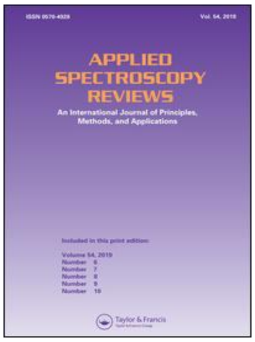

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The current state of heavy metal pollution in Pacific Island Countries: a review

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ABSTRACT

Contamination of the environment by pollutants like heavy metals is a growing phenomenon mainly driven by anthropogenic activities. The presence and mobility of metals in ecosystems lead to the contamination of marine resources and several materials. Accurate monitoring of metals concentration in various samples is of importance in order to minimize bio–magnification and health hazards resulting from their exposure. While much works have been carried out in developed countries, very little work has been conducted in Pacific Island Countries (PICs). Consequently, it is essential to have a general understanding of the basic methods of elemental analysis. The present review looks at the analytical methods which have been applied in the South Pacific Islands over the last three decades to characterize and report the environmental presence of heavy metals. The most sensitive techniques of elemental analysis such as atomic absorption/emission spectrometry, mass spectrometry, catalytic kinetic methods and nuclear techniques have been discussed with their applications in a range of sample matrices. An in–depth review of available studies points to activities such as mining, agriculture, manufacturing and poor waste disposal as major sources of these pollutants in PICs. The health impacts and human risk factors have briefly been discussed.

KEYWORDS

Spectroscopic analysis; heavy metal pollution; Pacific Islands; review

Introduction

The tropical islands of the South Pacific region are considered biodiversity hotspots with a wide variety of flora and fauna. These ecosystems (Coral reefs, Mangroves, etc.) proffer the region with services that are an essential source of revenue and livelihood which supports local communities. The South Pacific region is highly dependent on tourism which is a major source of income.[1] However, it is clear that certain pressures have led to the region showing signs of environmental stress and degradation. The Pacific Island countries (PICs), have seen significant economic and infrastructural growth in the last 3 decades.[2,3] This massive economic transition has led to a burgeoning middle class and growing consumerism. As a result, the production and processing of food and other consumer goods has grown significantly. However, poor waste

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disposal, increase in industrial and agricultural production and intense mining activities have all contributed to the contamination of soil and water resources.[4,5] Within this framework, ecological effects and human exposure to toxic chemicals such as trace metals, pesticides and persistent organic contaminants, etc. are of great importance.

Environmental proliferation of these trace elements, particularly heavy metals in soils and marine ecosystems has been shown to elicit numerous health risk to humans and organisms and also impedes on the overall functioning of the ecosystem.[6–9] The South Pacific Regional Environmental Program (SPREP) has long highlighted the extent of the problem and the long–term potential threats to the region.[10] Additionally, studies conducted in the region over the last 3 decades have confirmed high levels of contamination, usually of terrestrial origins.[11–14] Thus, the determination of several environmental pollutants has been attempted and reported by few researchers in PICs.[11–20]

There are several instrumental analytical methods which can be employed to measure the concentrations of heavy metals in various samples. The major factors which influence the method of choice include; cost of instrument, ease of use, elements of interest, detection limit and sensitivity. The most predominant techniques are Atomic absorption spectrometry (AAS), Atomic emission/fluorescence spectrometry (AES/AFS), Inductively coupled plasma mass spectrometry (ICP–MS), Inductively coupled plasma optical emission spectrometry (ICP–OES), Neutron activation analysis (NAA), X–ray fluorescence (XRF) and Anodic striping voltammetry (ASV). Recent studies conducted in PICs have employed these analytical methods to analyze and characterize trace metals and few other pollutants in different matrices including soil,[14–16] sediments,[13,17,18] water,[19,20] food,[21] sewage sludge[22] and bivalves.[23] Much of the work conducted in PICs has focused on quantification of heavy metals in soil, coastal sediments and to a smaller extent, marine bio–indicators such as bivalves. Regionally, flame and graphite furnace absorption spectrometry (FAAS and GFAAS) have been the most widely adopted methods for elemental determination due to their relative ease of use and low financial investment. We have been interested in the detection and determination of pollutants like heavy metals and several other chemical species of interest in different matrices,[14–16,20,21,24–26] including the removal of toxicants like fluoride.[27] Thus, we have reported an excellent review on the plasmonic nanoparticles for their fascinating optical property and their various applications in different fields[24] and also a review on the spectroscopic perspectives in fluoride removal.[27] The determination of metals in soil, sediments, water, selected food, seafood and fish have also been attempted by different authors around the globe.[6–9,14–16,20,21,28,29] Therefore, to have a database, the present review provides a critical overview of toxic metal pollution in the South Pacific Islands along with a review of the spectroscopic methods employed by several researchers to determine trace metals in PICs. Additionally, the sources and local impacts of heavy metals on the local ecosystem, communities and human health have also been discussed.

The Pacific Islands

The South Pacific Islands in the context of this review is the geographic region spanning from the Northern Mariana Islands north of the equator to Easter islands in the

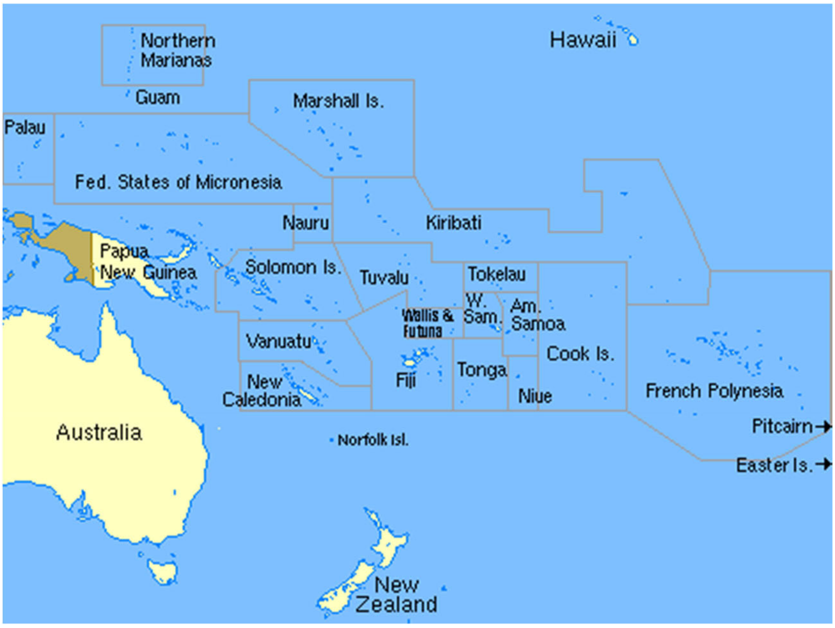

Figure 1. A map showing the locations of the countries and territories of the South Pacific (Source: sprep.org).

east and Papua New Guinea to the west. The region extends over approximately 100 million square kilometers of the Pacific Ocean spanning one–third of the earth's surface, but has a land surface area of only 8.5 million km^2.[30] Compared to most inhabited parts of the earth's surface, the Pacific Basin bounded by continental margins is different in land areas that are comparatively small and isolated from one another and from the Basin rim; land totals around 0.34% of the area of the Pacific Basin. The number of people occupying Pacific islands is approximately 10.8 million, some 0.15% of the earth's population.[30]

The Pacific Islands are a mixture of independent states, associated states, integral parts of non–Pacific Island countries, and dependent states. The defined region includes the independent countries of Cook Islands, Federated States of Micronesia (FSM), Fiji, Kiribati, Marshall Islands, Nauru, Niue, Palau, Papua New Guinea (PNG), Samoa, Solomon Islands, Tokelau, Tonga, Tuvalu, Vanuatu; the territories of American Samoa, French Polynesia, New Caledonia, Wallis, and Futuna; the commonwealth of the Northern Marianas Islands; the State of Hawaii; the US–administered islands in the Central Pacific; the Galapagos islands (Ecuador); and the Chile–administered islands in the Southeast Pacific. The 22 island countries and territories of the South Pacific region are scattered over a vast area of the Pacific Ocean and differ greatly in size. The larger islands are PNG, with a total land area of 462,200 km^2 (equal to 83% of the region's total land area of just over 500,000 km^2) is the largest, followed by Solomon Islands with an area of 28,520 km^2 (Figure 1). The remaining island countries are small to very small, with at least four—Tokelau, Tuvalu, Pitcairn Island and Nauru—each being 30 km^2 or less.

Each of these countries share similar challenges and opportunities as small and remote island economies. They are small in size with limited natural resources, narrowly–based economies, large distances away from major markets, and vulnerability to external shocks; all of which can affect growth and have often led to a high degree of economic volatility. PICs are also some of the most vulnerable in the world to the effects of climate change and natural disasters. The World Risk Index 2018 ranks six PICs among the top 20 most at–risk countries in the world, including Vanuatu and Tonga, which are ranked first and second, respectively.[31] This highlights the extreme vulnerabilities faced by this region of the world.

Environmental and health effects of heavy metals

According to a World Health Organization (WHO) study on the environmental burden of disease, 25% of the total burden of disease and 2.97 million human deaths are yearly attributed to environmental risk factors.[32,33] Toxic waste pollution presents a major challenge in the degradation of the environment and the effect on human health and livelihood has been well studied. This is particularly of great interest when toxic pollutants such as heavy metals are involved. Thus, heavy metals are significant environmental pollutants and their toxicity is a problem of increasing significance for ecological, evolutionary, nutritional and environmental reasons.[34,35] Pollution was cited as the main factor behind the lower population and diversity in marine species in Fiji especially around areas of high population density and waste.[36] Terrestrial discharges often flow into the marine environment contaminating water ways and affecting aquatic biota. Fragile ecosystems such as coral reefs and mangrove habitats are threatened by this continuous influx of sediments, nutrients and trace elements. Haywood et al.[37] conducted photographic surveys at 73 sites within 40 km of the Lihir Gold Mine in PNG to document impacts of mining operations on the hard coral communities. They concluded that mining operations in PNG have resulted in a significant decrease in coral cover, decreased species richness and a predominance of less complex growth forms within ∼2 km to the north and south of the mine waste disposal sites.

Marine invertebrates have a tendency to bioaccumulate heavy metals and thus, are good bioindicators of marine pollution. As highlighted by Dougherty,[23] bivalves around major population areas of Fiji accumulated significantly levels of heavy metals when compared to pristine areas. Morrison et al.[38] highlights the effects of anthropogenic activities and contaminated sediments on marine resources including coral reefs, fisheries in numerous PICs. Bioaccumulation of these toxic pollutants such as heavy metals in the environment, fisheries and food crops is the single most important pathway to human exposure. The bioaccumulation of toxic heavy metals in fish is of public health concern because they serve as an important food source, especially in PICs.[39]

A cross–sectional study in French Polynesia analyzed the umbilical cord blood of two hundred and forty–one (241) delivering women for metals and nutrients.[40] All parameters were found in high concentrations in cord blood samples except for lead (Pb). Mercury (Hg) concentrations averaged 64.6 nmol/L (or 13 microg/L) with values ranging from 0.25 to 240 nmol/L.[40] Of the sample, 82.5% had Hg concentrations above the USEPA blood guide–line of 5.8 microg/L.[40] Tuna was found to be the fish species which contributed the most to Hg exposure. According to the authors, high selenium (Se) and long chain polyunsaturated fatty acids (LC–PUFAs) may counterbalance the

Table 1. Different heavy metals, their regulatory limits and effects on human health.

Heavy metal	USEPA heavy metal limits in drinking water (ppm)[49]	Effects on human health	Ref.
As	0.10	Well–known as a poison and possibly carcinogenic; Acts to coagulate protein, Forms complexes with coenzymes and inhibits the production of adenosine triphosphate (ATP) during respiration; Gastrointestinal damage; Severe vomiting, Diarrhea; High–level exposure can cause death	[43, 46]
Cd	5.00	Neurodegenerative disorders, ESRD; breast cancer; prostate cancer; demineralization of bones; diabetes	[44, 50]
Cr	0.10	Excessive amount can cause toxicity; Allergic reaction of the skin; ulceration of the nasal septum mucosa and of the skin; Compounds of Cr(VI) are shown to induce epigenetic changes, mutations, chromosomal aberrations, and DNA damage	[9, 51]
Cu	1.30	Severe mucosal irritation and corrosion, widespread capillary damage, hepatic and renal damage and central nervous system irritation followed by depression. Severe gastrointestinal irritation and possible necrotic changes in the liver and kidney	[52, 53]
Hg	2.00	Disruption of the nervous system; Damage to brain functions; DNA damage and Chromosomal damage; Allergic reactions, tiredness and headaches; Negative reproductive effects, such as sperm damage, birth defects and miscarriages	[54]
Pb	15.00	Anemia (less Hb); hypertension, kidney damage, miscarriages; Disruption of nervous systems, brain damage; infertility; intellectual disorders	[45, 55]
Ni	0.20	Allergic contact dermatitis, oral hypersensitivity and risk of gingival hyperplasia, oral cancer, skin cancer, lung cancer, asthma, bronchitis, reproductive toxicity, carcinogenesis	[56, 57]
Zn	0.50	Excess amount can cause system dysfunctions that result in impairment of growth and reproduction. The clinical signs of zinc toxicosis have been reported as vomiting, diarrhea, bloody urine, icterus (yellow mucus membrane), liver failure, kidney failure and anemia	[58, 59]

potential risk of prenatal exposure to Hg in French Polynesia. Due to the high fish consumption by mothers, Polynesian newborns are prenatally exposed to high doses of Hg. Although Se and omega–3 fatty acids may counteract Hg toxicity, the authors concluded that informing pregnant women on both the mercury and nutrient content of local fish species is important.[40]

Bioavailable heavy metals which enter the environment predominantly as a result of anthropogenic activities (mining, industry, waste) have a tendency to bioaccumulate.[41,42] Heavy metals naturally exist in trace amounts in living organisms. Some of the metals are quintessential to maintain various biochemical and physiological functions in living organisms when in very low concentrations, however they become problematic when they exceed certain threshold concentrations. The effects of toxic heavy metals on the human body has been well documented in Table 1. For example, chronic exposure to arsenic (As) can lead to dermal lesions, skin cancer, peripheral neuropathy, and peripheral vascular disease,[43] while chronic ingestion of cadmium can have adverse effects such as prostatic proliferative lesions, bone fractures, kidney dysfunction, hypertension lung cancer, and pulmonary adenocarcinomas.[44] Excessive intake of Pb can damage the skeletal, circulatory, nervous, enzymatic, endocrine, and immune systems.[45]

Heavy metal toxicity may result from alterations of numerous physiological processes caused at cellular/molecular level by inactivating enzymes, blocking functional groups of metabolically important molecules, displacing or substituting for essential elements and disrupting membrane integrity.[7] This causes oxidative stress, an unevenness involving the production of free radicals and the capacity of cells to eradicate them or repair the damage.[46] This leads to base damage through formation of reactive oxygen species (ROS) which includes oxygen radicals (superoxide and hydroxyl)[47] and non–radical derivatives of molecular oxygen (O_2) such as hydrogen peroxide (H_2O_2), as well as breakage of the DNA molecule.[46,47] Heavy metal toxicity increases the production of ROS thereby decreasing the antioxidant systems (glutathione, superoxide dismutase, etc.) which protect cells. If this condition continues, the normal functioning of the organism is affected and may invariably lead to cell death.[48]

A scarcity of literature exists on the extent of heavy metals and other harmful pollutants in PICs. Furthermore, studies on the human risk factors to heavy metal exposure in Pacific Islands are few. A study by Jones et al.[60] examined the trace metal levels in the hair of residents of the OK Tedi region of Papua New Guinea. The authors collected hair from all the local villages in the vicinity of the mine site, as well as from Papua New Guinean nationals from other provinces, and European expatriates who were employed by the mining company and who were resident in the area. Although hair Cu, Pb, Zn and Hg all appeared to be within 'normal' limits by comparison with other general populations, hair from local people showed a remarkably high iron and cadmium content by comparison with previously studied populations.[60]

In addition to face to face interviews, urine samples were collected from 732 individuals in New Caledonia and analyzed for 4 heavy metals such as Co, Cr, Mg and Ni.[61] Environmental samples (soil, house dust, water, and foodstuffs) were also collected from two areas (one with and one without mining activity) to delineate determinants of exposure in more detail. The results showed that Ni and Cr were in the highest concentrations found in urine, especially in children, at levels exceeding reference values derived from representative national surveys elsewhere throughout the world (for children: 4.7 μg/g creatinine for Ni and 0.50 μg/g creatinine for Cr). 13% of children were found to have exceeded the reference value for nickel and 90% for chromium and large variations were observed by region, age, and sex.[61]

A recent study by Matakarawa[62] compared prevalence of acute upper respiratory infection (AURI), and the ARI–free survival rates of children born and living in a mining region and those born and living in a non–mining region, as a way of generalizing the possible effects of gold mining–related air pollution on child health. Respiratory records and vital statistics of a cohort of children born in 2011 in both the regions were retrospectively followed up from birth until their fifth birthdays in 2016. Living in non–gold–mining region (Odds Ratio = 48) and children of Indo–Fijian race were at higher risk of AURI (Odds Ratio = 2.4). Multivariable logistic regression showed living in non–gold–mining region as an independent risk factor for AURI (OR 39.6, 95% CI: 5.36–292; $p < 0.001$); while living in gold mining region was the single independent risk factor for pneumonia found by the study.[62]

Metal detection methods

Flame atomic absorption spectroscopy (FAAS)

FAAS is a relatively inexpensive and widely used technique for the determination of elements at part per million (ppm) concentration levels with excellent accuracy and good sensitivity. FAAS uses air acetylene and/or nitrous oxide flame atomizer. The sample is introduced as an aerosol into the flame by the sample introduction system consisting of a nebulizer and spray chamber. The burner head is aligned so that the light beam passes through the flame, where the light is absorbed. The major limitation of FAAS is that the burner–nebulizer system is a relatively inefficient sampling device. Only a small fraction of the sample reaches the flame, and the atomized sample passes quickly through the light path. However, FAAS technique provides fast analysis of 10–15 seconds per sample, with very good precision (repeatability) and moderate interferences that can be easily corrected at a relatively low cost.[63]

FAAS has successfully been applied in PICs for the determination of heavy metals in various matrices.[13–16] Most recently, FAAS was used to determine the concentration of heavy metals in road dust and road side soil of Suva City, Fiji. Reported metal concentrations were; Cd (3.7 and 3.1 mg/kg), Co (35.0 and 33.2 mg/kg), Cr (40.0 and 34.0 mg/kg), Ni (54.3 and 32.4 mg/kg), Cu (172.3 and 265.7 mg/kg), Pb (71.0 and 59.3 mg/kg), Zn (685.0 and 507.0 mg/kg), and Fe (41,010.4 and 39,525.5 mg/kg) for road dust and road soil samples respectively.[16]

Graphite furnace atomic absorption spectroscopy (GFAAS)

GFAAS is a suitable atomization technique used to determine analyte concentration in samples with an acceptable limit of precision reaching the parts per billion (ppb) level. With GFAAS, the sample is introduced directly into a graphite tube, which is then heated in a programed series of steps to remove the solvent and major matrix components and to atomize the aimed analyte in the sample. All of the analyte is atomized, and the atoms are retained within the tube (and the light path, which passes through the tube) for an extended period of time. As a result, sensitivity and detection limits are significantly improved over FAAS.[64] Additionally, the enhanced sensitivity of GFAAS, and its ability to analyze very small samples, significantly expands the capabilities of atomic absorption. However, compared to FAAS, analysis times are longer and fewer elements can be determined using GFAAS.

Using GFAAS, Chand et al.[65] reported the incidence of high arsenic (As) contamination in the sediments of the Lami estuary, Fiji. To achieve this, the authors employed a Perkin Elmer HGA 900 graphite furnace equipped with an integrated stabilized temperature platform (STPF) pyrolytic graphite coated tube and AS90 autosampler, combined with a Perkin Elmer AAnalyst 400 atomic absorption spectrometer (AAS) with deuterium background correction. The short–term variations in the concentrations of As in Lami estuary were found to be in the range of 1.0–334.0 mg/kg (dry weight), which ascended gradually over a period of one year.[65]

Hydride generation atomic absorption spectroscopy (HGAAS)

HGAAS is the most suitable analytical technique for elements (As, Sn, Bi, Sb, Te, Ge, Hg, Se, etc.) which form volatile hydrides when reacted with a reducing agent, such as sodium borohydride ($NaBH_4$). In this technique, a continuous flow system involves the reaction of acidified aqueous samples with a reducing agent to generate volatile hydride, which is then transported to the heated quartz cell i.e., atomizer along the optical axis of the conventional AAS by means of argon gas. In the quartz cell, the hydrides are converted to gaseous metalloid analyte atoms in the path of a source lamp and a signal is generated by measuring the amount of light absorbed. The quality of the results is subject to different parameters, such as the valence state of the analyte, gas pressures, acid concentration and the quartz cell temperature. Thus, achieving high quality data in this technique requires a high skilled operator.[66] HGAAS is a fast technique with good precision and good sensitivity however it is limited to specific elements, most of which have been shown above.

HGAAS was employed by Kapia et al.[67] to report the heavy metal (Hg, Cd, Cr, Cu, and Pb) contamination risks and safety of two species of fresh water fish namely; tilapia, (*Oreochromis mossambicus*) and carp, (*Cyprinus carpio*) which were farmed in the Yonki Reservoir in the Eastern Highlands of Papua New Guinea (PNG). The upper reaches of the reservoir are affected by alluvial and large–scale gold mining activities. The authors also assessed heavy metal levels in the surface waters, sediments and in selected aquatic plant species from the reservoir and streams that intersect the gold mining areas. The Hg content in all the environmental matrices were analyzed by HGAAS while the other metals were analyzed using ICP–OES. The Cd concentration in the sediments exceeded the US Environmental Protection Agency's (USEPA) Sediment Quality Guideline (SQG) values, and the geoaccumulation index (I_{geo}) values indicated heavy to extreme pollution. In addition, the Cd, Cu and Pb concentrations in aquatic plants exceeded the WHO guidelines for these contaminants. The fish species tilapia accumulated significantly higher ($P < 0.05$) Cu in their organ tissues than carp which confirmed the bioaccumulation of some metals in the aquatic fauna. The edible muscles of the fish specimens had metal concentrations below the maximum permissible limits established by statutory guidelines. These authors also performed human health risk assessment using the estimated weekly intake (EWI) values which confirmed that farmed fish from the Yonki Reservoir were safe for human consumption.[67]

A comparison of common spectroscopic techniques for metal determination is shown in Table 2.

Cold vapor atomic absorption spectrometer (CVAAS)

The unique characteristic of mercury (Hg) allows its vapor measurement at room temperature. Thus, CVAAS is a flameless AAS technique for Hg detection based on the absorption of radiation at 253.7 nm by Hg vapor. Hg is first reduced to the elemental state by a strong reducing agent such as $NaBH_4$ or stannous chloride ($SnCl_2$). The mercury vapor passes to the absorption cell positioned in the light path of the spectrophotometer by argon carrier gas for detection.[66] The advantages of CVAAS over FAAS is good sensitivity and precision and faster analysis, however, this method is limited to mercury only.

Sediment samples from four harbors in Guam, namely; Agana Boat Basin, Outer Apra Harbor, Agat Marina, and Merizo Pier, were collected and analyzed for heavy metal contamination. Users of Guam's harbors have included the US military (since World War II), commercial shippers, commercial and recreational fishermen, tourist operators (dinner cruises, diving, jet-skiing, sailing, etc.), and the general public.[68] As a result, some contamination of sediments was to be expected, but the extent was

Table 2. Comparison of common spectroscopic techniques for metal determination.

Parameters	Spectroscopic methods FAAS	GFAAS	HGAAS & CVAAS	ICP–OES	ICP–MS	NAA
Detection limit ranges (μg/L)	0.1–>260	0.01–0.5	0.005–0.1	0.1–30	0.01–<0.001	0.01–0.1
Sample throughput	10–15 sec per element	5–6 min per element	30–50 sec per element	60 elements in < 1 min	All elements of interest in < 1 min	1 min–Several hours for all elements of interest
Interferences	Few	Few	Very few	Many	Few	Few
Maximum number of elements analyzed	~65	~50	~8	~70	~70	~74
Chemical matrix	Many	Very few	Very few	Few	Some	Many
Sample volume required	Large	Very small	Large	Medium	Very small–very high	Large
Operator skills required	Low	Medium	Medium	Medium	High	High
Operation cost	Moderate	Moderate to high	Moderate to high	High	Very high	High

unknown before this study. All metal determinations were made by FAAS except Hg, which was made by CVAAS. The results showed that Hg levels were highest at Apra harbor while levels at other sampled harbors were within "pristine" levels.[68]

Catalytic kinetic method

In recent years, good progress has been made in the development of new kinetic methods of analysis (KMA), with applications in environmental determination. Most kinetic analytical measurements are based on homogeneous reaction systems.[69] KMA involves catalytic methods, non–catalytic methods and enzymatic methods. Among them, catalytic determinations have most widely been used for the measurement of heavy metal ions, involving different types of indicator reaction catalyzed by metal ions.[70] Their selectivity, simplicity and rapidity have made spectrophotometric catalytic kinetic methods (CKM) an attractive analytical tool for heavy metal determinations. Catalytic kinetic photometric and fluorometric methods have been demonstrated to be promising techniques for trace analysis of heavy metal ions due to the good analytical characteristics they offer such as high sensitivity and superior selectivity.[70]

A catalytic kinetic spectrophotometric method was developed by Prasad and Halafihi[71] for the determination of trace amounts of Cu(II) in water samples based on the catalytic effect of Cu(II) on the oxidation of cysteine (RSH) by hexacyanoferrate(III) in acidic medium. The reaction was monitored spectrophotometrically by measuring the decrease in absorbance of hexacyanoferrate(III) at 420 nm which led to the determination of Cu(II) at trace levels as 0.45 ± 0.04–0.84 ± 0.05 ng/mL.[71]

Similarly, Chand and Prasad[20] developed and utilized a CKM for the determination of total inorganic Se, Se(IV) and Se(VI) in water resources of Fiji. The method was based on the catalytic effect of Se(IV) on the reduction of bromate by hydrazine dihydrochloride in acidic media. The generated bromine decolorized methyl orange (MO) and the reaction was monitored spectrophotometrically at 507 nm as a function of time. The initial rate and fixed time methods were adopted for the determination and speciation of inorganic Se i.e., Se(IV) and Se(VI) at trace level with the observed relative standard deviation (RSD) less than 6%.

Inductively coupled plasma/optical emission spectrometry (ICP–OES)

As indicated by its name, ICP–OES or ICP–AES is a technique that uses plasma as a source of energy and relies on optical emission for analysis. However, unlike many other spectrometers, the sample is not simply placed in–between source and detector. ICP–OES is mainly used for liquid samples. Thus, solid samples require acid digestion prior to injection into the instrument. The sample solution is converted to an aerosol which is sent into the center of the plasma that maintains high atomization temperature of around 10,000 K. The atoms generated in the gaseous state due to adequate energy are converted to ions and promoted to excited states. The ions from excited state return to the ground state via emission of photons. The specific wavelength of the photons is used to identify the elements while the number of photons is directly proportional to the concentration of the element in the sample. A variety of sample introduction methods are used in this technique such as nebulization, hydride generation (HG) for certain elements such as As, Se and Sb as well as electrothermal vaporization (ETV) and laser ablation.[72] An important feature of ICP–OES is that it enables simultaneous multi element analysis and tolerates complex matrices, however the initial investment is much higher than AAS based methods.

The only use of extensive ICP–OES for analysis in the Pacific region was Chand and Prasad.[73] The authors compared a closed vessel microwave assisted aqua regia digestion (MAARD) and an alkaline fusion dissolution technique (AFDT) for determination of ten metals (Al, As, Co, Cr, Cu, Fe, Mn, Ni, Pb and Zn) in marine sediments. The precision and accuracy of the digestion procedures were verified using a reference material for sediment and analyzed by ICP-OES. Except for Al and As which were underestimated using the acid digestion method and the alkaline fusion method, respectively, both digestion methods showed no statistically significant difference in metal concentrations and recovery values for all metals were nearly quantitative ($>$82%). The average RSD for both digestion methods were less than 6%, indicating good method precision. The application of the two methods for the determination of ten heavy metals in ten sediment samples showed significant correlation between results achieved by both digestion methods for all the metals studied except for As. The study demonstrated that MAARD was more suitable for the determination of minor and volatile elements such as As, while AFDT was more suitable for the determination of silicate bound and refractory metals. Application of the proposed methods to sediments from a coastal environment in Fiji showed that the sediments were highly contaminated with metal levels as much as 345 mg/kg As, 519 mg/kg Cr, 530 mg/kg Cu, 1387 mg/kg Ni, 800 mg/kg Pb and 1720 mg/kg Zn.[73]

Inductively coupled plasma mass spectrometry (ICP–MS)

ICP–MS combines the multi–element capabilities of ICP techniques with exceptionally low detection limits equivalent to or below those of GFAAS. It is also one of the few analytical techniques that allows the quantification of elemental isotopic concentrations and ratios, as well as precise speciation capabilities. This feature enables the analytical chemists to determine the species i.e., speciation and not just the total concentration. ICP–MS uses an argon plasma source to dissociate the analyte from sample into its basic atoms or ions. It generates singly charged ions from the elemental species within a sample that are directed into a mass spectrometer and separated according to their mass–to–charge (m/e) ratio. Ions of the selected m/e ratio are then directed to a detector that determines the number of ions present i.e., concentration. Typically, a quadrupole mass spectrometer is used for its ease–of–use, robustness and speed. Due to the similarity of the sample–introduction and data–handling techniques, using an ICP–MS is very much like using an ICP–OES system.[72]

ICP–MS was employed by Ra et al.[17] in the analysis of heavy metals in the mangrove sediments of Chuuk and Kosrae in the Federated States of Micronesia (FSM). Mean concentrations of Cr, Ni, Cu, Zn, As, Cd and Pb were found to be 642, 125, 46.9, 149, 15.6, 0.14 and 8.55 μg/g, respectively.[17] Kosrae mangrove sediments showed the highest concentrations of Cr and Ni while Chuuk contained mangrove sediments more Cu, Zn, As, Cd and Pb. The authors concluded that As was the heaviest contaminant in the surface sediment from Micronesia whilst other metals (Cr, Ni, Cu, Zn, Cd and Pb) were present at slightly lesser levels.[17]

Anodic stripping voltammetry (ASV)

ASV is an electro-analytical technique in which reducing potential is firstly applied to the working electrode for a period of time which subsequently leads to the accumulation of the reduced analyte species onto its surface. Afterward, an oxidizing potential sweep is applied to the electrode and the analyte is re-oxidized at its characteristic oxidation potential, and the cathodic current generated is proportional to the amount of analyte initially deposited onto the electrode.[74] The stripping techniques have lower detection limit than any of the commonly used electrochemical techniques, and in addition, the sensitivity and selectivity are excellent. However, using stripping voltammetry the number of the measurable element is only about 20 elements compared with more than 70 for most atomic spectrometry analytical techniques.[75]

ASV has been applied for trace metals detection in a variety of matrices including environmental, clinical and industrial samples.[76–78] In a recent study, a method was developed and applied for the speciation of inorganic As in environmental water samples using linear sweep voltammetry (LSV) on a gold (Au) working electrode. The limit of detection of the method was found to be 0.763 μg/L [As(III)].[79] Using the proposed method, the authors reported As(III) and As(V) concentrations as 1.4-20.7 μg/L and 10.1-52.0 μg/L in Metapona river in Solomon islands, and 7.3-55.2 μg/L and 11.3-26.9 μg/L in Sabeto river in Fiji.[79]

Neutron activation analysis (NAA)

NAA is another type of analytical procedure used to detect the concentration of trace elements in different matrices. In this technique, the sample is exposed to a neutron flow after which radioactive isotopes for analyte element are generated. As the radioactive isotopes decay to a lower energy state, they emit delayed gamma rays with characteristic energies for each element. Quantitative measurement of the concentrations of various elements may be achieved by determining the intensities of the gamma rays emitted from the radioactive isotopes which are proportional to the amount of the element in the sample. Several advantages have been recorded for NAA method such as the ability to analyze a number of elements simultaneously without destroying the sample, and the high sensitivity for different elements ranging from 0.1 to 106 ppb.[80]

The NAA method has successfully been applied in Fiji to determine trace metal concentrations in different matrices. Garimella et al.[18] reported the concentration of 25 elements present in the sediments from four sites within the Suva lagoon. Their work showed that As, Cr and Zn exceeded USEPA guidelines. Similarly, Garimella et al.[81] developed a systematic study to investigate the quality of air in Suva, the capital city of Fiji Islands. Concentrations of some heavy metals and other trace elements in atmospheric aerosols were investigated by NAA and gamma spectrometry. The concentrations of total suspended particulates for residential, traffic and industrial areas were found to be in the range of 9–43, 20–58 and 33–91 $\mu g/m^3$, respectively. The elements Na and Fe were observed in relatively higher concentrations than other elements. The authors also calculated enrichment factors (EF) for some elements (As, Br, Co, Cr and Sb) and suggested possible anthropogenic inputs into air mainly through automobile exhaust emissions.

The determination of heavy metals carried out by different spectroscopic techniques is shown in Table 3. It is interesting to note that all studies on heavy metal contamination using ICP, except one,[73] were conducted outside the Pacific Islands in Korea, France, US and Canada[17,19,40,82] which are shown in Table 3. This further highlights the poor adoption and utilization of ICP in the Pacific Islands and the reliance on AAS based methods. In general, methods based on AAS are easier to implement and less costly than other available options in terms of the analytical instrumentation and have therefore been favored in the Pacific region.

Sources of waste pollution in the Pacific Islands

Among the major anthropogenic pollution sources identified for the Pacific Islands include landfills, mineral extraction (mining operations), waste from industrial operations and chemicals used in the agricultural sector. Less significant and future potential sources of pollution may arise from oil leakage from sunken World War II oil tanker ships and the growing use of sewage sludge as a nutrient source in Agriculture.

Landfills

Among the many challenges faced by PICs, pollution and improper waste management rank highly. Tens of thousands of tons of processed goods and raw materials are

Table 3. A summary of trace metal concentrations in Pacific Island Countries by various techniques.

Location	Sample/media	Detection method	Concentrations reported	Ref.
Futiga landfill, American Samoa	Sediments	ICP–OES	Pb (241–747), Ni (336–646), Cd (2.0–3.1), Cr (85–364), Co (45.3–95.1), Cu (23.6–84.4), Sn (16–37), Mg (6615–23608), Mn (1063–1947), Hg (9–417) and Zn (295–773) mg/kg	[19]
Laucala Bay, Fiji	Surface sediments	Mn, Zn, Cu, Pb, Cd: GFAAS. Hg: CVAAS	Mn (272–1333), Zn (32–153), Cu (23.9–93.6), Pb (3.32–13.25), Cd (0.6–1.23) and Hg (0.061–0.185) mg/kg	[83]
	Shellfish (*Anadara antiquata)*		Mn (44.1–119), Zn (94.9–136), Cu (7.6–15), Pb (2.9–4.6), Cd (1.7–3.4) and Hg (0.037–0.099) mg/kg	
Lami Dumpsite, Fiji	Soil	FAAS	Cu (−1.3–672.2), Zn (−48.7–853.1), Pb (−101.0–386.3) and Ni(<LOD–22.7) mg/kg dry wt	[14]
Suva Harbor, Fiji	Surface sediments	AAS	Cu (21.4–143.0), Fe (14000–48700), Pb (22.1–93.5), Zn (40.2–269.0) and Sn (1.1–2.6) mg/kg	[13]
	Bivalve (*A. Antiquata*)		Fe(III) (650 ± 40), Cu(II) (12.0 ± 1.0), Co(II) (2.5 ± 0.3), Mn(II) (48 ± 5), Ni(II) (4.0 ± 0.5) and Cr(III) (1.8 ± 0.3) ug/g dry wt	[23]
	Bivalve (*G. Tumidum*)		Fe(III) (500 ± 40), Cu(II) (11.0 ± 1.0), Co(II) (2.8 ± 0.3), Mn(II) (45 ± 6) and Ni(II) (4.5 ± 0.5) and Cr(III) (1.6 ± 0.2) ug/g dry wt	
Korotogo, Fiji	Bivalve (*A. Antiquata*)		Fe(III) (340 ± 50), Cu(II) (8.4 ± 1.4), Co(II) (2.2 ± 0.3), Mn(II) (40 ± 5) and Ni(II) (2.9 ± 0.3) and Cr(III) (1.0 ± 0.2) mg/kg dry wt	
	Bivalve (*G. Tumidum*)		Fe(III) (320 ± 50), Cu(II) (8.0 ± 1.0), Co(II) (2.0 ± 0.3), Mn(II) (42 ± 5) and Ni(II) (3.0 ± 0.4) and Cr(III) (1.2 ± 0.3) mg/kg dry wt	
Lami Coast, Fiji	Sediments	ICP–OES	Al (551000–858000), As (0.0–33.1), Co (20.5–37.8), Cr (39.0–518.7), Cu (10.4–504.9), Fe (36000–77300), Mn (409.8–1456.0), Ni (12.4–42.6), Pb (8.0–747.2) and Zn (99.0–1613.0) mg/kg dry wt	[73]
Suva, Fiji	Road dust	AAS	Cd (2.4–12.2), Co (27.1–57.7), Cr (21.1–81.9), Ni (32.1–109.8), Cu (59.3–328.3), Pb (33.6–234.5), Zn (146.2–3262.6), and Fe (26,091.8–104,807.4) mg/kg	[16]
Agana Boat Basin, Guam	Harbor sediments	Cd, Cr, Cu, Pb, Ni, Ag, Sn, Zn: AAS, As: HGAAS, Hg: CVAAS	Ag (<0.18–0.36), As (0.81–7.19), Cd (<0.07–0.27), Cr (3.16–31.2), Cu (0.49–96.1), Ni (0.56–21.2), Pb (1.02–324), Sn (<0.09–10.9), Zn (1.79–126) µg/g dry wt and Hg (3.10–123) ng/g dry wt	[68]
Merizo Pier, Guam			Ag (<0.17–<0.25) As (2.43–6.23), Cd <0.12–0.24), Cr (12.2–52.7), Cu (3.55–168), Ni (12.4–102), Pb (<0.38–129), Sn (<0.08–43.1), Zn (7.17–167) µg/g dry wt and Hg (7.53–73.3) ng/g dry wt	
French Polynesia	Human blood samples	ICP–MS	Se (1.2–4.9) µmol/L and Hg (0.25–240) nmol/L	[40]
Chuuk and Kosrae, FSM	Mangrove sediments	ICP–MS	Cr (642), Ni (125), Cu (46.9), Zn (149), As (15.6), Cd (0.14) and Pb (8.55) µg/g dry wt	[17]
O'ahu, Hawaii	Harbor sediments	AAS	Pb (82–110), Cu (110–146), Zn (172–223), Cd (1.04–1.38), Hg (0.99–1.28), Ni (57–68) and Cr (64–76) ppm	[84]
Kaneohe Bay, Hawaii	Oysters	FAAS	As (8.47–11.87), Ag (6.32–9.35), Cd (0.54–0.69), Cu (165.20–522.33), Cr (2.03–10.01), Mn (12.06–14.68), Pb	[85]

(*continued*)

Table 3. Continued.

Location	Sample/media	Detection method	Concentrations reported	Ref.
			(0.10–1.76), Se (2.88–3.41) and Zn (544.60–1211.27) µg/g dry wt	
Betio landfill, Kiribati	Landfill surface sediments	XRF	Cr (0.9–12.6), Cu (0.3–13.9), Pb (3.4–13.3), (Zn 1.2–77) Hg (0.3–1.3) µg/g dry wt	[86]
Conception Bay, New Caledonia	Mangrove sediments	HR–ICP–AES	Cu (0.08–0.51), Co (0.01–0.38), Ni (0.03–3.55), Cr (0.36–3.11), Zn (0.68–2.36), Mn (1.13–5.0) and Fe (22.64–721.69) µmol/g	[82]
Yonki reservoir, PNG	Sediment samples	Hg: HGAAS. Cd, Cr, Cu,	Cd (17.2), Cr (62.1), Cu (71.9), Hg (0.053) and Pb (31.9) µg/g dry wt	[67]
	Fish (*Oreochromis mossambica*)	Pb: ICP–OES.	Hg (< 0.01), Cd (< 0.01), Cr (< 0.01–0.02), Cu (< 0.01–3.87) and Pb (<0.01) µg/g dry wt	
OK Tedi, PNG	Human hair	CVAAS	Fe (4.00–4805.30), Cu (0.74–82.81), Cd (0.10–44.00), Pb (4.00–135.89), Hg (0.09–4.50) and Zn (14.50–362.39) mg/kg	[60]
Apia, Samoa	Sediment samples	FAAS	Cu (0.97–3.82) and Pb (1.23–2.82) mg/g dry wt	[87]
Metapona river, Solomon Islands	Water samples	ASV	As(III) (1.4-20.7), As(V) (10.1-52.0) µg/L	[79]
Marovo lagoon, Solomon Islands	Sediment samples	GFAAS	Pb (74.8–371), Cu (144–358), Cr (75–351) and Cd (24.7–47.1) µg/g dry wt	[88]
	Bivalves		Cd (1.70–10.2), Pb (24.0–85.5), Cr (9.34–41.8) and Cu (47.0–76.0) µg/g	
Fanga'uta, Tonga	Sediments	Ca, Mg, Fe, Al, K, Na, Sr, P: ICP–OES. Cu, Pb, Zn, Ni, Cd, Mn, Sn, As: ICP–MS. Hg: CVAAS.	Ca (7,440–288,000), Mg (3,590–15,800), Fe (1,550–114,000), Al (1,355–97,000), K (244–3,650), Na (960–20,500), Sr (99–4,760), P (130–5,310), Cu (2–180), Pb (<1–31), Zn (6–208), Ni (<2–25), Cd (<0.1–0.9), Mn (27–4550) and Sn (<0.5–17.7) mg/kg	[89]
	Shellfish		Cu (27–120), Ni (<7–20), Zn (18–140), As (25–80), Mn (2.3–17), Sr (73–170), Li (1.0–9.0), Se (<2–40), Al (32–350), Ca (5,100–15,800), Fe (400–3,300), K (8,260–13,500), Mg (9,580–16,600) and Na (70,900–128,000) mg/kg	
Fongafale islet, Tuvalu	Coastal sediments	ICP–MS	Cr (56.4–240.0), Mn (28.8–156.0), Ni (53.0–216.0), Cu (21.6–564.0), Zn (35.0–1440.0), Cd (0.6–11.2) and Pb (25.2–680.0) ng/g	[90]

nd = below detection limit

shipped annually to PICs (e.g., furniture, electronics, packaged foods, clothing, medicines, etc.), however very few possess the proper means and resources to adequately dispose or recycle such waste products.[91] As a consequence, landfills and rubbish dumps have become a repository for all types of waste.[5] This was the case in Fiji with the Lami rubbish dump site which served as the primary dump site for agricultural and industrial as well as household waste servicing the greater Suva area. The dump site which was operational since the 1940s was an open dump and lacked any waste acceptance criteria and had reached its capacity since the 1980s. Additionally, it was situated close to residential areas and had open access to the sea. The flow of leachate and toxic chemicals into the soil and marine environment became a major concern which eventually led to its closure in 2004.[14] However, the site has been regarded by few studies as highly contaminated exceeding the so called "Dutch standards".[14,92,93] The environmental pollution from the Lami dump impacted greatly on the health and the livelihood of the many people, who not only live around them but also those who fish, collect shellfish from the water, those who collect crabs from the mangrove swamps and those that scavenge the dump regularly.[92] The Lami dump was replaced in 2005 by the Naboro landfill, a sanitary engineered landfill with a modern waste disposal site.[94] However, cleaning and restoring the now abandoned Lami dump site still presents a major challenge and little effort has been made toward remediation and restoration of the site.

Industrial operations/manufacturing

Industrial operations have also been cited as a major source of recalcitrant inorganic pollutant in the environment especially heavy metals. The waste materials from these factories and manufacturing plants are usually released into the environment indiscriminately. A lack of concise framework and regulation guiding toxic waste disposal coupled with weak enforcement of policies by Pacific Island governments has further exacerbated the issue. Industrialization is limited to the larger islands and economies of the Pacific including Fiji, New Caledonia and PNG as smaller island nations with limited land and resources rely heavily on imports. In Fiji for example, the bulk of industrial operations occur in the Walu Bay and Vatuwaqa industrial sites around Suva. Walu Bay is located at the center of the capital, Suva and contains numerous processing, crude oil storage and transportation facilities (Figure 2). The 2006 Fiji National Liquid Waste Management Strategic Plan reported major changes occurring in the industrial zone of Walu Bay due to high levels of tributyl tin (TBT) from marine antifouling paints, petroleum pollutants, leached hazardous metals from a battery factory and effluents from nearby food processing factories. Few researchers have documented higher levels of heavy metals around these areas as a result of effluents and discharged waste from these operations.[4,13,15,65]

Other sources of metals and polycyclic aromatic hydrocarbons (PAHs) pollution in the environment arise from fossil fuel combustion as well as motor vehicle emissions and urban runoffs. The use of antifouling paints and agents such as TBT on ships and marine vessels, have also contributed to pollution of the marine environment in PICs. In Fiji, Suva lagoon sediments have been reported to have significant TBT contamination, including the highest reported TBT values in the world (92–360 mg/g).[95] However, monobutyl tin (MBT)/dibutyl tin (DBT) ratios were generally below 0.1, indicating that little or no additions of TBT occurred in recent years.[95] Table 4 shows the industrial applications and sources of some toxic heavy metals.

Agriculture

Commercial agricultural activities are another source of pollution in PICs. The economy of most PICs is largely dependent on agriculture which constitutes a significant segment of exports and gross domestic products (GDP). According to the World Bank,[97] agriculture contributes about 10.4%, 17.9%, 10.7%, 17.9% to the GDP of Fiji, PNG, Samoa and Tonga, respectively. However, poor land management practices and the loss of agricultural lands to other economic activities have led to increased use of pesticides and

Figure 2. Walu Bay, a major industrial area in the heart of Suva, the capital of Fiji.

Table 4. Industrial applications and sources of heavy metals.[96]

Heavy metals	Sources
As	Pesticides and wood preservatives
Cd	Paints and pigments, plastic stabilizers, electroplating of cadmium containing plastics, phosphate fertilizer
Cr	Tanneries, steel industries, fly ash and wood preservatives
Cu	Pesticides, fertilizers and wood preservatives
Hg	Release from Au–Ag mining and coal combustion, medical waste
Ni	Industrial effluents, kitchen appliances, surgical instruments, steel alloys, automobile batteries
Pb	Aerial emission from combustion of lead petrol, battery manufacture, herbicides and insecticides

fertilizers as nutrient inputs.[98] Extensive and improper pesticide and fertilizer usage contribute to soil and groundwater contamination. It is estimated that as much as 70% of applied pesticides, most of which contain heavy metals, is washed away and leaches into the soil and water resulting in excessive pesticide residue contamination in the local ecology and food chain.[99] For example, In American Samoa, stream sediments were reported to contain high concentrations of Pb, and some of Hg.[19] Several coastal stream waters showed relatively high concentrations of diethyl phthalate and of organophosphate pesticides, above chronic toxicity values for fish and other aquatic organisms. Parathion, which has been banned by the US Environmental Protection Agency since 2006, was also detected in several stream sites.[19]

Conversely, an emerging source of contamination of agricultural land is through the use of sewage sludge in agriculture. Sewage sludge are byproducts of insoluble waste produced in Waste Water Treatment plants. A study by Mani et al.[22] showed high concentrations of heavy metals in sewage sludge produced by the Kinoya waste water treatment plant (KWWTP) in Fiji. There is growing concern over the use of sewage sludge in agriculture as an alternate means of disposal due to its high nutrient and

Table 5. Some major mines in Pacific Island Countries and associated mineral deposits.

Country	Mines	Year opened	Mineral deposits	Annual production (tons)	Ref.
Fiji	Mt Kasi Gold Mine	1932–1998	Gold	=	
	Emperor Gold	1933	Gold	1.37	[106]
	Mine (Vatukoula)		Silver	0.50	[106]
	Nawailevu Mine	2011	Bauxite	400	
New Caledonia	Goro Nickel Mine	1992	Nickel	60,000	[107]
			cobalt	5,000	
	Thio	1875	Nickel	107,000	[102]
Nauru	=	1908–2000	Phosphate	=	[106]
Papua New Guinea	Panguna Mine	1972–1989	Copper, gold	165,000	[108, 109]
				14.06	
	Lihir Gold Mine	1997	Gold	24.06	[109]
	OK Tedi Mine	1984	Copper	180,000	[109, 110]
			Gold	16.88	
	Porgera Gold Mine	1990	Gold	17.89	[109]
			Silver	2.96	
Solomon Islands	Gold ridge Mine	1998	Gold	6.56[a]	[111]

[a]Total production to date.

organic matter content.[22] However, weak legislation framework currently exists to control their use and disposal in most PICs.

Mining

As shown in Table 5, PICs are endowed with tremendous mineral reserves and mining activities have significantly increased with poor environmental regulations or compliance. Among the major mines in operation are the OK Tedi Mine in Papua New Guinea, Vatukoula Gold Mine in Fiji, Gold Ridge Mine in Solomon Islands and Thio Mine in New Caledonia. PNG in particular, possesses among the largest deposits of Au, Cu, Ag, Ni, Co, petroleum and natural gas in the world. The mining industry is of pivotal importance and has dominated PNG's economy since 1970, constituting about 75% of PNG's total exports and GDP[100] and amounting to a total revenue of more than US$3.52 billion annually.[101] Similarly, New Caledonia contains 40% of the world's known Ni deposits, and 20% of the oxidized ore deposits.[102] However, large quantities of waste known as mine tailings containing heavy metals are produced during processing to recover the desired elements.[103] It is estimated that over 99% of extracted ore during gold mining are released as waste into the environment.[104] The tailings, which contain measurable levels of processing chemicals, explosives and heavy metals, are often dumped in the environment polluting soil, sediments and waterways.[105]

The mining industry in PNG has had a history of serious environmental and socio–economic issues. Most notably the Panguna Mine on Bougainville island which over a ten–year period has dumped more than 360 million tons of tailings and waste rock into the Kawerong/Jaba river system.[108] This has resulted in the loss of fish from the 480 kilometer catchment as well as local wildlife populations.[110] The Fly River system in the remote west of PNG has faced a similar environmental threat. The OK Tedi Mine, which is the world's largest copper mine located in PNG has been disposing its tailings and waste rock containing heavy metals into the OK Tedi River (a tributary of the Fly

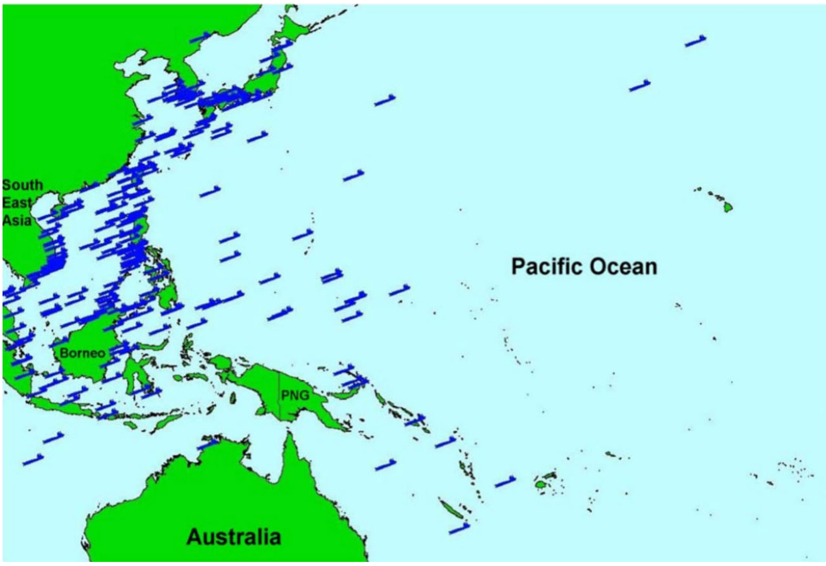

Figure 3. The locations of over 300 World War II tankers lost in the Pacific Ocean (112).

River) since the mid–1980s at a rate of approximately 65 million tons per year.[110] The accumulation of natural and mine–derived sediments containing heavy metals in the river system has produced flooding of the OK Tedi and Fly Rivers and depositing sediments across a wide area of the floodplains. This has caused an extensive vegetation dieback, the loss of food gardens, fish habitats and reduced fish populations in the floodplain areas.[110] Similar trends have been reported in the Panguna Mine in PNG[108] and in Giro Mine in New Caledonia.[107] It has been estimated that between 220 to 280 million cubic meters of waste containing heavy metals have been produced as a result of mining activities in New Caledonia.[102]

World war II shipwrecks

There has been a growing concern over the deteriorating condition of sunken World War II (WWII) vessels and shipwrecks.[112] The lasting legacy of those battles is the imminent danger and the environmental consequences of leaking oil, fuel, lubricants, chemicals, heavy metals or unexploded ordinances from over 3800 shipwrecks in the Pacific Ocean. Figure 3 shows the locations of over 300 WWII tankers in the Pacific Ocean. Another major concern is the corrosiveness of the sunken vessels, which according to an Earth Watch Report in 2010 will lose their corrosive strength by 2020 to 2025 years.[113] Thus, marine and coastal environments and fisheries, vital for the sustainable future of the people of the Pacific, are at extreme risk from marine pollution.[114]

Therefore, in a recent project of the Pacific Ocean Pollution Prevention Program (POPPP), the South Pacific Regional Environment Program (SPREP) has highlighted the extent of the risk posed by vessels lost in WWII to its member Governments. One of the main goals of POPPP activities has been the development and implementation of a Regional Strategy to Address Marine Pollution from WWII Wrecks.[115]

Conclusion

Pollution and contamination of soil, sediments and marine resources by heavy metals and other inorganic contaminants is clearly a growing challenge especially to the small developing island states in the Pacific. Livelihood and sustainable development of the region is currently threatened not only by climate change, but also due to degradation of the environment as a consequence of anthropogenic activities. A review of available literature points to a host of anthropogenic activities including industrial activities, use of chemicals in agriculture, leachate from poorly designed landfills and unregulated mining activities as major point sources of toxic metal pollutants. Nonetheless, there is a lack of awareness and research into the extent of contamination and associated human risk factors in the region. Therefore, there is a need for continuous monitoring and strengthening of studies on the environmental extent of contamination in PICs and establishment of clear guidelines and policies regarding the use and disposal of toxic materials including heavy metals, with a strong emphasis on enforcement.

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