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Determination of Baseline Data on Cadmium Levels for Selected Food Products from Volcanic Areas in East New Britain Province of Papua New Guinea

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Abstract

Food, agricultural crops and seafood from the Gazelle Peninsula of East New Britain Province (ENBP) of Papua New Guinea (PNG) were investigated for levels of heavy metal Cadmium, which is known to be widely distributed in the environment exposed to dust and gases emitted by active volcanoes[1]. The aim of this study was to establish the background concentrations in important staple foods both of plant and marine origin that are common in diets to the people of Gazelle Peninsula and to compare them against the tolerable intake levels. Food samples collected from selected sites within the 30 km radial zones from the epicenter of the Mount Tavurvur volcano were digested with *aqua regia* and prepared for total Cd concentration determination by flame atomic absorption spectrometry (FAAS). The Cd concentrations expressed as mg/kg dry matter basis in (a) food (vegetables and nut) were between 0.066 to 1.2 mg/kg (b) marine organisms were between 0.58 to 1.41 mg/kg; and (c) tobacco was between 1.97 to 3.4 mg/kg. The high level of Cd in foods is a contributing factor to high prevalence of diabetes in the East New Britain Province.

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The medical literature of Papua New Guinea (PNG) studies also revealed that type 2 mellitus diabetes is an increasing problem in PNG. Statistics from Port Moresby General Hospital showed that coastal Papua New Guinea share the same vulnerability with other Pacific Island countries such as Nauru and Solomon Islands and the Wanigela and Tolai ethnic groups in PNG.

Keywords: cadmium; diabetes; volcano; Mt Tavurvur; East New Britain; Papua New Guinea.

1. Introduction

Cadmium, having a high relative mass is a non-essential element having no known biological function in living tissues; however, it is known to serve as a metal ion cofactor in Cd-carbonic anhydrase in diatoms [2]. Cadmium seems to be involved in Mn (II) and Zn (II) transport systems, where Cd ions are actively taken up and replaced for Mn (II) and Zn (II). Presence of Cd in the environment is suggestive of contamination from foods, water or air exposed to environments containing Cd such as those exposed to volcanoes. The potential negative health effects and impact of toxic levels on the environment is often undetermined but at low temperatures the damage can be far greater causing damage or death in living matter such as in plants, animals and humans [3]. The metal has a tendency to accumulate over time in specific organs (kidney, liver, lung, bones, placenta, brain and the central nervous system) of animals including humans [4]. Cadmium and cadmium compounds are known as carcinogenic based on evidence of studies in humans, including epidemiological and mechanistic studies in the 9th carcinogen reports in 2000 [5].

1.1 Cadmium Exposure and Incidences of its Intoxication

The uptake and accumulation of Cd in food is usually associated with contamination of the source; such as from polluted environments [6], from areas of high volcanic activities [7,8] and from various anthropogenic sources [9]. Areas of high volcanic activities (Mt. Pinatubo of Philippines, for example) have shown elevated levels of metals (including Cd) in food crops [10]. Humans are exposed to this carcinogenic metal through consumption of food crops or animals containing accumulated levels of Cd [11,12]. Cadmium uptake by humans can result from exposure to contaminated sources through respiration, ingestion and epidermal contacts. However, dietary intake through foods and smoke inhalation from cigarettes have been reported to be the two major routes [7], [13].

The potential health risks associated with heavy metals from exposure to volcanic dust are very significant. Cadmium poisoning is experienced in many parts of the world and the dreadful one to be reported is the "*itai-itai*" or "*ouch-ouch*" sickness in Japan during 1960's and the symptoms are very similar to Li Wenxiang's "soft foot" condition causes renal toxicity and resides in the kidney for a longer period of time [14]. Whilst Ca(II) has preference for oxygen ligation, Cd(II) prefers nitrogen / sulphur ligations and they are actively replaced because of similar ionic radii (0.96 and 0.98 Å respectively [15]. Epidemiological studies suggested a positive association between exposure to the environmental pollutant cadmium and their incidence and severity of diabetes in humans. The accumulation of the metal in pancreas reduces the serum insulin level and hence suggests a possible direct toxic effect on the pancreas [16]. Type II diabetes is a chronic progressive disease that is associated with combination of genetic, life style and environmental factors [16].

An active volcano (Mount Tavurvur) located at Rabaul town in ENBP frequently erupts (for example, during Jan. 2013 and Sept. 2014). The people living around the area are frequently in contact with the volcanic ash through various media. Cadmium is present in significant concentrations in volcanic soils [17] . As of date, no baseline data is available on the cadmium levels in common food commodities sold around Rabaul. This paper reports (a) the identification of food sources containing elevated levels of cadmium taken up from the volcanic soils and (b) the establishment of their anecdotal association with adverse health of the human population in the area.

2. Materials and Methods

2.1 Study Area and Description

Food (vegetable and fish) samples were collected from villages at various radial zones from the active volcano epicenter of Mt.Tavurvur. Sampling zones were demarcated into four radial zones from the epicenter of Mt.Tavurvur (Figure 1).

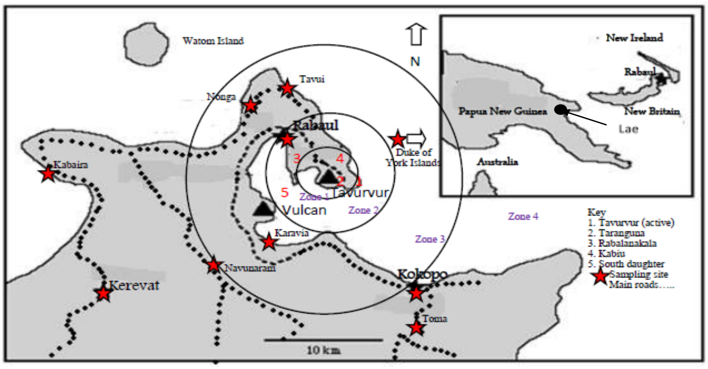

Figure 1: Map showing volcanic distribution and zone selection

Zone 1 (Z1) included the Matupit villages on the island of Matupit inside the 10 km radius of volcano epicenter. Zone 2 (Z2) areas are those within the 20 km radius of the volcano epicenter and include Rabaul Town, Nordup, Bai and Matalau. Zone 3 (Z3) are areas in the 30 km radial zone and include Tavui, Nonga, Pilapila, Kokopo and Karavia, Kuraip, Barovon, Navunaram, Ialakua, Ramale and Nangananga.

Zone 4 (Z4) are areas outside the 30 km radial zone and include Lungalunga, Toma, Warangoi, Tokua, Kabaira, Keravat and the Duke of York (DoY) Islands. Lae is the second largest city in PNG, located near the delta of Markham River and is the largest cargo port and the industrial hub of the country. Lae is the gateway to the mountainous interior where mining and agriculture are important activities. The reference point (R), namely, Erap, Nadzab, Labu, Situm and NARI are located from Lae at distances of 40, 30, 27, 20 and 14 km respectively.

2.2 Samples and Sample Preparation

Food items collected were in accordance to the observation made on their common consumption as major food sources based on demand and frequency.

Coastal fish species from lagoons and tropical reefs collected mainly included sardine species.

Selected food items known for having high Cd according to cited literature [18,19] and preliminary findings (Hundang *et.al*, unpublished) included peanut (*Arachis hypogaea*), tobacco (*Nicotina tabacum*), mollusc (*Meretrix meretrix*) and green leafy vegetables (slippery cabbage), locally called as *aibika* (*Abelmoschus manihot* (L.) Medik). Sample specimens were purchased from roadside markets or obtained from people in villages from coastal areas along the North Coast, Rabaul, to Kokopo and Tokua roads as well as the Duke of York Islands as indicated in Figure 1. Sampling of food items was based on the assumption that soil within the precinct of the active volcano was generally contaminated with toxicants from volcanic emissions of dusts and gases.

2.3 Moisture Content

The moisture and volatile contents were determined by oven drying using methodology prescribed in the literature [20]. Ground food or fish samples were weighed accurately (2.00 g) into pre-dried aluminum moisture trays and dried at 135±2°C for 2 hrs. Samples were cooled in a desiccator and weighed. The percent moisture was calculated as percent weight lost during drying.

2.4 Determination of Cadmium

Powdered samples of food and fish (duplicates) were accurately weighed (2.00 g) into a 250 mL beaker and digested using *aqua regia* (15-20 mL) for dissolution.

The digested samples were then transferred to 100 mL volumetric flasks and diluted with deionized water. Samples were determined for Cd by flame atomic absorption spectrometry (Spectra AA 240 model). The standard condition for Atomic absorption spectrophotometer was set at wavelength 228.8 nm for cadmium with a detection limit of 0.002 ppm (mg/kg) using air-acetylene gas.

2.5 Statistical Analysis

Single Test analysis of variance (ANOVA) was performed for both edible and non-edible items. The results of the statistical analysis are listed in tables 1 and 3. A student t-test was performed for the means of soil samples for the study and the reference sites.

3. Result

Mean Cd concentrations of fish, *aibika*, peanut and tobacco are provided in Figures 2-5.

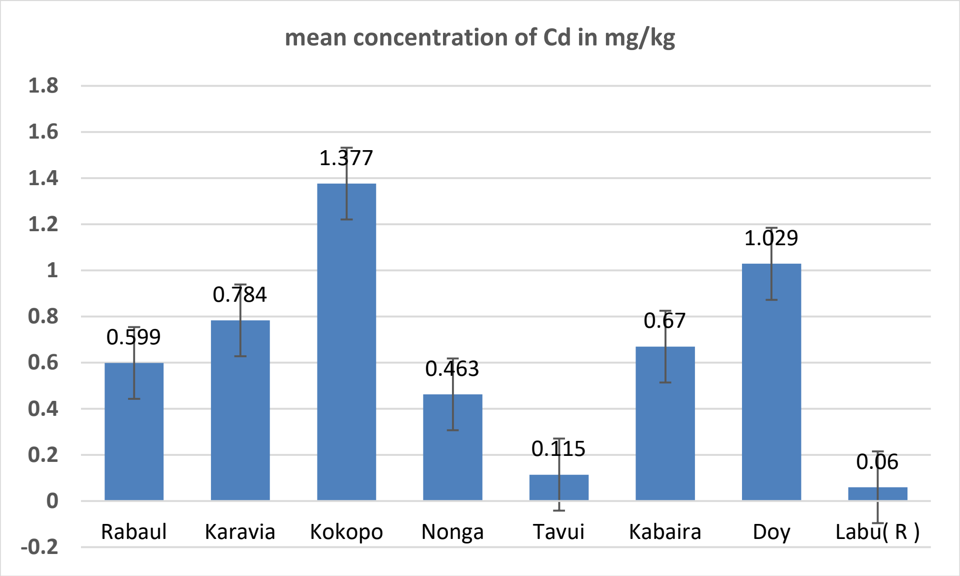

Figure 2: Mean concentration of Cd in fish, *Sardina pilchardus*

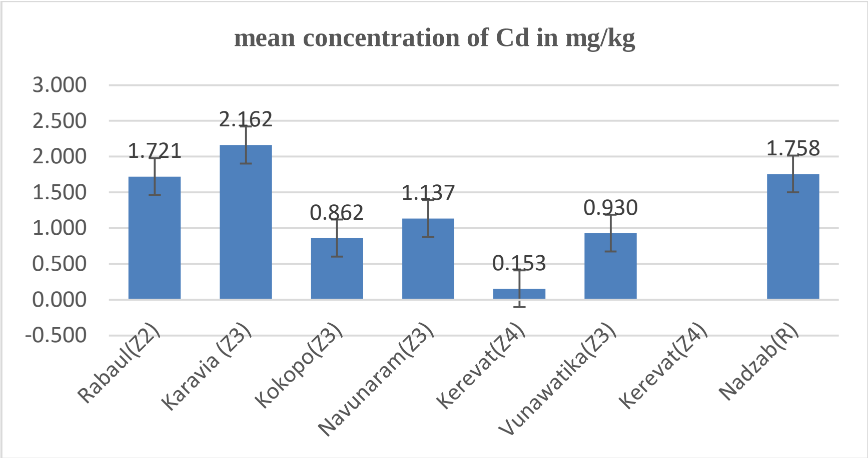

Figure 3: Mean concentration of Cd in aibika, Abelmoschus manihot

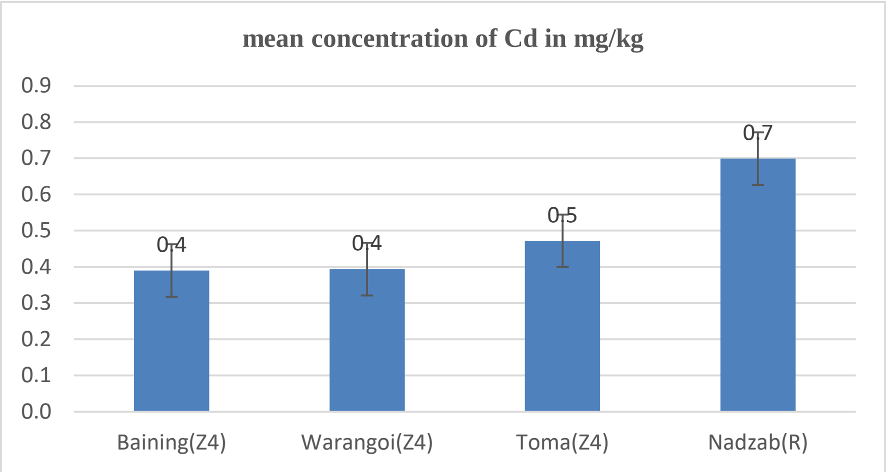

Figure 4: Mean concentration of Cd in peanut, Arachis hypogaea

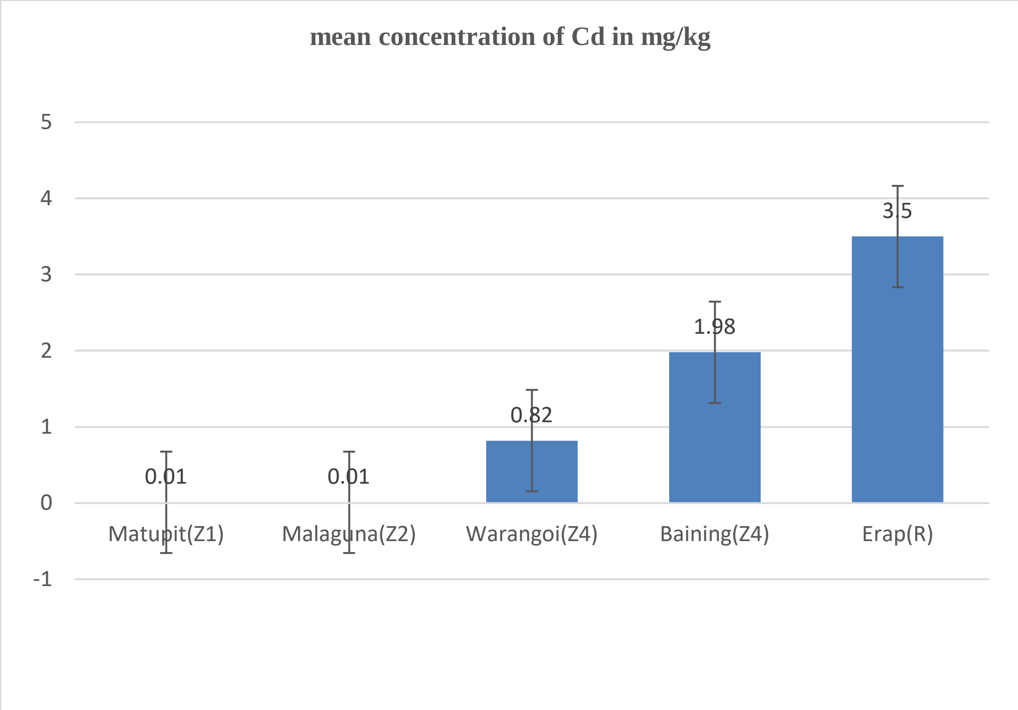

Figure 5: Mean concentration of in tobacco, *Nicotina tabacum*

Figure 6 shows Cd concentration in soils from various places around Lae (Morobe province, non-volcano region, Reference point) and Rabaul (East New Britain Province, volcano region and study site) towns.

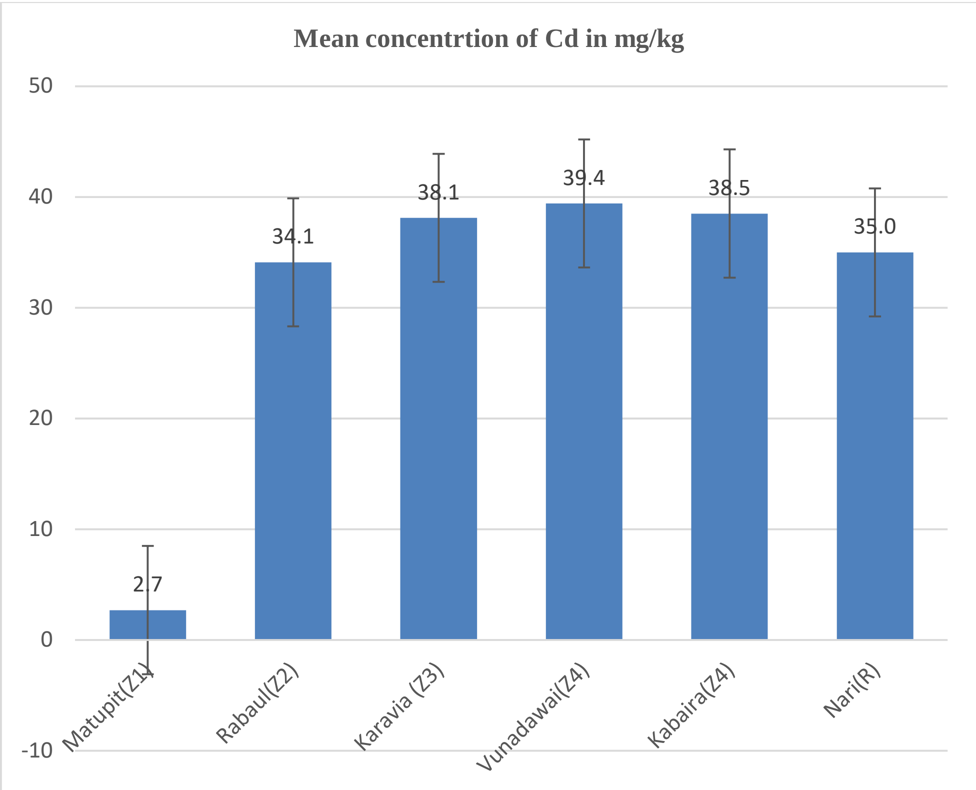

Figure 6: Mean concentrations of in soils of Lae and Rabaul

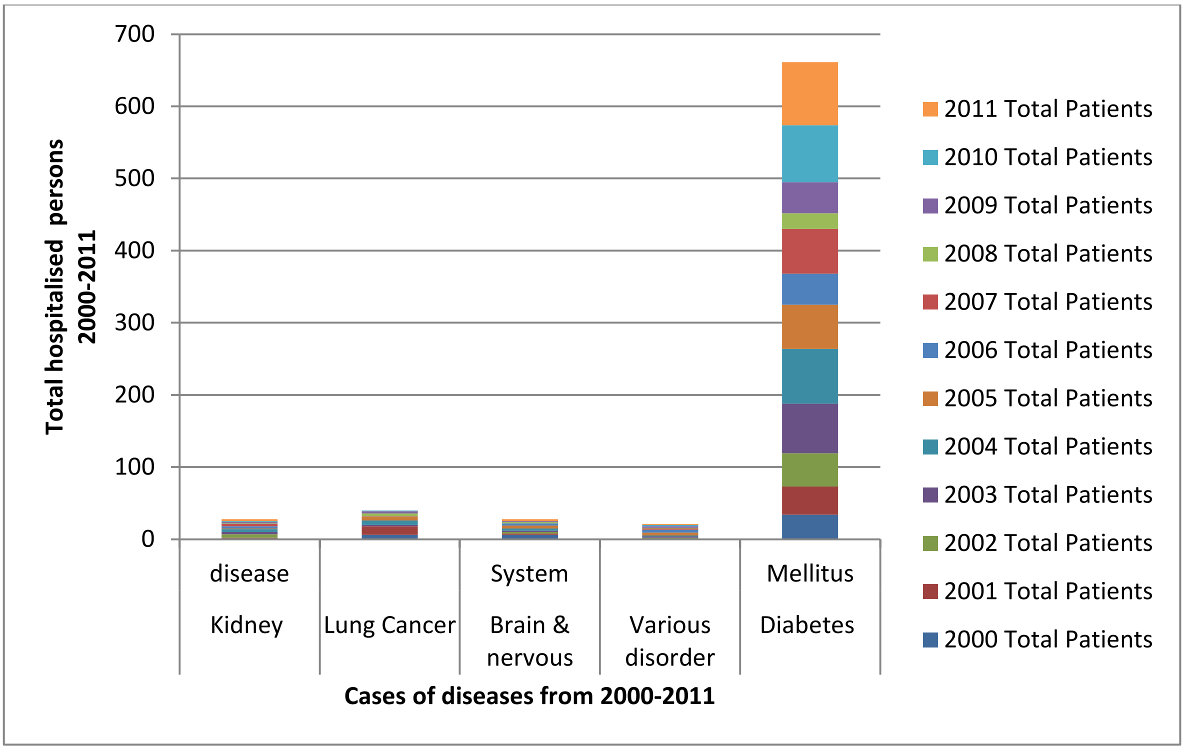

Figure 1: Cases of diseases recorded at Nonga Hospital from 2000 - 2011

Cadmium concentrations in the selected food and non-food items of the study site (Gazelle Peninsula) and reference point (Lae) are provided in Table 1.

The cadmium concentrations in selected food and non-food items sold in Gazelle Peninsula are compared with JECFA maximum levels and provided in Table 2.

A summary of ANOVA results for food as well as non-food samples for control (Lae) and volcano-exposed (ENB) areas is provided in Table 3.

Table 1: Samples with the highest Cd concentrations (mg/kg) in food and non-food samples and their comparison with the control site.

Common name	Scientific name	Study site Gazelle Peninsula (mg/kg)		Reference site Lae (mg/kg)		P-Value
Fish	*Sardina pilchardus*	Kokopo (Z4)	1.4	Labu (**R**)	< 0.1	< 0.05
Aibika	*Abelmoschus manihot (L.)*	Karavia (Z3)	2.2	Nadzab (**R**)	1.8	< 0.05
Peanut	*Arachis hypogaea*	Toma (Z4)	0.6	Nadzad (**R**)	0.7	> 0.05
Tobacco	*Nicotina tabaccum*	Baining (Z4)	2.0	Erap (**R**)	3.5	< 0.05

Table 2: Average cadmium content (mg/kg) in selected food and non-food items in Gazelle Peninsula (PNG) as compared to JECFA maximum level [21].

Item Description	Average concentration (mg/kg)	JECFA Maximum level (mg/kg)
Species of Fish		
Plectropomus leopardus	0.15	2.0
Lethrinus olivaceus	0.15	2.0
Aphareus rutilans	0.17	2.0
Lutjanus lutjanus	0.12	2.0
Epinephelus areolatus	0.13	2.0
Ballistapus undulates	0.14	2.0
*Sardina pilchardus**	0.37	2.0
Fish (unknown species)	0.25	2.0
Clam (wild)	0.82	2.0
Food Crops		
Peanut	0.6	0.1
Sweet potato	0.13	0.1
Banana	0.13	0.1
Cassava	0.08	0.1
*Aibika**	1.1	0.2
Non-Food Crops		
Tobacco	2.1	

*Commonly consumed by people of Gazelle Peninsula.

Table 3: Summary of ANOVA results for food and non-food samples for control and exposed samples

Item	F-Calculated		F-Critical		P-Value	
	Exposed	**Reference**	**Exposed**	**Reference**	**Exposed**	**Reference**
Fish	59.95	#	2.24	--	0.00	--
Aibika	369.92	#	2.25	--	0.00	--
Peanuts	0.13	0.19	3.24	5.32	0.94	0.68
Tobacco	36467.05	#	3.47	--	0.00	--
Soil	245.32	0.76	3.50	4.39	0.00	0.61

#ANOVA couldn't be done because samples were collected from only one location.

Calculations

1. For *Sardina pilchardus*, a type of fish (staple food)

The Provisional Tolerable Monthly Intake (PTMI) for Cd is 25 µg/Kg b.w

So for a 70 kg adult PTMI 70 x 25 = 1750 µg

Calculating Concentration of Cd by wet weight

Wet weight con. = 0.37 x 100/ moisture content

= 0.37 x 100 / 13 = 2.85 mg = 2850 µg

This means a 70kg adult would be consuming 60% more Cd in a month than the PTMI as set by WHO.

2. For *Abelmoschus manihot (L.)*, a type of green leaves (*Aibika*, staple food)

Average Cd in *Aibika* = 1.1 mg/kg (refer Table 2) dry weight

So for a 70 kg adult PTMI 70 x 25 = 1750 µg

Calculating Concentration of Cd by wet weight

Wet weight con. = 1.1 x 100/ moisture content = 1.1 x 100/7 = 15.714 mg = 15714 µg

This means that a 70kg adult would consume 9 times more Cd in month from leafy vegetables aibika than the Provisional Tolerable Monthly Intake as set by WHO. The study, the data and the calculations pertain to areas (villages) in zones 3 and 4; they also clarify a point and further support the known fact [22] that cadmium can travel long distances by: (a) leaching and water transport (hydrosphere); (by) particle diffusion in air (volcanic ash is defined as loose unconsolidated material with diameter < 2.00 mm [23] and long-range transport (atmosphere); and (c) weathering and erosion of soils, rocks, etc. (lithosphere). These ways of transport could be taken up by plants and lower marine organisms (like fish, mollusks, crustaceans, etc.) and gradually travel up the top of the food chain where it reaches humans (biosphere) in relatively high concentrations (bio magnification). In addition to this, human activities have richly contributed too much higher concentrations in the four essential "spheres" of the environment.

Statistical Analysis of Results

All food samples, except peanut, showed $P < 0.05$ and hence significantly different with respect to zones (Table 1). This clearly corroborates the fact that the food samples of the volcanic region are contaminated with cadmium.The mean Cd concentrations for soils of Lae were not significantly different while those from Gazelle area were significantly different (Table 3). The mean Cd levels in soils from the Gazelle area were increasing in the order Matupit (Z1) < Rabaul (Z2) < Karavia (Z3) < Vunadawai (Z4). Reports [24] indicate that an intermediate-scale eruption is expected to occur from any of the five sources vents (Tavurvur, Vulcan, Rabaul, Ulawun and Lolobau); with the given range of wind conditions, a high volcanic ash would be distributed towards the northern and western regions of the Province. Areas which are most likely to experience this impact are concentrated around source vent areas in the north (Tavurvur, Vulcan and Rabaul) and west (Ulawun and Lolobau) and where a distribution of volcanic ash from the northern and western source vents overlaps.

According to a weather report recorded by PNG University of Natural Resources and Environment [25], the north-westerly wind has been recorded as predominant to the volcano with speeds sometimes reaching up to 182.1 km/h. This implies that the volcanic ash could be carried away from the volcanic sources to most of the villages within the north-west zones (Fig. 1). Mean Cd concentrations in samples of food (fish and *aibika*) and tobacco were significantly different for both Lae and the Gazelle area; while mean Cd concentration for peanut for both areas were not significant. This clearly shows that food items were exposed to Cd from volcanic ash in the Gazelle area while Cd in Lae is attributed to anthropogenic sources. Coincidentally, the statistical results for fish, *aibika* and tobacco showed significant differences and were directly exposed to the environment, while insignificant difference noted for peanuts were protected in their shells.

Disease Statistics at Nonga General Hospital, Rabaul, ENB

Recent data on the diseases recorded at the hospital (Fig. 7) indicates high cases of diabetes with an average of 54 cases per year with increasing number of various non-communicable diseases (~100 cases / yr.). This is 0.03 % of the total population (260,000). A recent nutritional survey carried out at Gazelle Peninsula (Hundang and his colleagues unpublished) showed that: (a) 40-80 % of the population use rain water for cooking and drinking; (b) 80-100 % of the population use firewood for cooking; (c) > 50 % consume alcohol; (d) 65-80 % smoke tobacco; (e) 85-91 % chew betel nut daily; (f) > 85 % of the population consume garden foods daily; and (g) > 70 % of the population live with diabetes. On overall the prevalence of diabetes in Papua New Guinea in 2016 was 11.8% according to WHO diabetes profile for PNG. Hospital statistics showed that PNG diabetes has increased since 1980. By the year 2008-2009 studies funded and done by WHO showed 14.4 % of adults aged 15-64 years had a fasting blood glucose level of ≥6.1mm/L. This is a serious problem which mainly affects the educated and working class in PNG. Other ethnic groups that suffer high prevalence of diabetes in Papua New Guinea apart from the Tolais (East New Britain Province) are the Wanigelas in Port Moresby, Manus Province and coastal villages like Sepik and Madang but it not common in the highlands provinces of Papua New Guinea.

4. Conclusions

The study emphasized the fact that there is significant amount of Cd present in commonly consumed food in the Gazelle Peninsula. Cadmium taken in from food (fish and *aibika*) consumption was found to be larger compared to the provisional tolerable monthly intake (PTMI) of 25µg/Kg. Impact of volcanic ash is experienced high in the township of Rabaul and Kokopo. This study also provided a baseline data for selected food and non-food samples used in the volcanic region of East New Britain Province which could be used for future studies. From this study, it further suggests that dietary is a major route of Cd transfer through food chain as Cd concentrations were found high in fish which may further contribute towards high sugar level and risks of diabetes.

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