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

Kā Rongo te Hā o Rūaumoko… Ka Mua, ka Muri – Understanding the Impacts of Air Pollution from Past to Present

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Keywords: Whakarewarewa Village, Rotorua; atmospheric H_2S concentrations; hauora (health); air pollution.

ABSTRACT

The Whakarewarewa Village Charitable Trust has been collaborating with GNS Science for the past four years to build a framework for integrating related scientific data and Mātauranga-a-iwi. The focus of our work has been to better understand the immediate and chronic health effects caused by air pollution events.

As outlined in the attestation letter from the Whakarewarewa Village Charitable Trust, the opportunity to undertake this project has been really exciting for us. It has allowed us to incorporate our own indigenous knowledge alongside western science understanding of the historic volcanic eruptions at Mt Tarawera, used by our guides with 300,000 plus annual visitors to Whakarewarewa Village.

Our joint design of the project with GNS Science took into account the realities of living with natural hazards and adapting to this environment. Information was shared at hui and regular group governance meetings. Our research team contained experts from Whakarewarewa Village and GNS Science who shared an interest in exploring synergies between the two knowledge systems. A large report entitled: Effect of air pollution on humans exposed to extreme environmental conditions - Transition of Tūhourangi, following the 1886 Mt Tarawera eruption- has resulted from this work. This was a significant achievement and underpins our successful partnership with GNS Science in air pollution science. The success of this project and our partnership has laid the foundation for identifying new research opportunities. For the last two years Whakarewarewa and GNS Science have been successful in obtaining a second Vision Mātauranga project entitled: **Te haurehu waikawa pungatara e pa ana te kaimahi Māori - Impacting of H_2S on Māori workforce**. This project is presented in this paper.

Both organisations are looking forward to building our Mātauranga Māori and science capability into the future.

1. INTRODUCTION

Whakarewarewa is an iconic centre of Māori culture and of geothermal features in the New Zealand. Residents at Whakarewarewa over the decades have witnessed an evolution in geothermal and cultural tourism, now encompassing 200 years of traditional knowledge, guiding and innovation, and have developed guidelines to ensure sustainable energy resource and economic development opportunities will continue to flourish in the future.

This cultural and science research examines the effects of the geothermal environments upon Tūhourangi-Ngāti Wāhiao – people living at Whakarewarewa. The study focuses on a research approach drawn from two different knowledge systems, through kaupapa Māori and Western Science. The integration of mātauranga-ā-iwi and geothermal gas impacts data provides unique insights into understanding the effects of geothermal gases upon the health of Tūhourangi-Ngāti Wāhiao ki Whakarewarewa.

1.1 Background

The Tuhourangi/Ngāti Wāhiao people have lived in and around the thermal area at Whakarewarewa for more than 200 years. An opportunity arose in 1997 for the people of Tūhourangi-Ngāti Wāhiao to initiate an independent tourism experience through Whakarewarewa, and consequently established The Whakarewarewa Thermal Village Tours (in 1998) under the umbrella of the Whakarewarewa Village Charitable Trust.

GNS Science and Whakarewarewa Village Charitable Trust are working together to demonstrate a framework for integrating related scientific data and Mātauranga-a-iwi (traditional knowledge of the tribe and its land base) to better understand hydrogen sulfide (H_2S) emissions behaviour surrounding the Whakarewarewa Village, and the possible impact on human health. The research team contains experts who share an interest in exploring synergies between these two knowledge systems (Figure 1). Whakarewarewa - The Living Māori Village, provides guides and other staff for tourism businesses, and this project targets improvements in the workforce to realise opportunities in growing the business and ensuring the health of the Māori workforce. This research has two mutual benefits:

1. to improve Māori understanding of the science of hydrogen sulfide and the possible risk to human health when exposed to high concentrations, and;
2. corroboration of historical and current events concerning hydrogen sulfide and its possible health effects.

Figure 1: (Left) GNS house located in the Whakarewarewa village; (Right) Whakanuia day (6th February 2015) at Whakarewarewa with GNS Science staff at the GNS house.

1.2 Objectives

In this study, there are three overarching goals:

1.2.1 Mātauranga-a-Iwi ki Whakarewarewa

Māori conceive the arrival of geothermal waters, heat and energy as being quite separate in time from the creation of the land. There is acceptance amongst Māori historians, especially those that whakapapa (are related) to the story's descendants, whenua and taonga, that the origin of geothermal activity in the volcanic plateau is from Ngātoroirangi and his sisters, Kuiwai and Haungaroa, and the goddesses Te Pupu and Te Hoata. According to the late tohunga whakairo (master carver) and historian Te Keepa geothermal origins are credited to Te Pupu and Te Hoata who brought "fire to the shores of these islands".

This example of Mātauranga Māori, which is, the unique Māori way of viewing the world, encompassing both traditional knowledge and culture to preserve their culture and identity, and the relationships that culture and identity derive from environmentally-located knowledge within tribal lands. It follows that Mātauranga Māori, and kaupapa Māori theory, with their roots in mātauranga-a-iwi, must ultimately be understood as a relationship between the tribal environment and its people. Recollection of oral histories, tradition and mōteatea (waiata, haka) on H_2S gas for the Whakarewarewa geothermal area on Tūhourangi-Ngāti Wāhiao helped to understand the health impact that H_2S could have.

1.2.2 Pātaka Mātauranga

Geothermal areas have historically been used by Māori for their curative properties, especially for skin diseases and rheumatism. Since firewood was not easily found in the central volcanic region, hot springs were also essential for cooking. Indeed, from time immemorial Māori have used thermal springs as a natural kitchen, whilst housing around the volcanic regions were deliberately built over hot springs as a form of natural central heating. Settlement patterns were determined by access to surface geothermal activity because they were essential for daily activities, such as cooking, bathing and curing aliments, in a region that was otherwise agriculturally deficient. It is unsurprising, that Māori developed a strong spiritual and cultural connection with the geothermal areas (Figure 2).

Figure 2: Te Arawa people occupied the valley in 1325, generations of guides to pioneering leaders of tourism today.

The goal of this Pātaka Mātauranga is examining current cultural assets through a resilience lens and to develop adaptive and transformative strategies within a merged science-based and Māori framework. This will be achieved within a range of case studies concentrating on assets relating to Whakarewarewa with science hazard data augmented by local Mātauranga.

1.2.3 Knowledge Transfer

Sharing of research findings and experience was performed through wānanga, development of resources and guiding of information. Māori researchers will develop a greater understanding of the scientific and technical detail for geothermal resources. The integrated approach assisted all team members, the wider Tūhourangi-Ngāti Wāhiao stakeholders, and ultimately other groups across New Zealand, to benefit from this work and understand how it will contribute to future decision making, resource management and community resilience.

2. TŪHOURANGI-NGĀTI WĀHIAO KI WHAKAREWAREWA – CONTEXT

Nau mai, haere mai, "Welcome to our World" a living culture, utilising the gifts of Papatūānuku, [earth mother] to provide sustenance to ourselves and our guests. Whakarewarewa -The Living Māori Village (Whakarewarewa), also known as *Te Whakarewarewa-o-te-ope-taua-a-Wāhiao* is a *pa* (fortified village) where the *Tūhorangi-Ngāti Wāhiao ki Whakarewarewa* tribe carry out their daily lives amongst the geysers, steam vents, mud pools and hot springs The tribe has a long established heritage of hosting international and domestic visitors for over two hundred years, and 'continue to demonstrate their utilisation of natural geothermal features for domestic, arts and crafts, and social activities' (Neilson et al, 2010). Whakarewarewa - The Living Māori Village is the only *pa* (fortified village) in the world where tourism, Māori culture and heritage, family homes, and businesses operate on a major geothermal field in an urbanised area. The village sits within the Whakarewarewa Geothermal Field regarded as a national treasure for its environmental, economic, cultural and scientific value. It contributes to an almost $30 billion tourist industry (Statistics New Zealand, 2015), which is the main driver for the Rotorua and Bay of Plenty regional economy. Most importantly, for the villagers of Whakarewarewa *pa* (village), it is home for Tūhourangi-Ngāti Wāhiao, and for their unique lifestyle to be protected, looked after and sustained for future generations (Tapuke and Markwitz, 2016).

Figure 3: Entranceway, Courtesy of Whakarewarewa - The Living Māori Village, 2016 (from Tapuke and Markwitz, 2016)

Whakarewarewa is located on the Rotorua Geothermal Field, and lies within the Okataina Volcanic Centre, and is bounded by the Taupō Volcanic Centre, within the Taupō Volcanic Complex – which is geologically active, and volatile. Major commercial forests, and four water tributaries feed into the Puarenga stream which passes through the village. It is also surrounded by residential and manufacturing areas (Figure 4).

Figure 4: Location of Whakarewarewa Village south of Rotorua and surrounded by geothermal features.

The health of Puarenga stream, and as a result, the health of the village is an ongoing concern due to the high level of contaminants found upstream from a combination of farming, forestry, industrial and waste water disposal sources. (Tūhourangi Tribal Authority, 2011). Puarenga is also a crucial ecological point where the freshwater and the geothermal waters mix to create a thermal stream (Kusabs and Shaw, 2008). In an assessment of the Puarenga stream, Suren and Lee (2014) observed that 'generations of children belonging to this village have dived for pennies in the Puarenga Stream. It is this long connection with the river that has fuelled a desire to see this stream once again safe for swimming'.

Land use intensification, industrial development and population growth around the fragile geothermal system area saw 50% of geysers disappear over a 30-year period in the Whakarewarewa area (Radio New Zealand, 1982). The sharp decline in geyser activity created a fear that the geothermal field would follow the same fate as the geysers in Wairakei and disappear. In 1987, the Minister of Energy passed legislation to shut down all bores within a 1.5 km radius of the geothermal field. In 2013, the Papakura Geyser came back to life after it stopped erupting in 1976. There is hope that many others will follow suit.

Critical to the village are the guides, who are genealogically connected to the thermal landscape, and maintain one of the oldest traditions in New Zealand's tourist industry spanning over 200 years. They have received over millions of visitors through their home since 1886 and are considered an institution. Not only are the descendants, and guides, of Tūhourangi-Ngāti Wāhiao long-term and sustainable investors in the local economy, they are also repositories of both ancient and contemporary knowledge of the village and its surrounding areas. Through this intimate knowledge with the volcanic and geothermal environment, the guides, supported by their tribe, has developed a unique knowledge system, *mātauranga-ā-iwi* (tribal knowledge).

Mātauranga-ā-iwi is the application of *mātauranga Māori* (Māori knowledge) to a specific locality. Mātauranga Māori is a composite knowledge base of mauri Atua (spiritual life-force), mauri whenua (environmental life-force), and mauri tangata (socio-cultural life-force) context, which transcends time and space, and multi-dimensionally expresses itself as ira (physical state) and mana (force and power). This knowledge system is embedded with values, principles and protocols around its use, and applicability for the area. The sustenance of their knowledge system is crucial to Tūhourangi-Ngāti Wāhiao, and this correlates with their own health and wellbeing.

The health of the guides and the villagers opens the question of air quality. Rotorua has the worst winter air quality in the North Island (Environment Bay of Plenty (EBOP), 2018). The National Environment Standard for Air Quality of 50 µg m^{-3} for PM_{10} (24-hour average) was breached 13 times in 2017 within the Rotorua Urban Air shed (EBOP, 2018). The air pollution is attributed mainly to home heating practices. There is limited data on the effects of natural geothermal gas emissions on human health. It is therefore of interest to examine the impacts of geothermal gases on health and wellbeing of those living in the village. The project advances and model's delivery across vision Mātauranga and science.

3. MATAURANGA-A-IWI KI WHAKAREWAREWA

3.1 Wāhiao -The People of Whakarewarewa

The Whakarewarewa thermal valley has important connections to Wāhiao, who is said to have assembled a war party of 140 men of Wāhiao in the valley to march against the Ngāti-Tama tribe at Rotorua.

Wāhiao was the great-great-great grandson of Tūhourangi. Mākereti Papakura describes the great mana held by them:

'*The mana of Tūhorangi commenced on the day of Tūhorangi the great ancestor. It was conferred on him by Rangitihi his father, above his elder brothers. There were seven older than he by different mothers. Tūhourangi was the youngest son. Their father made them walk under Tūhourangi. They did so with the exception of Rātorua who escaped the ceremony. Wāhiao being male direct descendant from Tūhourangi, the mana was inherited by him. He had a double mana, over the people and over the land*.'

Hone Tarawhiti tells of how Hōri Taiāwhio and Sophia (Te Paea) Gray, known as Guide Sophia, came to Whakarewarewa after the Tarawera eruption:

'*During post eruption Hōri and Sophia were relocated to Paeroa in Hauraki from their home of Te Wairoa. It was while they were living in Hauraki that Mita sent an invitation to Hōri Taiāwhio to come and live at Whakarewarewa. A plot of land was offered by the other Rangatira called Maika. They like many other families from Te Waiora who had been dispersed throughout Te Arawa to places like Awahou and Ōhinemutu, were invited to stay and live amongst their close relatives of the Wāhiao tribe. Maika gifted the land to Hōri and his family on account of Maika's marriage to the daughter of Hōri Taiāwhio, Te Paea Hinemahanga, who was also the daughter of Kapekape. This justifies that this family surely is one of many families that were provided aroha and support and became Tūhorangi ki Whakarewarewa*.'

Mauriora Kīngi – **kaumātua knowledge holder** wrote of Ngātoroirangi and his conquest of Tongariro; of Wāhiao and his mana over the people and the land; of Whakarewarewa and his own journey of connection with every hot lake, mud pool, geyser, fissure, spring and stream.

3.2 Relationship between Wāhiao and the Thermal Manifestations

Te Ao Māori – Māori World View

Many indigenous cultures share similar understandings about the special relationship that people have with the environment. Divine origins of the world and its people are chronicled in oral histories especially myths and legends which enshrine the spiritual dimension through accounts of cultural heroes. In Aotearoa, Ranginui (sky father) and Papatūānuku (earth mother) personify the progenitors of creation. Through their separation emerged Te Ao Marama, the world of being, the world we inhabit today.

He panui tenei kia haramai ki ta tatou hui tuatahi o te kapa o Tūhourangi Ngāti Wāhiao hei ako i te mōteatea a Mauriora ara "Me Timata i a Ngātoroirangi".

The pūrākau (legendary) recalls the journey of exploration by Ngātoroirangi. Ka u ki Matanuku – I arrive where unknown earth is under my feet. This is one of the incantations offered by Ngātoroirangi upon arrival in Aotearoa New Zealand.

"Me Timata e ahau i a Ngātoroirangi": this chant explains how geothermal activity came to Whakarewarewa. It was composed for Te Rōpū Ngāti Rotowhio (formely the NZ Maori Arts and Crafts staff, now Te Puia). The Te Arawa canoe made three landfalls; at Whangaparāoa, Te Awa-o-te-Atua (at Matatā), and [finally] Maketū. But when it landed at Te Awa-o-te-Atua, Ngātoroirangi and Tia got off [to explore inland]. A competition to be the first to arrive at the peak of Tongariro then began, with each claiming land along the way.

In the chant the names of boiling pools are recited even though some have dried up, but all the hot pools have relevance, have stories, and histories are retained from those pools. Therefore, there are many boiling pools that are named in this pātere (song). In the pātere we also name some of the sacred places, for instance Te Kūmete. Those were places where ancestors of Ngāti Tama lived. According to Taparoto Nicholson, he, Mauriora and Te Keepa Marsh eventually decided that the chant modelled on "Poia atu taku poi".

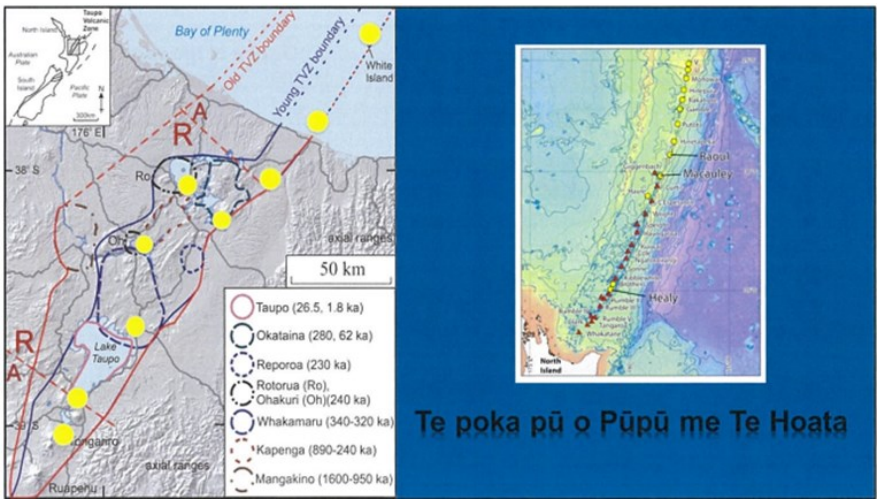

Figure 5: Pūrākau - The journey according to Te Arawa tradition –

Na matou te nuinga o te Arawa tenei: (1) Tonga trench; (2) Kermadec trench (Whakatane, Tangaroa, Ngatoro, Kuiwai, Hauhangaroa, Hinetapu, Putoto, Rakahere, Hinepuia, Monowai), (3) Te Paepae ki Aotea (Whakaari/White Island), (4) Mautohora, (5) Rotorua, (6) Tarawera, (7) Orakei Korako, (8) Wairakei, (9) Waihi, (10) Tongariro.

Pūrākau- means precise knowledge by which the ancestors recorded for perpetuity in traditional knowledge. Shared amongst a select few and considered (pono) the facts. Used today as a framework for those to apply reason, to inform decisions which assists to shape our futures. Particularly in relation to environmental issues and future management of natural geothermal resources.

Names of the pools, geysers, ngawhā, urupā and old settlements of the Whakarewarewa Thermal Valley are those of Tūhourangi ki Whakarewarewa and Wāhiao. The Waitangi Report on the Central North Island claims noted in 2008 that:

"At Whakarewarewa…Wāhiao can name every hot pool, mud pool, geyser, fissure, and stream, knowing how they are connected to each other."

Mauriora Kīngi composed a beautiful chant that recognises the ancestors and their relationships with these springs and geysers (Mare and Parker, 2017).

Huia Te Hau told the Waitangi Tribunal in 2005 how important the thermal resources are to Wāhiao identity:

'*Our mythology and legends are rich with examples of humans, gods and the thermal elements – the pursuit of Hatu Patu by the bird woman Kurangāituku who met her fate in a boiling pool in Whakarewarewa is a particular favourite. The names of every hot pool, mud pool, geyser, fissure, stream and in the thermal valley, how they are connected to each other and their respective function, the daily physical associations-all of these things provide a rich tapestry of knowledge, understanding and commitment, which our people over time strengthens our identity – who we are, where we are and why*.'

Huia said the resources at Whakarewarewa had long provided the people with '*life's basic needs; warmth and comfort and an economic base*.'

Jonathan Mane-Wheoki summarised the evidence of continued customary used of the Whakarewarewa geothermal amenities for Wāhiao in 1996: 'the ngāwha for bathing, healing and cooking – and the resources – raupō, flax, pigments and mud' from the period of early settlement onwards.

3.3 Hauora of people working and living at the Whakarewarewa village

GNS Science and Whakarewarewa Village Charitable Trust are working together to demonstrate a framework for integrating related scientific data and Mātauranga-a-iwi to better understand Hydrogen Sulfide (H_2S) behaviour surrounding the Whakarewarewa village, and the possible impact on human health.

A face to face survey was performed by Ringahora Huata and was designed to help us understand the impact of H_2S on people living and/or working in the village if any. The survey showed that the villagers are concerned about illness relating to asthma and worried as to what could be the cause. Two people shared a story on how gas might impact their health:

- Ringahora Huata (Manager of Tourist guides) on 28 March 2017, reported that: '*My daughter will be 14 years old in November 2017. From birth she has been having Asthma / Eczema. With the use of mud soap source from the village mineral water has seen clear skin. I am not saying modern medicine doesn't work, it didn't for my girl. It also saw a reduction of use on inhalers.*'

- A villager reported that: '*My sister is a chronic asthmatic so when I hear her start to wheeze, I take her to Korotiotio and tell her to take deep breaths and she is better after 3-4 minutes*.'

From an history point of view, Tarati Kinita remembers as a child in the 1960s she used the Hirere and the Oil baths, always supervised by an adult. She also told of the healing uses of the Oil baths:

'*The Oil baths were the primary healing pools. A pool would be prepared specifically for a person who was māuiui (sick)…Depending upon the nature of the māuiui, the bath was either cleaned after use, or others were allowed to use after the pool was vacated. Women who had their period had to wait for the last bath, using the small pools, nobody else could use the pool, and the pool had to be emptied and cleaned after use.*'

Ngāmoni Huata is a rongoa trainer, collecting and harvesting all her own medicine within the Village. She uses the Oil baths as part of this long tradition of using the healing waters. Ngāmoni says she looks on Rotowhio as a part of her whakapapa (genealogy):

'*It was my playground. I felt safe. The landmarks, the history, the hot pools, the guided tours and the guides of the times became my mentors*.'

There are two fundamental principles to this approach adopted for the survey:

- **Kaupapa Māori** theory is based on a number of key principles. Mātauranga Māori is created by Māori humans according to a worldview entitled 'Te Ao Mārama' and by the employment of methodologies derived from this worldview to explain the Māori experience of the world. (Royal, 1998) Mātauranga Māori "**Rangahau** is grounded in a cultural perspective which is tikanga Māori and ahuatanga Māori. It is an indigenous perspective with different experiences, different truths." ... Research is an English word that carries with it western cultural assumptions, whereas **Rangahau** is grounded in Te Ao Māori.

- Smith & Cram's (kaupapa Māori research) involves **aroha ki te tangata**' and that is about meeting with the tangata whenua to carry out research in their space on their terms. The other one is **'kanohi kitea**' or being the seen face. This means that whoever engages with the whānau (family) would need to be seen frequently, not only through this research, but also in other hui Māori such as tangihanga, kapa haka, and other hui that supports the advancement of Māori wellbeing and similar type events.

4. POISONOUS H_2S

Air Pollution in Rotorua is a major issue for long-term population health effects, and also the tourist industry which includes organisations such as Whakarewarewa – The Living Māori Village. In a survey map built by Horwell et al. (2005), the village was included in the highest concentration zone (Figure 6). Three ecological studies of the health effects of chronic exposure to H_2S were conducted by Bates et al. (1997). A study from Bassindale and Hosking (2011) showed that two people who died in an enclosed pool fed with Rotorua's geothermal waters were poisoned by H_2S. They found high levels of thiosulphate (marker for the exposure of H_2S) in their urine samples. However, no related stories were recorded at the Whakarewarewa village.

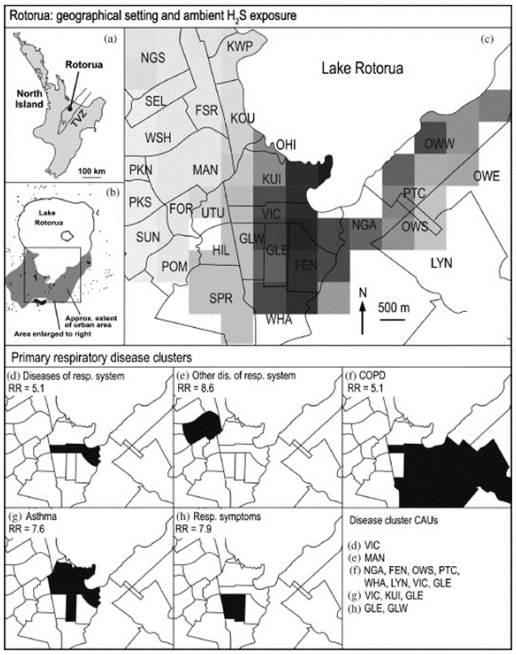

Figure 6: H_2S survey map (from Horwell et al, 2005)

Soil gas emissions from geothermal fields occur constantly and thus, iwi populating such areas may be chronically exposed to elevated gas concentrations. In addition, individuals near to areas of strong gas emissions or working underground may be acutely exposed. Hydrogen sulfide gas produces an offensive "rotten egg" or "sulfur water" odor and taste in water. In some cases, the odor may be noticeable only when the water is initially turned on or when hot water is run. Heat forces the gas into the air, which may cause the odor to be especially offensive in a shower. Occasionally, a hot water heater is a source of hydrogen sulfide odor. The magnesium corrosion control rod present in many hot water heaters can chemically reduce naturally occurring sulfates to hydrogen sulfide.

Focus on health impacts of living in environments impacted by geothermal emissions for use as an educational resource and assessment of future impacts.

4.1 Health effects

For public health, the emission of potentially toxic geothermal gases from soil is a key consequence of the thermal activity in the Whakarewarewa village. Gases are exsolved from the geothermal fluids and rise through the gas-permeable pumice formations and subsurface faults to fill the pore spaces in the soil matrix and be absorbed onto the surface of soil particles. Geothermal gases are ultimately emitted at the surface and usually include hydrogen sulfide (H_2S) and carbon dioxide (CO_2).

CO_2, which is denser than air, may accumulate to asphyxiant levels in poorly ventilated spaces on ground floors. H_2S is also a prominent gas and easily recognised at low concentrations by way of its pungent odour; H_2S penetrates indoor directly from the ground in some areas, as well as entering buildings by the mixing of indoor and outdoor air. Acute exposure to H_2S at high concentrations has caused numerous deaths in volcanic and geothermal areas (Snyder at al., 1995; Milby and Baselt, 1999; Bassindale and Hosking, 2011), and is particularly dangerous because of the olfactory system is paralysed at exposures above 150-250 ppm. The gas is therefore not detectable by smell at immediately dangerous levels. Figure 7 lists health effects of CO_2 and H_2S, the main gases studied in this work and the workplace exposure standards.

Gas (normal concentration in air)	Recommended exposure limits	Health effects	
H_2S (<0.001 ppm)	Permissible exposure limit : 10 ppm Short term exposure limit (15 mins): 15 ppm	1000-2000: (ppm)	Immediate collapse with paralysis of respiration
		530-1000:	Strong CNS stimulation, hyperpnoea followed by respiratory arrest
		320-530:	Pulmonary oedema with risk of death
		150-250:	Loss of olfactory sense
		50-100:	Serious eye damage
		10-20:	Threshold for eye irritation
CO_2 (250-350 ppm)	Permissible exposure limit : 5,000 ppm Short term exposure limit (15 mins): 30,000 ppm	20,000 (ppm): (several hours)	Headache, dyspnea upon mild exertion
		30,000 (1 hour):	Mild headache, sweating, and dyspnea at rest
		40,000-50,000: (within a few minutes)	Headache, dizziness, increased blood pressure, uncomfortable dyspnea
		60,000: (1-2 minutes)	Hearing and visual disturbances
		70,000-100,000: (few minutes)	Unconsciousness, near unconsciousness
		> 100,000-150,000: (1 minute to several minutes)	Dizziness, drowsiness, severe muscle twitching, unconsciousness
		170,000-300,000: (within 1 minute)	Loss of controlled and purposeful activity, unconsciousness, convulsions, coma, death

Figure 7: Health effects of respiratory exposure to hydrogen sulfide (H_2S) from WHO, 1981 and 2000 and from Guidotti, 2010 and carbon dioxide (CO_2) from CCOHS, 1990 and OSHA, 1989.

4.2 H_2S and CO_2 concentrations measurements at Whakarewarewa village

This study includes measuring H_2S and CO_2 concentrations in the atmosphere at 9 sites at Whakarewarewa village, Rotorua every 3 months during the time of the project. Five surveys have been done from September 2017 to December 2018, and at some sites that showed steam activity, more measurements were made at different heights from the vent.

The methodology and the results of the measurements are presented below with data interpretation and analysis.

4.2.1 Methodology

H_2S and CO_2 concentrations were measured by connecting a probe tube to a Li-COR and a WS-HC gas flux instruments. The gas meters measure the rate of concentration increase of the target gas until a stable concentration value is reached. The probe was placed just at close at possible to the ground or to the vent. This method measures the absolute concentration of H_2S and CO_2 at the sample point. The accuracy of the measurements for CO_2 and H_2S were ± 3 % and ± 5 %, respectively.

4.2.2 Field measurements

Nine sites for H_2S/CO_2 concentration measurements were chosen to cover all the village with 5 located inside the buildings, 3 over steam/fumarole vents and 1 by a boiling pool (Figure 8). The measurements were taken as close as possible to the ground. Five campaigns have been performed (September and December 2017, March, August and December 2018) and at each campaign, three measurements were taken in the morning, midday and afternoon to relate any changes with meteorological conditions. Another set of measurements were made on one fumarole vent to examine the dilution of the gases from the vent to the atmosphere.

Figure 8: Sites of H_2S/CO_2 concentration measurements in the Whakarewarewa village. Site 1: inside the admissions building; Site 2: By the security house, over a hole with steam emissions. Site 3: Inside the Café by the counter. Site 4: over fumarole area, presence of sulfur deposit around the vent. Site 5: In the ground opposite Korotiotio Pool. Site 6: Inside GNS house. Site 7: Inside Souvenir Shop. Site 8: Inside Catholic Church. Site 9: Outside Concert area, over steaming ground covered with rocks.

4.2.3 Temporal variation in H_2S and CO_2 concentrations

From the five campaigns performed at the 9 sites, two examples are shown below based on the findings in H_2S and CO_2 concentration levels:

- Sites 3 (Inside Café), 6 (Inside GNS house), 5 (By the fence of the spring opposite Korotiotio), 7 (Inside souvenir Shop) and 8 (Inside Catholic Church)

H_2S was measured but with low concentration values (< 1 ppm) due to the sites location surrounded by steam and fumaroles (Figure 9). H_2S values were close to 0 in March and August 2018.

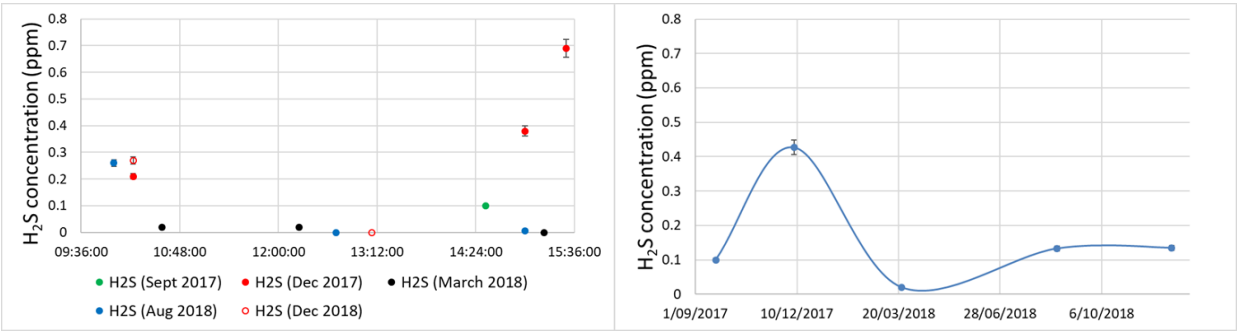

Figure 9: (Left) H_2S concentration at Site 5 during the day; (Right) Average H_2S concentrations at Site 5 at different dates.

CO_2 concentration values were similar to background values for indoor area (500 to 600 ppm). CO_2 concentration was slightly higher in winter because of the closed entrance door. There was no change in CO_2 concentration during the day (Figure 10).

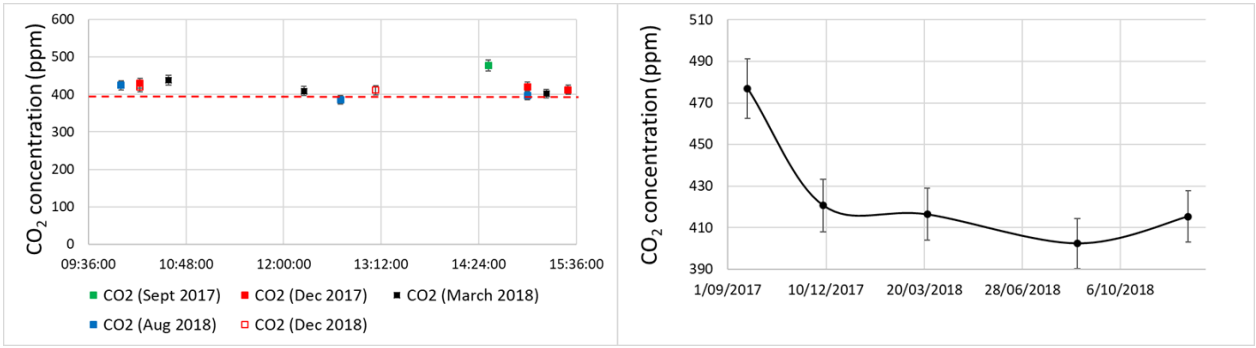

Figure 10: (Left) CO_2 concentration at Site 5 during the day. The red dashed line is the average atmospheric CO_2 background (400 ppm); (Right) Average CO_2 concentrations at Site 5 at different dates.

- Site 4 (Steaming, pile of rock and sulfur deposit vent)

Really high H_2S concentration was measured at the top of the rock pile (~ 4 ppm; Figure 11) but the concentration was decreasing rapidly at 1 m from the vent (0.2 ppm). Furthermore, really high values were measured in December 2017, August and December 2018 (25 ppm), higher than the short-term exposure limit (15 ppm). But a fence was installed around the site to prevent people getting too close to the vent.

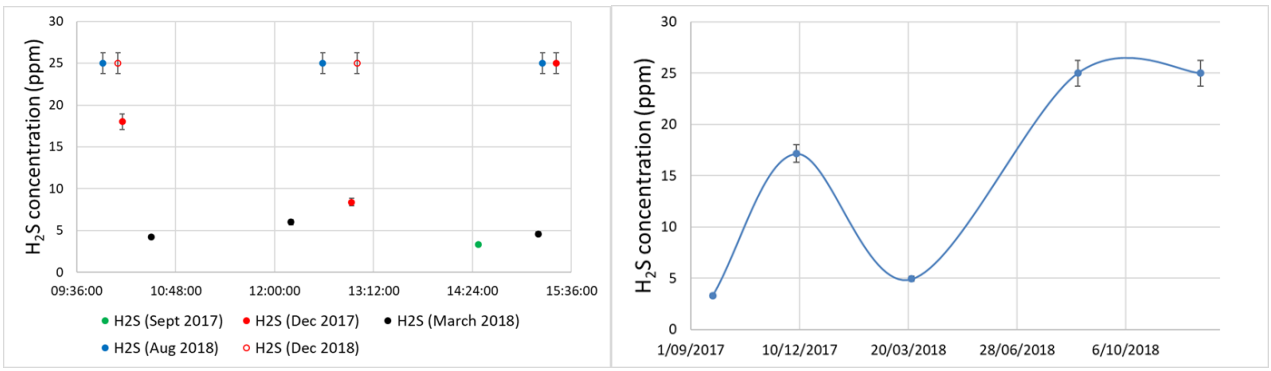

Figure 11: (Left) H_2S concentration at Site 4 during the day; (Right) Average H_2S concentrations at Site 4 at different dates.

CO_2 concentration values were high at this site but lower than the permissible exposure limit (5000 ppm). There was an increased in CO_2 concentration in December 2017 in the afternoon and midday in August 2018.

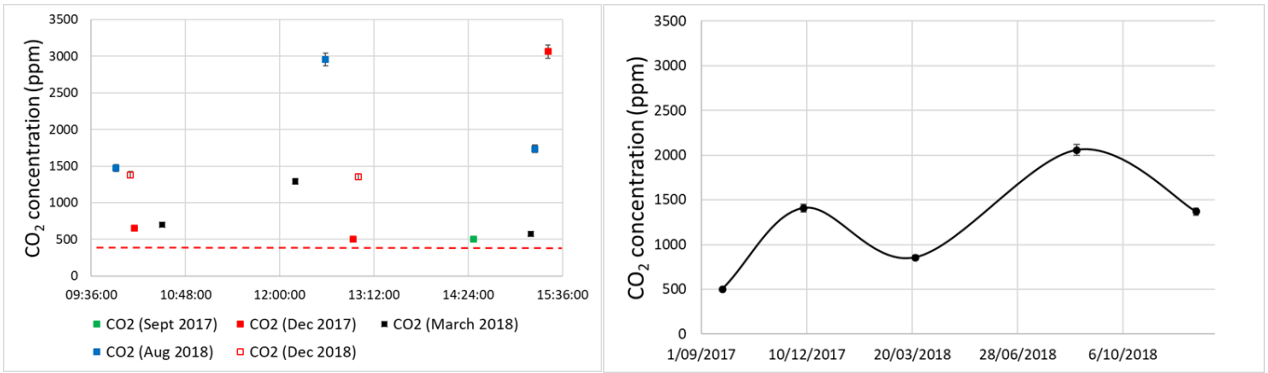

Figure 12: (Left) CO_2 concentration at Site 4 during the day. The red dashed line is the average atmospheric CO_2 background (400 ppm); (Right) Average CO_2 concentrations at Site 4 at different dates.

From the five campaigns performed at the 9 sites, three different type of gas levels were highlighted: (1) Low H_2S and CO_2 concentrations were measured inside building; (2) High CO_2 and H_2S concentrations were recorded on top of steaming ground but diluted rapidly (0.5 to 1 m away from the source downwind); and (3) at Site 2 the measurements showed high CO_2 concentration values and low to zero H_2S concentration values.

5. THE BEHAVIOUR OF H_2S AND CO_2 AT WHAKAREWAREWA VILLAGE AND SYNERGIES BETWEEN MĀTAURANGA-Ā-IWI AND WESTERN SCIENCE

From the five campaigns, various differences in H_2S and CO_2 concentrations have been recorded. Advice has been given to the Vision Mātauranga project about high H_2S emissions at two places (Site 4 and 9, Figure 8) in the village. The advice has been gratefully accepted.

H_2S and CO_2 concentrations at two monitoring sites were observed to change during the day. Temperatures were measured just above the vent and one metre above the vent alongside the measurements of the gas concentrations. The vent temperatures were observed to change during the day and were found to be related to the increase in concentrations but not the ambient temperature. The changes in H_2S and CO_2 concentrations during the day were likely to be related to the geothermal processes underground. A report and a presentation have been given on these results to Vision Mātauranga project partners with recommendations on one place that showed higher gas concentrations then earlier in 2017 but values similar to December 2017. The research studies had a high impact for Whakarewarewa staff. The changes and high H_2S and CO_2 concentrations recorded at two sites and the reports produced have resulted in further restriction of access with the installation of fences and piling of rocks on top of the vents and concrete to constrain the hot steam flow to a smaller area.

Further to this study, the transfer of the science knowledge has been presented and a poster on understanding the effects of H_2S on health have been included in the GNS house at the Whakarewarewa village for informing the tourists and for the guides who are doing the tour to the village.

Whakarewarewa village and Civil Defence designed a basic evacuation map in case of major event and evacuation procedures are in the process of being written and designed. The Rotorua Lakes Council Civil Defence Emergency Management Plan describes the hazards in geothermal areas and how their emergency will respond to these hazards and co-ordinate the community's response. The results of the gas measurements will bring valuable information in the design of the procedures specifically for Whakarewarewa village.

Māori are also concerned about the effects air pollution has on customary resources - plants and animals require clear and pure airways. Native plants provide food and natural medicines. In the past, the only thing that disturbed the natural quality of the air was the cooking fires of tupuna (ancestors).

H_2S can impact on four well beings: environmental, social, economic and cultural. A key outcome of the integration research was determining impact upon mauri of certain H_2S contaminants. The research enhances sustainability practices for future generations and reach solutions that neither science nor traditional bodies of knowledge could reach in isolation.

Tihei mauri ora: The right to breathe

It's important to Māori to exercise kaitiakitanga to protect and maintain the mauri - (life force) of air. Tangata whenua across the region are concerned about the health effects of the increasing emission of contaminants into the air from volcanic events. As they exercise kaitiakitanga (responsibilities as guardians of the environment in accordance with tikanga Māori), it is important for Māori to ensure the mauri (life force) and hau (vitality) of the air is protected and enhanced.

Kupu Whakamutunga

Ki te wheiao (To the glimmer of dawn)
Ki te ao mārama (To the bright light of day)
Tihei mauri ora! (The first breath of life)
Tihei wā mauri ora (to the last breath taken)
Haere atu rā (Go forth and farewell)

This whakataukī speaks of the hope and potential of the dawn as it forms into a new day. The glimmer of light is a metaphor for learning new knowledge. From this knowledge comes understanding, an acknowledgment of moving from a place of unknowing or a glimmer of light, into the full light of day. Knowledge and understanding shapes the values and ideals we embrace as we move into the world of parenting, breathing life into the new journey we embark on as do parents to a new baby pēpi.

A child is born into Te Ao Mārama, the physical world where they take their first breath of life. A person *in extremis* (Tuamatangi) is farewelled were the breath of life leaves the body of the sufferer, when life has run its course.

6. CONCLUSIONS

The whakapapa of the airscape shows a genealogical connection between Te Arawa through Pūhaorangi, who is a celestial being descending from Rangi, through Toi-te-huatahi, who descends from the air deities, and as a descent of Tāne who created the airspace through the separation of Rangi and Papa-tū-ā-nuku. The villagers of Whakarewarewa such as Guide Maggie Papakura and Ngātoroirangi descend from Te Heketanga-a-rangi.

The airspace is of heavenly origins through Te Heketanga-a-rangi and his ancestors; it is of volcanic origins through Te Pupu and Hoata; it is of the many manifestations of Tāne including trees, water bodies, rocks, flora and fauna, and people, presented in the form of ira (physical matter, genes).

The moist air that is carried through Tāne (Deity of trees and humans) and Tawhirimātea (Winds), gives life, and also brings decay. There are pools in Whakarewarewa which have the same purpose from cradle (Roto-pouri) to grave (Roto-kanapanapa). Perhaps there is air that is silent and can bring death, as represented by Tamaohoi (silence gas) – who does not roar (King et al, 2007).

Utu (balance, equilibrium) forms a cause-effect thinking through whanaungatanga (relationships) which can either be negative, as captured in the sentiments of Tērā te Auahi, or it can be positive, as relayed by the guides of Whakarewarewa, who have utilised the geothermal lands, which contributes to their overall health and wellbeing.

The interconnectedness between the environment, people and the metaphysical is such that it requires the maintenance of mātauranga (knowledge). Tāne retrieving the baskets of knowledge equates to life itself which was for the kaupapa of the people (collective

benefit of all). Each time the guides or the elders talk and share about their whakapapa (genealogy), pūrākau (tribal stories) or waiata (tribal songs) it brings life to them and their environment. Embedded within their stories are the notions of manaakitanga (ethic of care), kaitiakitanga (ethic of sustainability), and whanaungatanga (ethic of positive relationships). Collectively this upholds their Rangatira (pursuit to independence, self-sustenance, and resilience).

Through government directives such as Vision Mātauranga, cross-cultural collaborative research projects are being created. Cross-cultural collaborative research projects between iwi and Crown Research Institutes (CRI), such as GNS, are increasing. Pardo et al (2015) demonstrates how Ngāti Rangi and volcanologists work together to create synergies between mātauranga-ā-iwi and science.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the Whakarewarewa Village Charitable Trust, guiding staff, Kuia Nanny Moochie, without whom this work could not have been undertaken and all the kai mahi involved in supporting this project to assist the people of Tūhourangi and Ngāti Wāhiao to understand further the importance of impact of H_2S on people living and working in the village. This research was funded by the New Zealand Ministry of Business, Innovation and Enterprise as part of the Vision Mātauranga Funding (VM C05X1615 2017- Te haurehu waikawa pungatara e pa ana te kaimahi Māori – Impact of H_2S on Māori workforce).

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