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Environmental risk assessment: case study of Eburru geothermal wellhead power plant

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Abstract

The broad objective of the study was to investigate potential environmental risks of Eburru wellhead geothermal power plant on the local community. Primary data on perception of the local community towards the potential risks was collected through focus group discussions, interviews and structured questionnaires. The questionnaires were administered to ninety five (95) households residing in four villages neighbouring the power plant in Eburru location, Gilgil Sub-county. Historical data on brine chemistry, noise and hydrogen sulphide (H_2S) gas was also reviewed and analyzed. The study found out that the local community consider Eburru wellhead power plant to impact them negatively. In terms of severity of the impacts, the highest ranked risk was associated with H_2S gas odour, followed by noise emission, atmospheric venting of geothermal fluids and brine discharge. The chemistry of the brine did not meet the recommended limit for effluent discharge into the environment. The ambient H_2S gas levels measured outside the boundary of the power plant exceeded the 24 hour average tolerant limit of 0.0355 ppm up to a distance of 100 m in the northern direction. Ambient noise levels exceeded the tolerable limit of 35 dB (A) up to a distance of 1100 m from the boundary of the power plant. The ambient noise level does not warrant hearing impairment. Atmospheric brine spray can cause damage to the surrounding vegetation due to elevated levels of boron. Relocation of the affected persons within a radius of 1.5 km from the boundary of the power plant is recommended. Other measures include use of engineering measures to reduce noise, H_2S and atmospheric spray of brine, installation of a reinjection system and stepping up education and awareness among the locals. Precautionary principle should be considered in the initial design of future geothermal power plants. Further research should consider studies on diurnal variation of H_2S gas emission, epidemiological studies to determine real impacts of noise and H_2S on the health of the locals and an experiment to determine the fall out area of atmospheric brine spray and deposition.

Keywords: Precautionary Principle; Wellhead; Eburru; Community Perception

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1. Introduction

Eburru wellhead geothermal power plant was commissioned by KenGen in 2012. The power plant is located in Eburru location, Gilgil subcounty in Nakuru county. The power plant lies within Eburru forest and in its immediate neighbourhood we have some households residing in four villages. Understanding how the local community perceive geothermal energy development is vital. This is because the public should be provided with an opportunity to contribute to the project planning process in order for the project to receive public support. In so doing, the tension between developers like KenGen and the local communities can be reduced thereby providing momentum to the government's desire to spur geothermal energy development. This study has contributed towards identification of concrete measures whose implementation by KenGen will positively influence the community's perception of risks associated with operation of the wellhead power plant. Positive attitude will guarantee accelerated expansion of geothermal energy.

2. Background of the Study

2.1. Planning for geothermal energy development

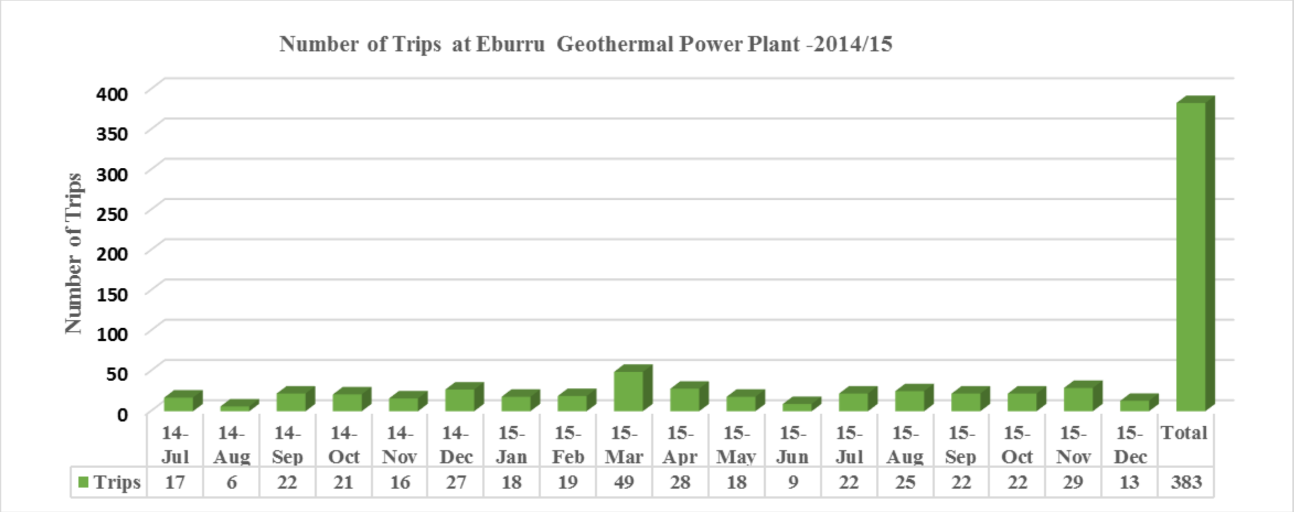
Energy production and use present the biggest challenge to the quality of the environment as opposed to other economic activities (Goodstein, 2002). In this regard, the fundamental concepts of environmental and social sustainability in the energy sector are presently recognized by a wide range of stakeholders including policymakers, development institutions, and society at large (Energy Sector Management Assistance, 2012). If sustainable development goals are to be attained, then there is need to ensure a holistic integration of economic, social and environmental concerns in the energy development process (Economic Commission for Africa, 2005 and Nuclear Energy Agency, 2002). The Kenyan government has committed resources to enhance accelerated development of geothermal energy thus making the country one of the fastest growing geothermal markets in the world (Matek, 2013). These efforts are facing a setback because they are not backed with an effective energy planning system. The planning process is in most cases not very well organized, lacks adequate stakeholder participation component and does not adequately address social and environmental issues (United Nations Environment Program, 2006b). In the wake of societal change and rapid technological development which could result to potential impacts capable of posing irreversible risks to human health and that of the ecosystem, there is need for enhancing the energy planning process (World Health Organization, 2004). This should entail scaling up stakeholder engagement strategies relative to the risks and impacts that the energy project is likely to create (International Finance Corporation, 2007). Proper understanding of how the local community perceive the Eburru geothermal wellhead power plant would greatly assist in planning for future expansion of geothermal projects (Firestone, Kempton, Lilley and Samoteskul, 2012).

2.2. Precautionary principle

The precautionary principle states that in the case of serious or irreversible threats to the health of humans or the ecosystem, acknowledged scientific uncertainty should not be used as a reason to postpone preventive measures (World Health Organization, 2004). In this context, uncertainty refers to a situation where well-founded hypotheses of potential negative impacts are there, yet it has not been proven to cause harm to human health or the ecosystem (Renn, Stirling and Muller-Herold, 2004). Uncertainty could be as a result of limited knowledge, inadequate empirical information, as well as biases or imperfections in the instruments, models or techniques used to investigate the real impact on human health or the ecosystem (Milieu Ltd, 2011). Precautionary approach with respect to risk management can take many forms ranging from implementation of pollution-prevention measures to placing the burden of proof safety on the person or proponent intending to carry out an activity that is likely to cause harm (United Nations Environment Program, 2006a). Undertaking studies on public perception may help to provide vital information on the possible risks associated with a certain technology thus contributing towards identification of appropriate mitigation measures (Omanga, Ulmer, Berhane and Gatari, 2014).

2.3. Eburru wellhead geothermal power plant

Based on their design and characteristic of the reservoirs, geothermal power plants are known to have very low planned and unplanned outage rates (Kagel, Bates and Gawell, 2007). Despite the well-known availability factor, Eburru wellhead geothermal power plant experiences frequent trips ever since it was commissioned in 2012. For instance within the period July 2014 and December 2015, the number of trips was 383 as shown in figure 1.



	14-Jul	14-Aug	14-Sep	14-Oct	14-Nov	14-Dec	15-Jan	15-Feb	15-Mar	15-Apr	15-May	15-Jun	15-Jul	15-Aug	15-Sep	15-Oct	15-Nov	15-Dec	Total
🟩 Trips	17	6	22	21	16	27	18	19	49	28	18	9	22	25	22	22	29	13	383

Figure 1. Number of trips at Eburru wellhead power plant between July 2014 and December 2015 (KenGen, 2014 and 2015)

Any time a geothermal power plant experiences outages or trips, steam has to be vented directly to the atmosphere (Nolasco, 2010). The reason for carrying out atmospheric venting of the geothermal fluids is to maintain stable operational control or to start-up or shut-down a geothermal power plant (Harwood and Hunt, 2014). Like any other geothermal power plant, the main environmental impacts associated with operation of

Eburru geothermal power plant revolve around air pollution, discharge of solid and liquid wastes, and noise emission (Nguyen, Caskey, Pfundstein and Rifkin, 1980).

3. Problem statement

Since commissioning of Eburru wellhead geothermal power plant, antagonism between the local community and KenGen has been witnessed due to negative perception of the risks associated with the power plant. The perception is as a result of noise, hydrogen sulphide gas and atmospheric venting of hot geothermal fluids. Farmers have complained about crop damage brought about by atmospheric venting of geothermal fluids. To address these concerns, some of the affected farmers were compensated by KenGen in 2012 and 2016. Continual negative community perceptions and protests, will considerably derail the government's efforts to accelerate geothermal development thus the need to investigate the concerns raised and recommend a long lasting solution.

4. Objectives of the Study

4.1. Broad objective

The broad objective of the study was to investigate potential environmental risks of Eburru wellhead geothermal power plant on the local community.

4.2. Specific objectives

The specific objectives of the study were to:

1- Explore communities' perception towards Eburru geothermal power plant in terms of environmental and social risks;

2- Analyse the data on chemistry of geothermal brine released from the rock muffler of the power plant vis-à-vis water quality standard;

3- Analyse the measured levels of noise and hydrogen sulphide gas emissions from the power plant vis-à-vis the air quality and noise standards and

4- Determine whether Eburru wellhead geothermal power plant presents any risk to the local community in the neighbourhood.

5. Methodology

Stratified random sampling of ninety five (95) households located in four villages neighbouring Eburru geothermal wellhead power plant was used in this research. The villages were Ex-Lewis, Ex-Major, Ex-Morgan and Ex-Peter. Ex-Lewis is the closest village to the power plant and the houses are marked green in figure 2. The area below geothermal well EW-02, southern side, is Ex-Peter while Ex-major is located to the north of well EW-06 extending towards Songoloi Primary School. To the east of well EW-03 is Ex-Morgan village which is the furthest village from the power plant.

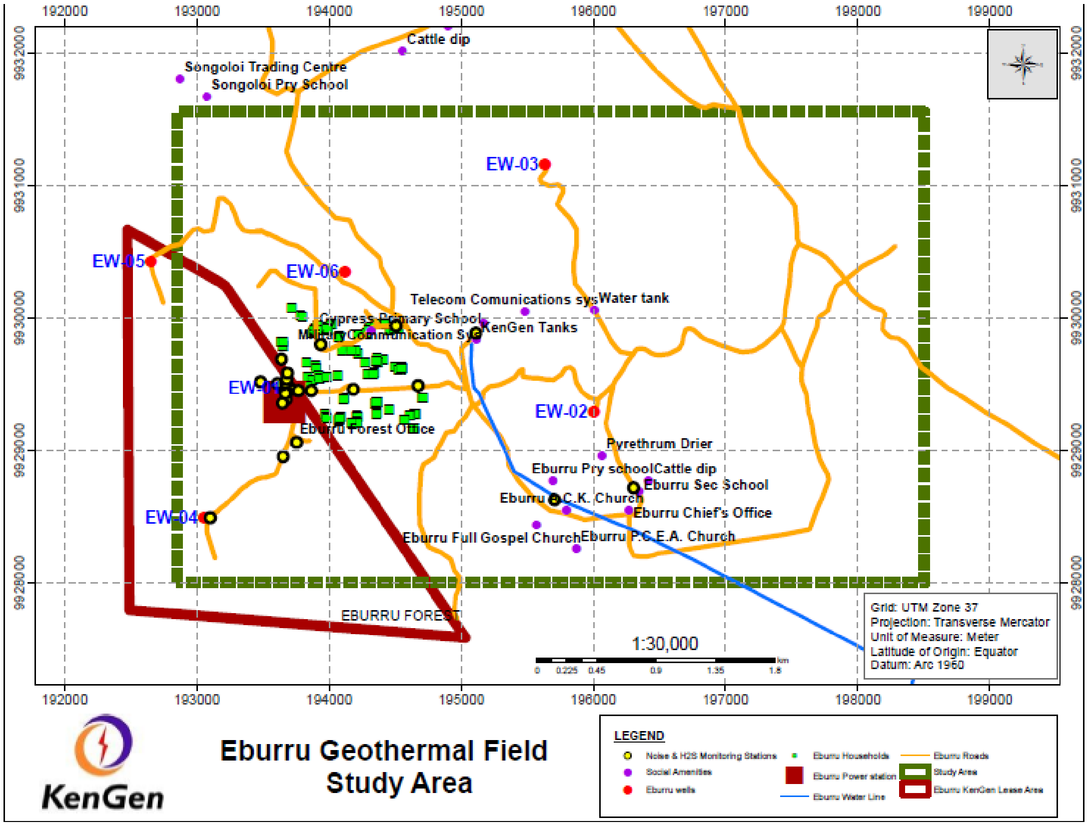


Figure 2. Map showing the study area

The study also relied on a set of historical data on brine chemistry, noise and hydrogen sulphide gas emission maintained by KenGen since commissioning of Eburru geothermal wellhead power plant. A triangulation approach was used to analyze the findings on perceptions of the local community. Brine chemistry, noise and hydrogen sulphide gas levels were analyzed vis-à-vis the applicable standards.

6. Results and Discussions

The results of the study are presented below.

6.1. Respondent's perception on Eburru power plant

6.1.1. Sample population

Table 1 and figure 3 shows the sample size per village that completed the questionnaires.

Table 1. Sample size per village

Village	Ex-Lewis	Ex-Peter	Ex-Morgan	Ex-Major
Sample Size Per Village	30	25	20	20

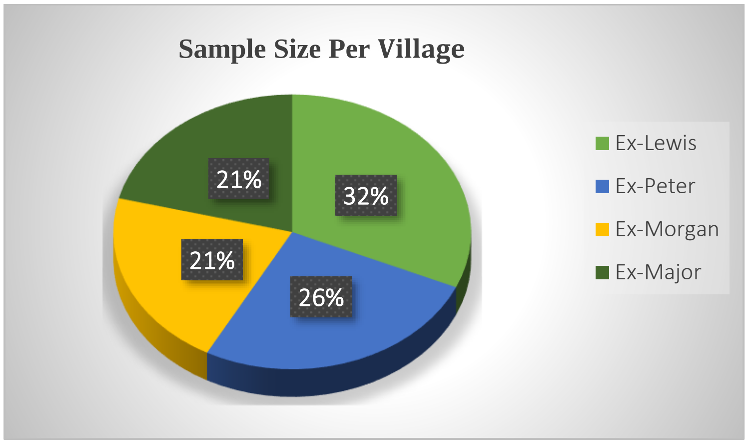
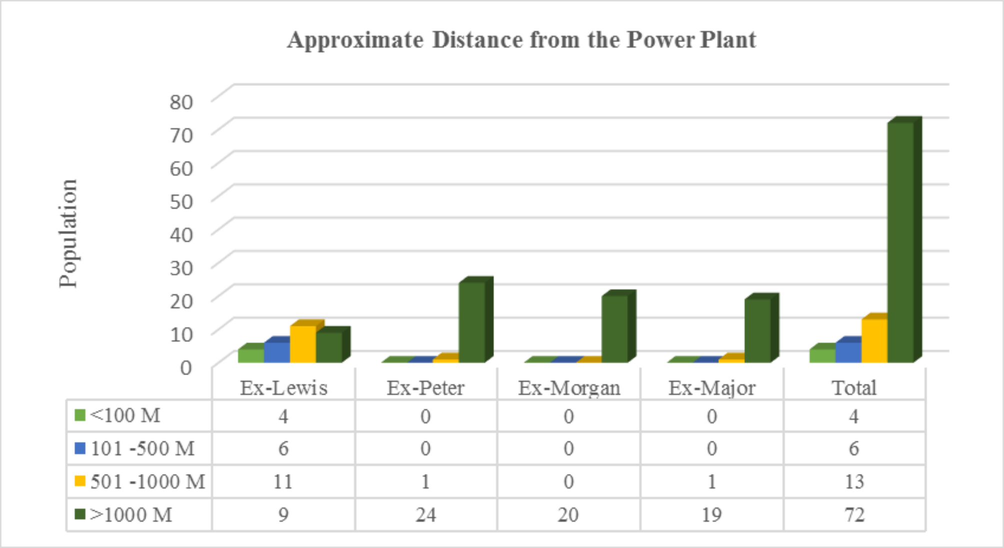


Figure 3. Sample size per village

6.1.2. Approximate distance of the respondent's homesteads from the power plant



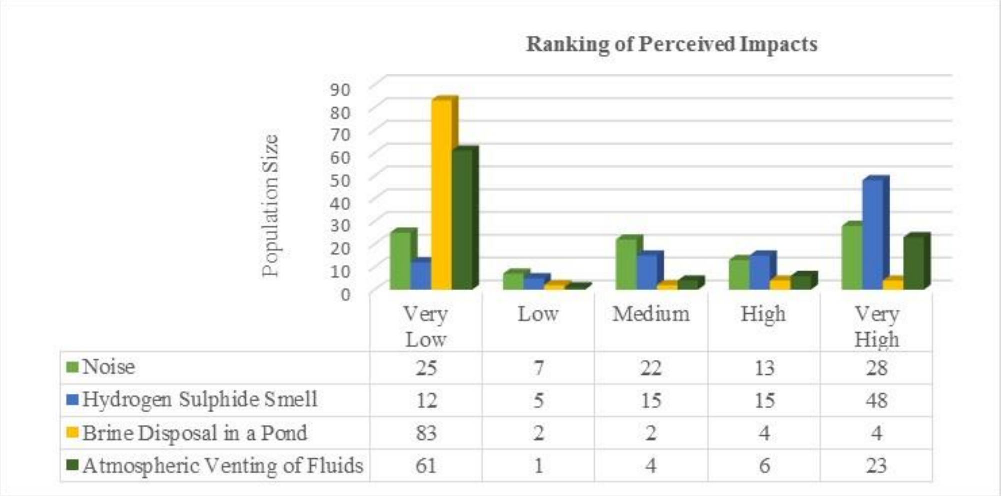
	Ex-Lewis	Ex-Peter	Ex-Morgan	Ex-Major	Total
<100 M	4	0	0	0	4
101 -500 M	6	0	0	0	6
501 -1000 M	11	1	0	1	13
>1000 M	9	24	20	19	72

Figure 4. Approximate distance of respondents' homesteads from the power plant

The respondents were required to specify the approximate distance of their homesteads from Eburru wellhead geothermal power plant. Figure 3 shows that 4% (4) of the respondents stay within 100 m from the power plant, 6% (6) within 101 -500 m, 14% (13) within 5001 -1000 m and 76% beyond 1000 m from the power plant. Majority 22% (21) of those who stay within 1000 m from the power plant are from Ex-Lewis village.

6.1.3. Ranking of perceived impacts

From the results obtained on the perceived environmental impacts of Eburru geothermal wellhead power plant, the researcher ranked the impacts based on the perceptions of severity of the impacts as pointed out by the respondents. As shown in Figure 5, 66% (63) of the respondents felt that hydrogen sulphide gas odour had high to very high impact followed by noise emission {43% (41) of the respondents}, atmospheric venting of geothermal fluids {31% (29) of the respondents} and brine disposal in a containment pond {8% (8) of respondents} as the least. The finding on Hydrogen sulphide is consistent with what has been documented. H_2S is the major pollutant that is deemed to result to the greatest environmental impact due to its odour smell and toxicity (Kagel, Bates and Gawell, 2007).



	Very Low	Low	Medium	High	Very High
🟩 Noise	25	7	22	13	28
🟦 Hydrogen Sulphide Smell	12	5	15	15	48
🟨 Brine Disposal in a Pond	83	2	2	4	4
■ Atmospheric Venting of Fluids	61	1	4	6	23

Figure 5. Ranking of Perceived Impacts by the respondents

6.1.4. Perception of hydrogen sulphide gas emission on human health

According to Figure 6, 55% (52) of the respondents perceive hydrogen sulphide gas emission to have a negative impact on human health. Majority of those who perceive hydrogen sulphide to have negative health impacts were from Ex-Lewis village 22% (22) followed by Ex-Peter 13% (12), Ex-Major 12% (11) and Ex-Morgan 8% (8). A similar study on the perceived impact of odour from Pajam and Ampar Tenang landfills found out that 80.5% of the respondents attributed their ill health to the foul smell (Sakawi, Mastura, Jaafar and Mahmud, 2011). For the case of Eburru, 66% (63) of the respondents perceived hydrogen sulphide gas odour to be high to very high. It can therefore be concluded that perception of odour effect has a positive correlation with the perceived negative health impacts associated with a pollutant in question.

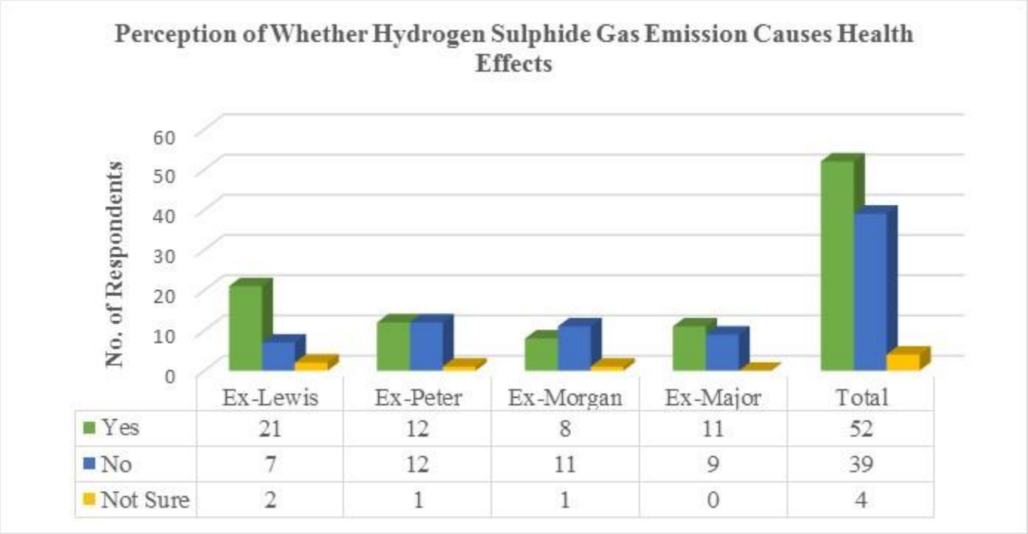


Figure 6. Perception of hydrogen sulphide gas on Human Health

6.2. Analysis of the quality of brine

Data on brine quality was analysed by obtaining the mean values for each parameter and comparing it with the standard of effluent discharge into the environment as provided for by the third schedule of the Environmental Management and Coordination (Water Quality) Regulations, 2006 (Government of Kenya, 2006). For the parameters whose standard had not been provided in this regulation, the gap was filled by making reference to the water quality standard provided by Environmental Protection Agency (Environmental Protection Agency, 2001). The results are presented in tables 2 and 3.

Table 2. Analysis of concentrations of non-metals in brine samples

Period	**Measured Parameters (Non Metals) in Brine Sample from the Weir Box**				
	pH	**Electrical Conductivity (µs/cm)**	**Total Dissolved Solids (TDS) mg/l**	**Chlorides (mg/l)**	**Sulphates (SO4) mg/l**
15-02-2012	9.53	4850	2410	35.5	134.3
14-12-2012	9.35	2994	1498	1358.94	
Mean	**9.44**	**3922**	**1954**	**697.22**	
Limit	6.5 -8.5	1000	1200	250	200
Reference Std	NEMA	EPA	NEMA	NEMA	EPA

Table 3. Analysis of concentrations of metals in brine sample

Period	**Measured Parameters (Metals) in Brine Sample from the Weir Box**					
	Barium (Ba) mg/l	**Boron (B) mg/l**	**Cadmium (Cd) mg/l**	**Copper (CU) mg/l**	**Lead (Pb) mg/l**	**Zinc (Zn) mg/l**
Qtr 2-11/12	0.27436	6.9869	0.002208	0.027951	0.000798	0.019863
Qtr 1-12/13	0.08162	3.0151	0.00485	0.00189	0.00612	0.08421
Qtr 2-12/13	0.01018	0.0183	0.000576	ND	0.01158	0.09845
Mean	**0.122053333**	**3.3401**	0.002544667	0.0149205	0.006166	0.067508
Limit	0.1	1	0.01	1	0.01	0.5
Reference Std	EPA	NEMA	NEMA	NEMA	NEMA	NEMA

These findings indicate that the pH, electrical conductivity and concentrations of Total Dissolved Solids (TDS), Chloride, Barium and Boron exceeded the tolerable limits. In his study of geothermal fluid from well E-01 at Eburru, Arusei (1991) found the concentration of boron, TDS, conductivity, chloride and pH to exceed the tolerable limits for effluent discharge into the environment. Wetangula (2004) also found the concentration of boron (2150 µg/l) from Olkaria geothermal field to be higher than the recommended level. Presence of boron in geothermal fluids has the potential of causing harm to the surrounding vegetation (Asia Pacific Energy Research Centre, 2015). In Philippines, it was observed that atmospheric venting of the production well generated geothermal brine spray that caused defoliation of the surrounding dense forest vegetation up to 100 metres from the well (Lacambra et al., 2008). Severe injury to plants is observed even at a distance of 200 meters from the source and mild injury may be observed up to 500 meters in all the directions from the source (Gheorghe and Ion, 2011).

6.3. Analysis of hydrogen sulphide (h2s) gas emission

The measured hydrogen sulphide levels in 2013 and 2016 are shown in tables 4 and 5.

Table 4. Measured Hydrogen sulphide gas levels in 2013

Measured Ambient Hydrogen Sulphide Gas Levels (in ppm) Within the Perimeter Fence					**Ambient H_2S Gas Levels (in ppm) Measured in the Northern Direction**	
Time	**Date**	**Rock Muffler**	**E01 Wellhead**	**Turbine**	**50 m**	**100 m**
8.10am-1.45pm	14.06.13	**0.2**	0.0	0.0	**0.2**	0.0
9.30am-2.00pm	17.06.13	0.0	**0.2**	0.0		
9.00am-2.10pm	18.06.13	0.1	0.0	0.0	0.0	0.0
8.30am-2.20pm	19.06.13	0.0	**0.3**	0.0	**0.1**	0
8.40am-1.45pm	20.06.13	**0.1**	**0.2**	0.0	0.0	**0.1**
9.00am-1.50pm	21.06.13	0.0	0.0	0.0		
11.20am-3.50pm	25.06.13	**0.1**	0.0	0.0	**0.1**	**0.2**
9.00am-2.30pm	26.06.13	0.0	**0.2**	**0.1**		
8.45am-2.20am	27.06.13	**0.2**	0.0	0.0	**0.1**	0.0

Table 5. Hydrogen sulphide gas levels measured in 2016

Ambient Hydrogen Sulphide Gas Measurement within Perimeter Fence					**H_2S Levels Outside Perimeter Fence in Northern Direction**		
Elevations (M)	2592	2589	2596	2593	2591	2602	2608
Northings	9929483	9929482	9929385	9929357	9929509	9929537	9929582
Eastings	193668	193686	193676	193649	193674	193682	193688

Location		**Rock Muffler**	**EW-01 Wellhead**	**Cooling Tower**	**Turbine**	**25 m**	**50 m**	**100 m**
Plant Status	**Date**	**Measured Hydrogen Sulphide Gas Levels**						
Operating	15.03.16	0.043	0.004	0.005	0.047	0.13	0.005	0.005
Shut Down	10.06.16	0.000	0.000	0.000	0.004	0.001	0.000	0.000

The first schedule of the Environmental Management and Coordination (Air Quality) Regulations, 2014 provides the ambient air quality tolerance limits (Government of Kenya, 2014). According to this schedule, the 24 hour average ambient tolerant limit for H_2S is 150 μg/m³ (0.1065 ppm). The schedule also stipulates that the 24 hour average ambient tolerance limit for H_2S measured at the property boundary should be 50 μg/m³ (0.0355 ppm). The regulation further provides that the 24 hour average tolerant limit should not be exceeded more than three times in one year (Government of Kenya, 2014).

The ambient H_2S gas levels measured outside the boundary fence exceeded the recommended limit of 0.0355 ppm six times. In the northern direction, the highest measured H_2S level (0.2 ppm) exceeded the tolerance limit by a very big margin (463%) since this is the direction where winds blows to. The findings imply that long term exposure to H_2S levels exceeding 0.0355 ppm has the potential of creating a health risk for the residents of Ex-Lewis village residing within 100 m from the boundary of Eburru geothermal wellhead power plant. 4% (4) of the sampled respondents stay within 100 m from the boundary of the power plant.

Bearing in mind that H_2S gas odour can be detected by 20% of the population at a concentration of as low as 0.002 ppm (Layton, Anspaugh and O'Banion, 1981), the nuisance effect would extend up to a distance of 200 m to the north (0.009 ppm), 940 m to the Northeast (0.003 ppm), 200 m to the West (0.005 ppm), 500 m to the south (0.006 ppm) and 2750 m (0.003 ppm) to the East from the boundary of the plant. In terms of risk of dour, the most impacted village is Ex-Lewis followed by Ex-Peter. 14% (13) respondents stay within a distance of 5001 -1000 m from the power plant. The risk of odour will also culminate into annoyance reactions which will intensify other responses, such as headaches and fatigue for those who will smell it. A similar study on the perceived impact of odour from Pajam and Ampar Tenang landfills found out that 80.5% of the respondents attributed their ill health to the foul smell (Sakawi, Mastura, Jaafar and Mahmud, 2011). However, the low levels of H_2S have got no negative effects on the crops or surrounding vegetation. Layton, Anspaugh and O'Banion, (1981) examined the potential effects of H_2S emissions on forest plants and crops and concluded that it favoured growth enhancement as opposed to retarded growth or damage. Similarly, an isotopic study of woolly fringe moss from lava fields around Hellisheiði and Nesjavellir geothermal power plants in Iceland also found no correlation between H_2S and decline of vegetation around the power plants (Gautason and Widory, 2015).

6.4. Analysis of noise emission

In line with the precautionary principle, analysis of the ambient noise levels was done against the night time permissible noise level of 35 dB(A). This is because the power plant operates for 24 hours and it is assumed that the noise levels emitted from the source is somehow constant. Table 6 shows the measured ambient noise levels that exceeded the maximum permissible ambient noise limit of 35 dB(A) outside the boundary of the power plant where the local community reside.

Table 6. Measured ambient noise levels based on levels that exceeded the maximum permissible noise limit of 35 dB(A)

Noise Level Outside the Boundary of the Power Plant Based on Levels that Exceeded Maximum Limit of 35 dB(A)					
Direction from the Power Plant	**Distance (M) from the Boundary of the Plant**	**Number of Monitoring Times (n)**	**Frequency {Number of Times Maximum Limit of 35dB(A) was exceeded}**	**Range dB(A) {Measurement above 35 dB(A)}**	
				Highest Level	**Lowest**
Eastern	50	10	10	68.3	61.2
	100	10	10	62.3	49.7
	250	9	8	43.1	36.7
	500	10	5	39.5	35.6
	910	8	8	39.3	36.8
	1000	9	1	36.4	
Southern	55	9	9	80.6	69.2
	200	4	4	55.8	43.2
	500	4	0	34.7	30.6
South Eastern	100	5	5	58.7	54
	200	5	5	45.2	44.3
	450	5	4	46.7	36.4
	600	5	1	41.7	38.1
	900	5	1	37.5	
	1090	5	0	34.8	32.7
Northern Direction	50	6	6	74.3	63
	100	6	6	89.4	58.1
	650	4	0	34.7	25.1
North Eastern	325	4	3	46.2	35.6
	700	4	0	34.4	25.7
North Western	260	4	4	43.6	39.8
	500	4	4	54.3	43.7
	900	4	3	41.2	38.1

The results indicate that the safe margin (area where the noise levels are within the maximum permissible ambient noise limit) from the boundary of the power plant in comparison with the ambient noise levels stretches from as low as 500 m in the southern direction to 1090 m in the south eastern direction. The areas inhabited by the local community in Ex-Lewis and Ex-Peter villages are in the Northern, North eastern and

Eastern directions where the safe margin ranges from 650 m in the north to a distance slightly above 1000 m in the eastern direction. According to World Health Organization (1999), long-term exposure to 24 hour average noise levels of up to 70 dB(A) cannot result to hearing impairment.

7. Recommendations

Compensation for crop damage should be treated as a short term measure which is likely to result to compensation syndrome. This would jeopardize future expansion of the geothermal energy development in Eburru. For this reason, relocation of the affected farmers in Ex-Lewis village should be considered as the most appropriate long term measure. In line with precautionary principle, relocation would result to the avoidance of potential health risk and annoyance effects. The relocation should cover a radius of 1.5 km from the boundary of the power plant.

When planning to carry out vertical discharge of geothermal fluids, the local community should be informed beforehand and where feasible discharge should be done during day time, 8.00 am to 6.00 pm. This would minimize the potential negative effect on noise.

Use of engineering measures should be adopted to minimize the potential risk of noise, atmospheric discharge of geothermal fluid and H_2S emissions. Such measures include use of vertical diffuser to minimize the fall out area of the geothermal fluids, use of improved mufflers to minimize high noise levels and H_2S abatement techniques.

Even though the brine presents very low risk to the environment, installation of a reinjection system should be considered. This measure will prevent the potential for brine discharge into the environment and also minimize contact with the local community.

There is need to step up education and awareness among the local community on the potential impacts of geothermal energy technology and what KenGen is doing to address them. Such a move is likely to change the attitude of the community towards Eburru geothermal wellhead power plant.

Installation of a continuous H_2S monitoring system at a strategic point near the rock muffler and E01 wellhead will enhance the monitoring process thus ensuring compliance with the Environmental Management and Coordination (Air Quality) Regulations, 2014.

The local community should be actively involved in developing small size projects addressing their local rural needs. This would include installation of condensing units for harvesting condensate from fumaroles since Eburru area is a water scarce area and facilitating power connection to their houses. Such initiative would change their perceptions.

Further research should consider studies on diurnal variation of H_2S gas emission, epidemiological studies to determine actual impacts of noise and H_2S on the health of the locals and an experiment to determine the fall out area of atmospheric brine spray and deposition.

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