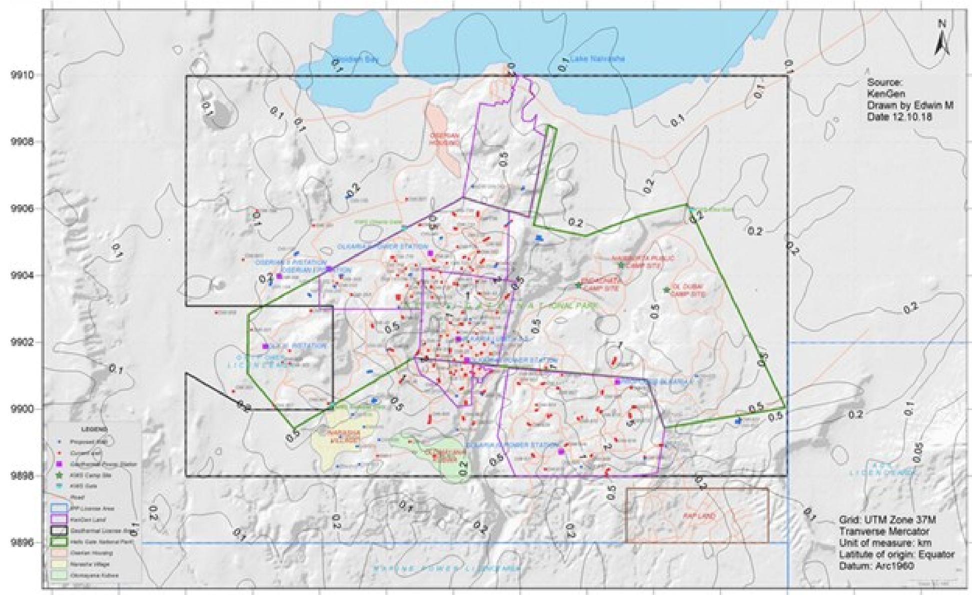

Figure 4: Predicted maximum 1-hour average hydrogen sulphide concentrations for Case 1 operations (in ppm)

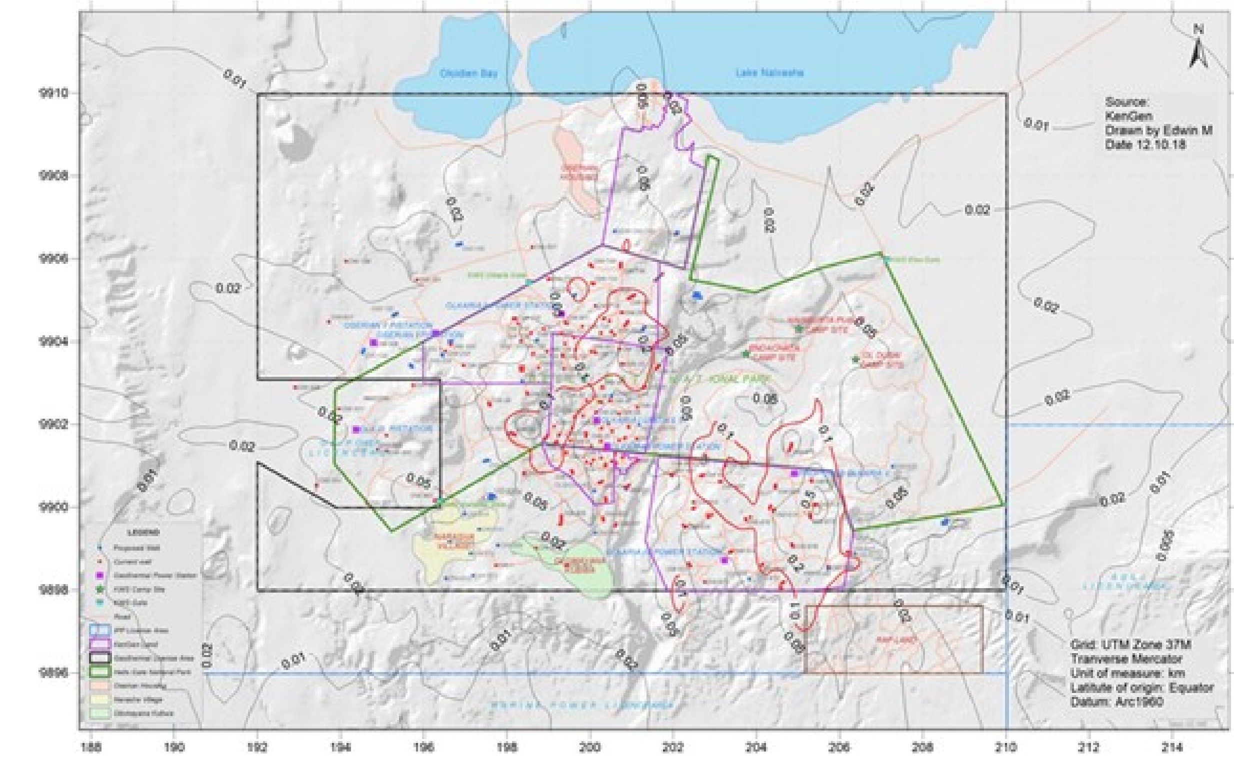

Figure 5: Predicted maximum 24-hour average hydrogen sulphide concentrations for Case 1 operations (in ppm)

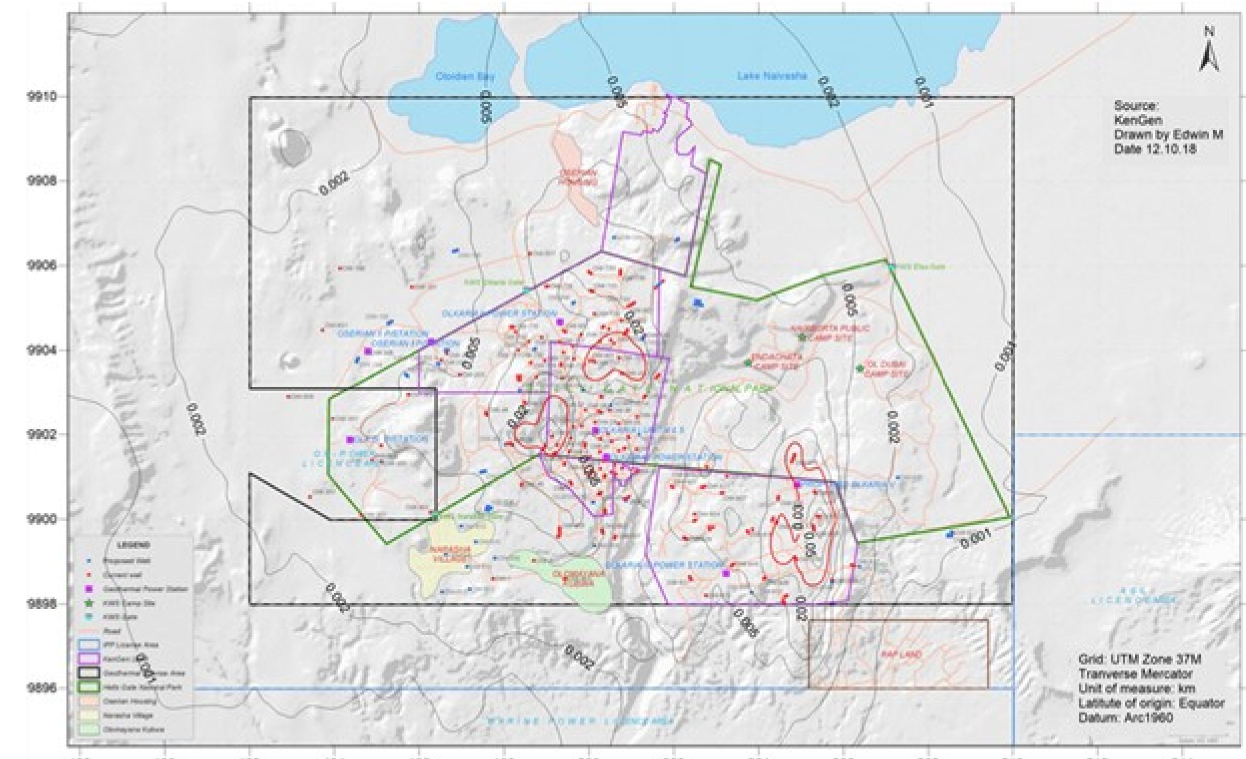

Figure 6: Predicted annual average hydrogen sulphide concentrations for Case 1 operations (in ppm)

6.3 Case 2

Figures 7, 8 & 9 show the predicted maximum 1-hour, 24-hour and annual average hydrogen sulphide concentrations for Case 2 operations. Case 2 includes all the operating power plants and wellheads for Case 1 plus 70MWe Olkarai I AU 6 and 140MWe Olkaria V, which are under construction. The total installed capacity for Case 2 is 726.8MWe.

Figure 7 shows that the highest 1-hour average concentrations are predicted to occur near OW-914. The emissions from plants using gas ejectors are dispersed far less effectively than those released in either wet or dry cooling towers, where the additional plume-rise generated by the buoyant cooling tower emissions gives rise to much lower ground level concentrations. The predictions indicate that odours could be detected (at least for some hours in the year) over all of the prediction grid.

The red contours in Figure 8 shows the areas where the Kenyan 24-hour tolerance limit is predicted to be exceeded. It should be noted that the tolerance limit of 0.1 ppm may be exceeded on seven (non-consecutive) 24-hour periods in the year. The contours in the figure are the highest 24-hour concentrations.

Figure 9 shows the areas where annual average concentrations are predicted to exceed the 0.03 ppm the concentration value selected to protect commercial crops and native vegetation. The red (0.03 ppm) contours are contained within the geothermal license area.

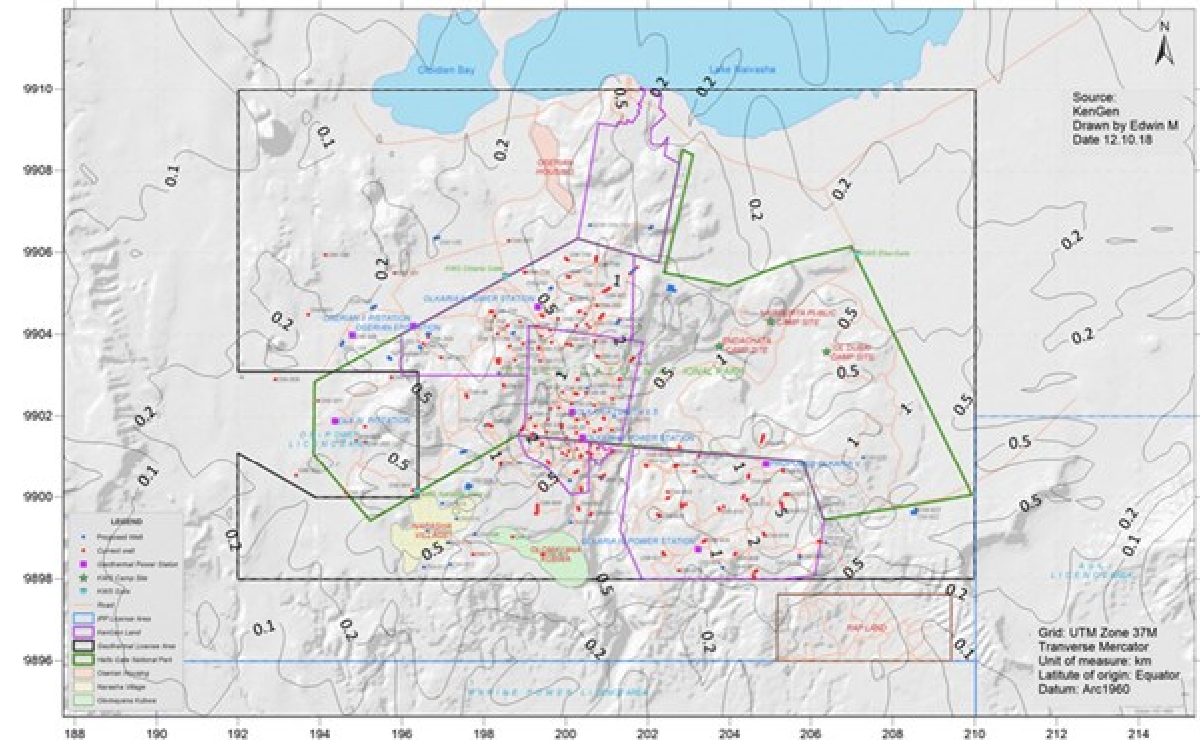

Figure 7: Predicted maximum 1-hour average hydrogen sulphide concentrations for Case 2 operations (in ppm)

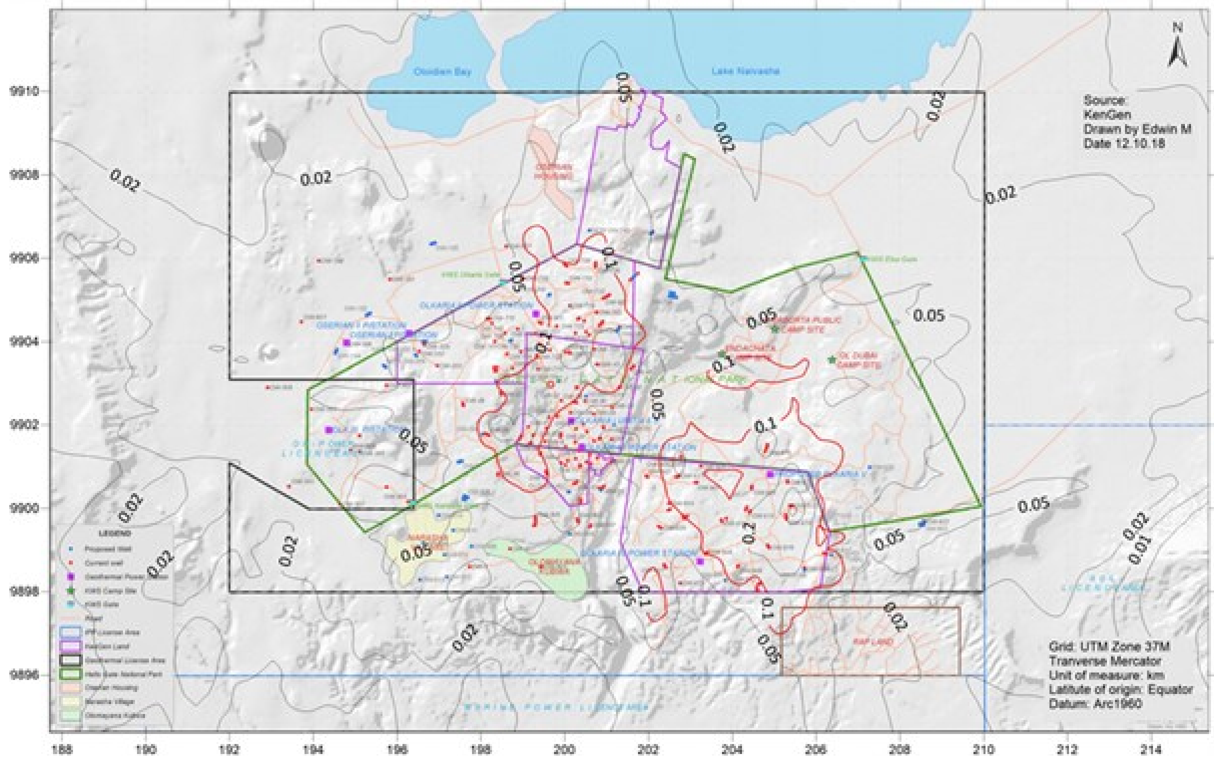

Figure 8: Predicted maximum 24-hour average hydrogen sulphide concentrations for Case 2 operations (in ppm)

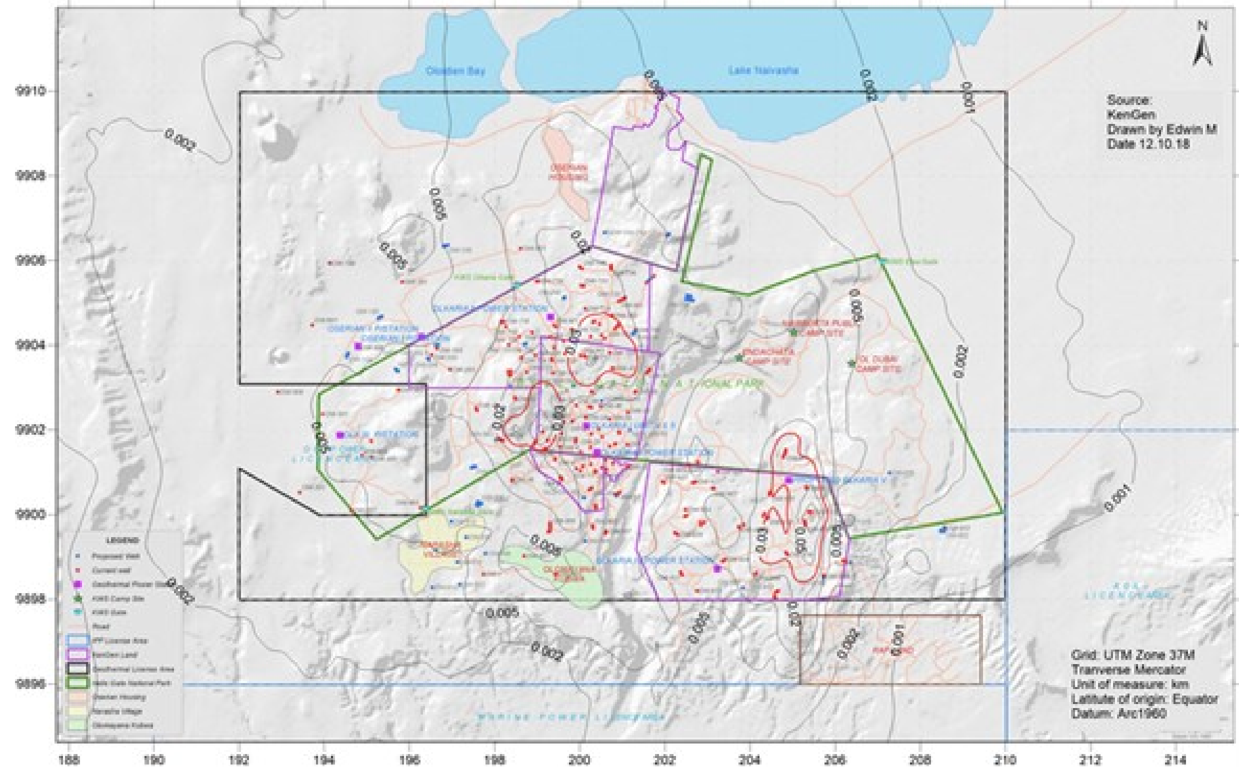

Figure 9: Predicted annual average hydrogen sulphide concentrations for Case 2 operations (in ppm)

6.4 Case 3

Figures 10, 11 & 12 show the predicted maximum 1-hour, 24-hour and annual average hydrogen sulphide concentrations for Case 3 operations. The operating installations include all Case 2 above plus 140MWe Olkaria VI (units 1 & 2) PPP Power Plant, 140MWe Olkaria VII (units 1 & 2) Power Plant and 61MWe Modular Geothermal Power Plant (comprising of 2 units; 31MWe OW-733 which will be binary and 30MWe OW-R5 which will be conventional). The installed capacity for Case 3 is 1,067.8MWe and the total associated hydrogen sulphide emission rate from all sources is estimated to be 420.9 g/s.

Error! Reference source not found. shows that the highest 1-hour average concentrations are predicted to occur near OW-R5 (30 MWe wellhead power plant). There is elevated concentrations near OW-914 which uses gas ejectors. Emissions from plants using gas ejectors are dispersed far less effectively than those released in either wet or dry cooling towers, where the additional plume-rise generated by the buoyant cooling tower emissions gives rise to much lower ground level concentrations. The predictions indicate that odours could be detected (at least for some hours in the year) over all of the prediction grid. The effect of emissions from Olkaria VII can be seen in the southwest of the geothermal licence area for all three averaging times.

Figure 11 (red contours) shows the areas where the Kenyan 24-hour tolerance limit is predicted to be exceeded. It should be noted that the tolerance limit of 0.1 ppm may be exceeded on seven (non-consecutive) days in the year. The contours in the figure are the highest 24-hour concentrations. In practice, it is likely that the 0.1 ppm contours would be contained within the Olkaria geothermal license area for Case 3, even though the modelling does show the maximum 24-hour concentrations extend beyond the boundary both to the north and south.

Figure 12 shows the areas where annual average concentrations are predicted to exceed the 0.03 ppm the concentration value selected to protect commercial crops and native vegetation. The red (0.03 ppm) contours are contained within the Olkaria geothermal license area.

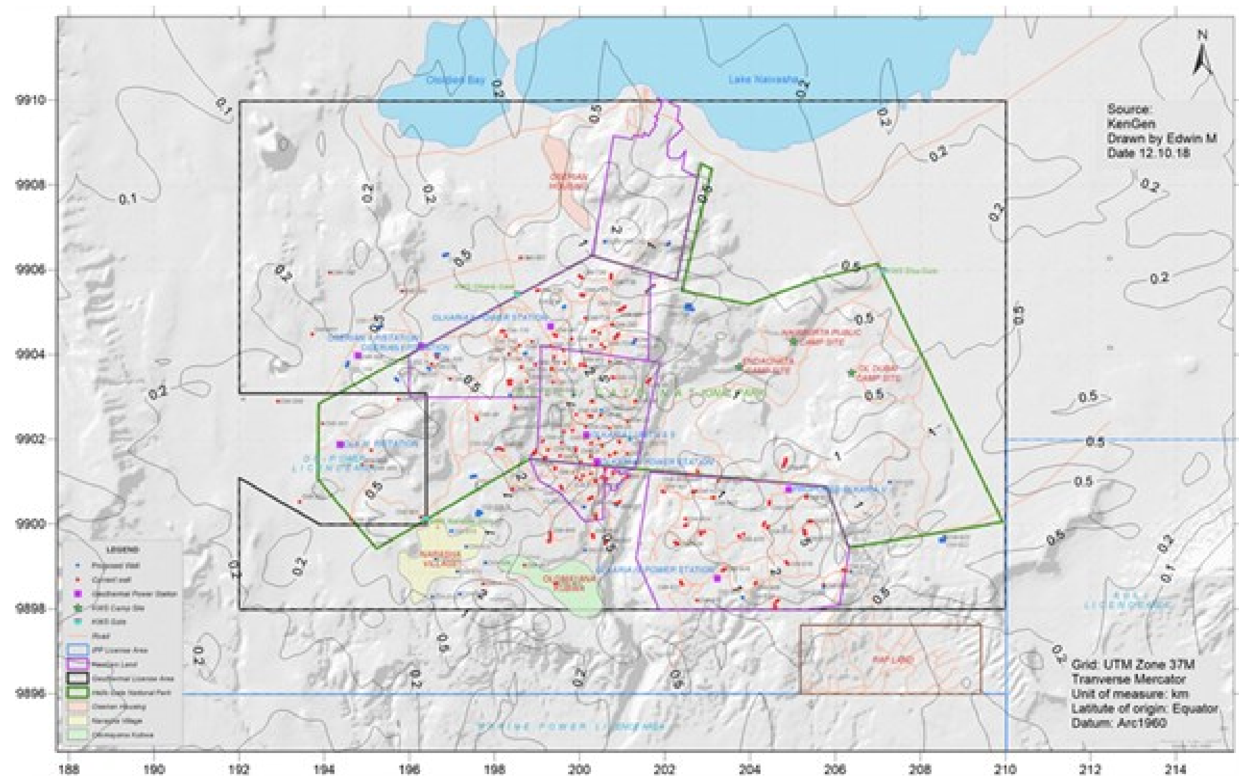

Figure 10: Predicted maximum 1-hour average hydrogen sulphide concentrations for Case 3 operations (in ppm)

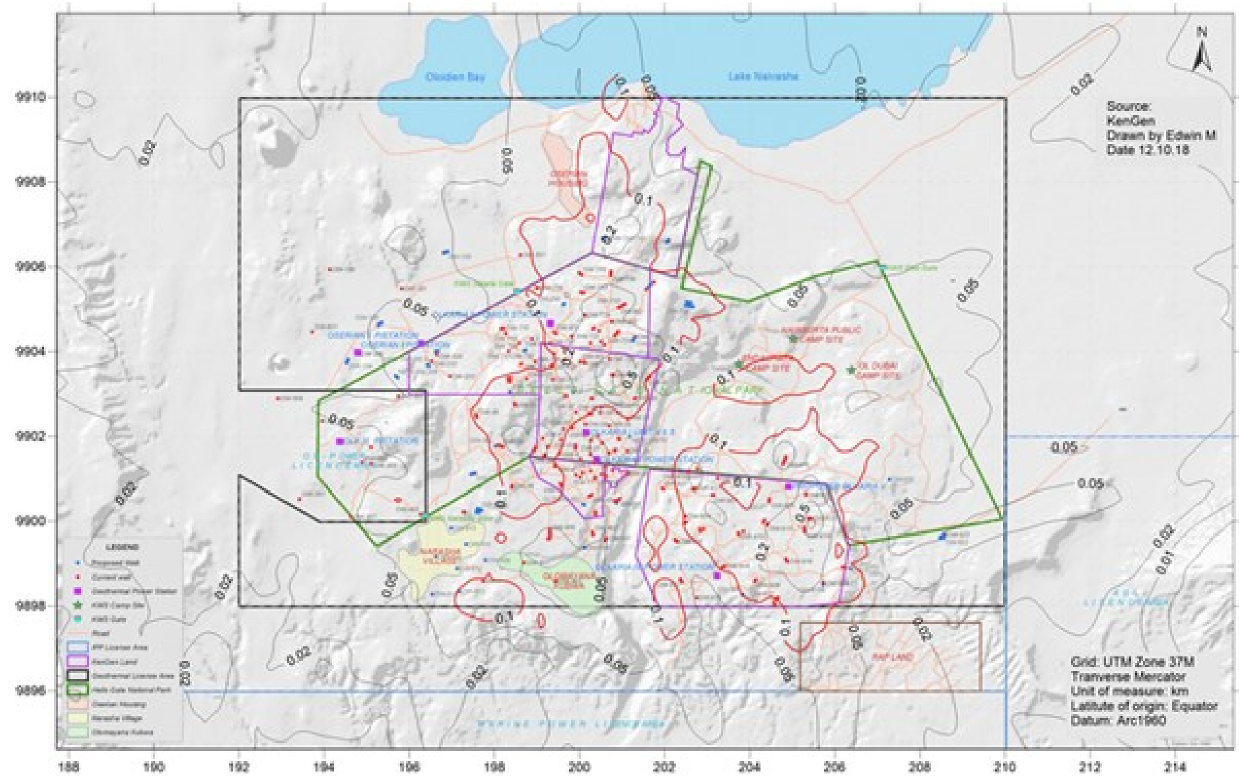

Figure 11: Predicted maximum 24-hour average hydrogen sulphide concentrations for Case 3 operations (in ppm)

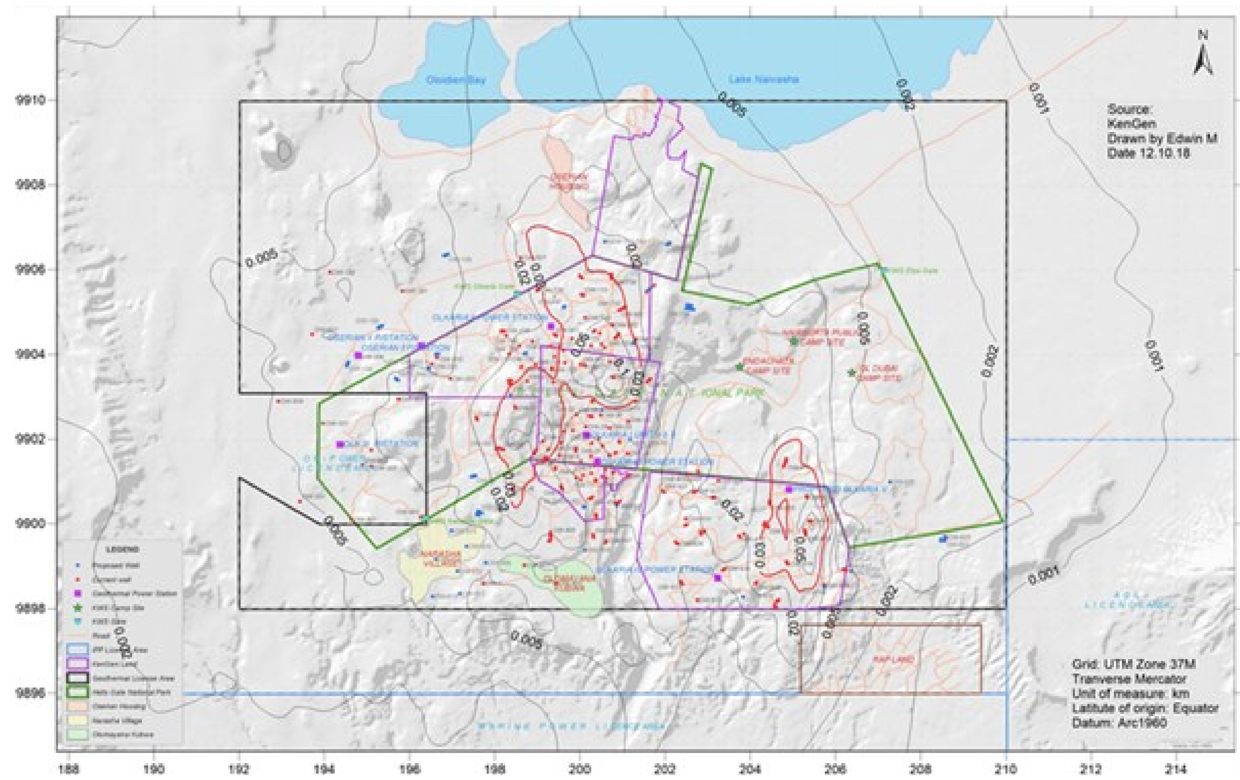

Figure 12: Predicted annual average hydrogen sulphide concentrations for Case 3 operations (in ppm)

7. CONCLUSION

The model results presented in this report show maximum 1-hour, maximum 24-hour and annual average predicted hydrogen sulphide concentrations for a number of development or operating options for Olkaria geothermal field. The maximum 1-hour average concentrations can be used to gauge the areas of land where hydrogen sulphide odours will be expected to occur. Odour is detectable (0.0046 ppm) over large areas extending over the order of 10 to 15 km and further from emission sources at Olkaria.

Case 3 show some residential areas (southern end of Oserian Housing and southern shore of Lake Naivasha) are predicted to experience 24-hour average hydrogen sulphide concentrations above the Kenyan and WHO 0.1 ppm level. The Kenyan 24-hour tolerance level is permitted to be exceeded two percent of the days (approximately seven days) in a year provided no consecutive days are included. Thus, in practice the Kenyan limit is likely to be complied within the Olkaria geothermal license area. It is important to note that the OW-733 and OW-R5, which dispose of non-condensable gases (NGCs) via gas ejectors rather than in the cooling tower air flow, have a disproportionately large influence on ground-level hydrogen sulphide concentrations, when compared with their power output. Similarly, the wellhead generating units are designed to use gas ejectors, and thus emissions are dispersed far less effectively than those released in either wet or dry cooling towers, where the additional plume-rise generated by the buoyant cooling tower emissions gives rise to much lower ground level concentrations.

Some areas are predicted to experience annual average hydrogen sulphide concentrations above the 0.03 ppm level, and these may include areas where commercial crops are grown for Case 3. The paper recommends use of hydrogen sulphide abatement techniques or binary system which has negligible hydrogen sulphide emissions if we are to operate all the installations under Case 3. Incremental development of proposed power plants is encouraged, as we verify our model results with actual data.

In the light of the predicted increase in the size of areas predicted to experience odour and the increase in frequency at which odour is predicted to be above the odour detection level it will be important to establish officially approved assessment criteria for hydrogen sulphide based on odour. There is a need to verify the estimated emissions of hydrogen sulphide used in these scenarios. This should be done both for existing emissions and for new sources when new wells are developed, and hydrogen sulphide emissions data can be collected.

Ambient monitoring of hydrogen sulphide concentrations using equipment with a sensitivity sufficient to detect likely ambient levels (e.g. 10-minute concentrations of 0.001 ppm) should be commenced at for example Oserian Housing, Lakeside Housing, or Olkaria Gate. These data could be used to assess the accuracy the model predictions made in this report. Alternatively, or as well as monitoring of short-term concentrations, it is suggested that passive monitors (diffusions tubes) could be used to monitor longer-term concentrations (monthly and annual average hydrogen sulphide concentrations). These would be useful in validating the modelling.

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