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SHORT RESEARCH AND DISCUSSION ARTICLE

Impact of WWII dumpsites on Saipan (CNMI): heavy metal status of soils and sediments

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Abstract A number of dumpsites occur on the island of Saipan and in the surrounding coastal waters. Many of these sites date back to the immediate post WWII clean-up period and contain a variety of wartime wastes. Metallic debris is generally the most visible waste material and commonly includes bomb fragments, artillery shells, bullets, and other military hardware. In this investigation, we examined the heavy metal status of soils from around several of these dumpsites and in any obvious drainage pathways leading from them to the coast. Sediments were also taken for analysis from a number of coastal discharge points and three submerged sites. Metal enrichment was evident for one or more elements in deposits from two of the three submerged sites and 24 of the 32 land-based sites visited. Copper, Pb, and Zn were the most commonly encountered contaminant metals with levels well in excess of 1000 μg/g^{-1} in several instances. Elevated Hg and Cd concentrations were also relatively widespread throughout the study area although levels of each element seldom exceeded 1.0 and 10.0 μg/g^{-1}, respectively. Silver, another element of toxicological concern, was only occasionally detected despite registering a high of 42 μg/g^{-1} at one particular site. The metal data were weighed against established benchmarks formulated for the protection of human and ecological health. Implications of the findings and issues of primary concern are briefly addressed.

Keywords WWII dumpsites · Heavy metals · Soil · Sediments · Ecological and human health · Saipan · Commonwealth of the Northern Mariana Islands (CNMI)

Introduction

Saipan (15°12 N, 145°43 E) is the largest island in the Commonwealth of the Northern Mariana Islands and second most densely populated island in Micronesia. It is about 19 km long, 9 km wide and covers an area close to 115 sq km. The eastern coastline is composed primarily of rugged, rocky cliffs while the western side is bounded by a large lagoon that extends almost the entire length of the island. Saipan was of tactical importance to the US military during WWII and its capture from the Japanese in summer of 1944 ultimately marked the turning point of the war.

The massive clean-up and redevelopment of Saipan at the end of WWII gave rise to unprecedented waste disposal problems that were largely solved by bulldozing unwanted materials into the ocean, burying them in caves, or dumping and burning them at relatively remote locations on land. Virtually every kind of material used in warfare was among the items disposed of in this way, in addition to demolition and construction debris and other residual materials associated with the rebuilding effort. Close to two dozen such military dumpsites were identified in Saipan under the US Department of Defense *Formerly Used Defense Site* (FUDS) *Environmental Restoration Program*, initiated in 1986 (Eugenio 2014). A number of other sites contaminated with wartime and civilian wastes were identified on the island

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under the *Brownfields Program* administered through the US EPA (De Guzman 2009).

Materials often seen at these old dumpsites included pottery shards, glass beverage and medicinal bottles, fragmented bombs and artillery shells, unexploded ordnance (UXO), bullets, weapons, rusted out metal drums, aircraft and motor vehicle parts, and other types of military hardware (AMPRO 2005; USACE 2007). The pervasiveness of abandoned and remnant munitions was of particular concern given the high toxicity of several heavy metals employed in their manufacture (Bausinger et al. 2007; Della Torre et al. 2010; Denton et al. 2014) and the propensity of these elements to migrate from their corroding sources into other quarters of the environment over time (Fancis and Alama 2011; Callaway et al. 2011). The objectives of the following investigation were, therefore, to (i) evaluate the extent to which adjacent soil and sedimentary compartments had become impacted by these wartime wastes, and (ii) identify high risk areas where the metal status of traditionally harvested food organisms may have risen beyond that which is acceptable for human consumption on an unrestricted basis.

Materials and methods

Site locations

Most dumpsites visited during this study were located on the eastern side of the island (Fig. 1) in sinkholes, forested areas, streams and ravines, on cliff edges, and in the ocean. While some had been partially remediated, the great majority were in their original state, weathering effects and vegetation overgrowth notwithstanding. They included seven documented and three undocumented waste disposal sites as well as several suspected but as yet unconfirmed sites in dense jungle areas. In all, 32 land-based soil/sediment sample collection sites at or close to these dumpsites, their drainage pathways, or their coastal discharge points, were visited (Table 1). Sediments were also sampled from one suspected and two known submerged dumpsites.

Sample collection and analysis

Surface soils and sediments were collected using all plastic instruments and containers. A minimum of three co-located, discrete samples were collected within an approximate 3-m radius at each site of interest. After drying to constant weight at 30 °C, the samples were disaggregated and sieved through a 1 mm nylon screen. They were then tumbled repeatedly with clean Teflon-coated bar magnets to remove metallic Fe fragments. Each sample was digested in duplicate with concentrated nitric acid (~1 g/10 ml) at 100 °C for 3 hours, then made up to volume (30 ml) with deionized water and allowed to stand overnight. Finally, clear aliquots of each digest were decanted into polyethylene screw-cap vials (50 ml) for later analysis by atomic absorption spectroscopy (AAS). Total Hg determinations were made by flameless AAS using the syringe technique developed by Stainton (1971). All other metals (Ag, Cd, Cr, Cu, Fe, Mn, Ni, Pb, Zn) were determined by conventional flame AAS. Corrections for nonatomic absorption were made simultaneously by the instrument. Quality control and quality assurance procedures were rigidly adhered to. Recoveries for all elements were in good agreement with certified values for the standard reference material, *PriorityPollutnT^{TM}/CLP Inorganic Soils* (Catalog No. PPS-46; Lot No. 233).

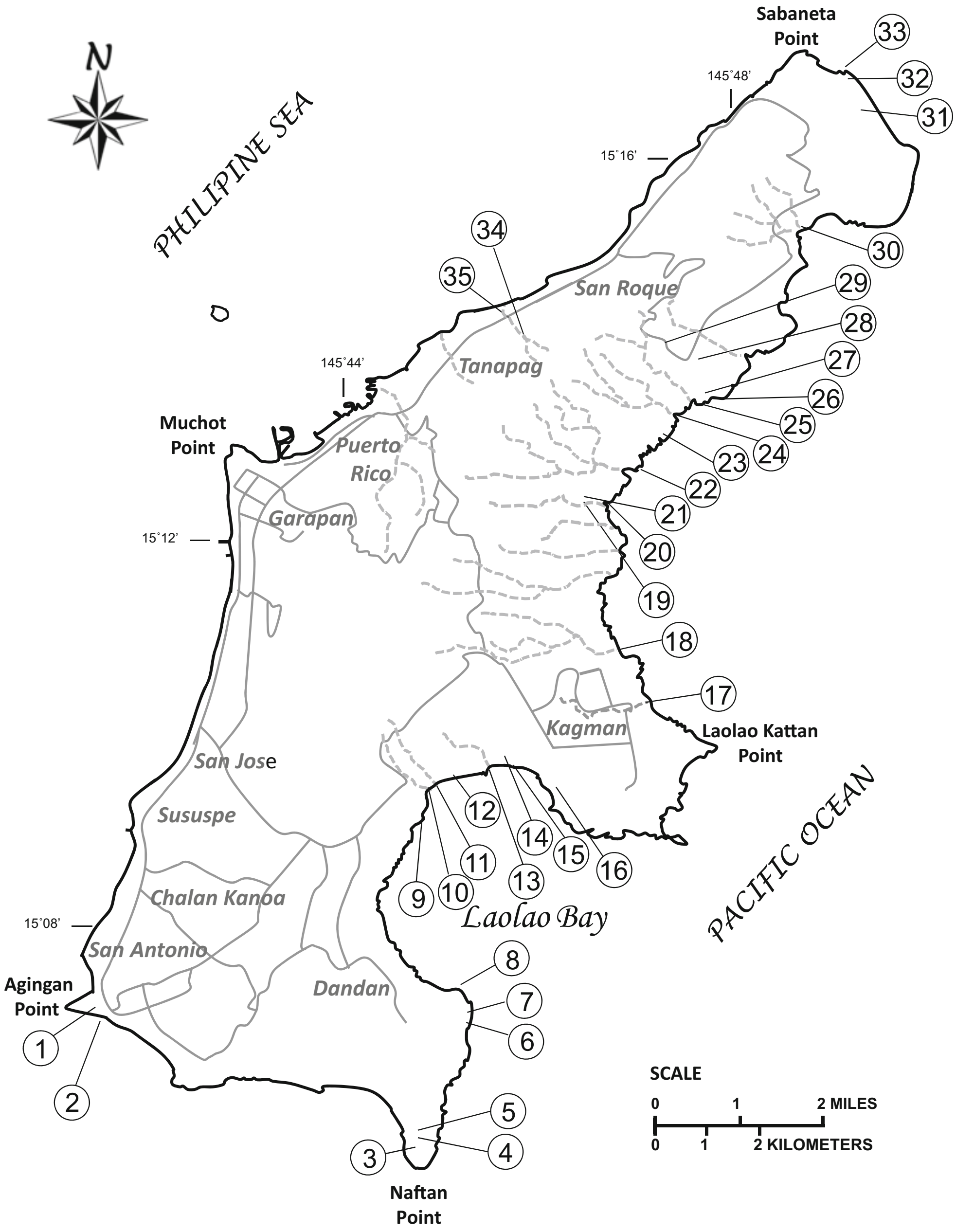
Results and discussion

The analytical findings are summarized in Table 2. Background metal concentrations in Saipan soils and sediments are presented in Table 3 together with levels found in similar substrates from Guam and the USA. Whether the Saipan soil values in the latter table are true representations of natural background levels is debatable given the heavy military assaults that occurred over much of the island during WWII (O'Brien 1997). Nevertheless, they do permit broad comparisons with the data gathered here.

Data from the present study were also weighed against soil screening levels currently adopted by Saipan's Division of Environmental Quality (DEQ 2012) and USEPA (USEPA 2005) for the protection of human health and ecological health, respectively (Table 4). Both sets of benchmarks are considered conservative insofar as being well below levels thought to cause acute health effects. They also represent preliminary screening tools for evaluating site contaminant levels and determining whether further investigations are necessary. The numerical sediment quality guidelines developed for Florida coastal waters (MacDonald et al. 1996) are applicable to calcium carbonate rich sediments and were used to evaluate potential ecological impacts of metals in all submerged deposits examined (see Table 4 legend for further details).

Clearly, considerable elemental differences exist between sites and presumably reflect differences in waste characteristics (e.g., munitions, medical, construction/demolition, general) and treatment (i.e., detonated and/or burned or not). UXO detonation sites, ammunition dumps, and burn-pit areas were among the most heavily contaminated areas examined. Soil from around the extensively fired ravine dump at 'Naftan Point' (sites 3–5), for example, was notably enriched with all metals, especially Ag, Cd, Cu, Hg, Pb, and Zn. Maximum values for these elements exceeded US soil maxima (Table 3) by over three orders of magnitude in the case of Cu, and between one and two orders of magnitude for the other five metals. And all of these elements except Hg exceeded DEQ's soil screening levels (DEQ 2012).

Fig. 1 Map of Saipan showing site locations (see Table 1 for details), major villages, roads (*solid lines*), streams (*broken lines*), and prominent landmarks



Exceedances of these benchmarks were also noted for Cu, Pb, and Zn in soil from the former 'Agingan Point' dump (site 1). This site was used for the ocean disposal of ammunition after WWII and continued as a repository for civilian wastes until the 1970s (Kluge 1969). Despite clean-up efforts on the point itself, submerged marine sediments in this area (site 2) continue to be impacted by an extensive debris field containing metallic wastes, construction and demolition materials, glass objects (bottles, jars, car headlamps), and a large number of bullets. These wastes undoubtedly account for the very high Pb levels found in bottom deposits from this site and explain why Cu, Fe, Hg, and Zn concentrations were at least an order of magnitude above those encountered in clean carbonate sediments from elsewhere in this part of the world (Table 3). The sediment quality guideline exceedances for Pb, Cu, and Hg at this site (Table 4) also suggest that sensitive species living in close proximity to these deposits may be exhibiting adverse biological effects.

Other major site exceedances of Saipan's soil screening levels were noted for Cu at 'Old Man by the Sea Beach' (site 20), Zn at 'Hospital Dump' (site 23), and Pb and Zn at a former dumpsite and ocean disposal tipping point atop 'Banzai Cliff' (site 32). Additional exceedances emerged for one or more elements in over 80 % of all sites visited upon weighing the data against the more conservative ecological screening levels formulated by USEPA (2005). The Cd exceedances noted at all sites between 'Nanasu Beach' and

Table 1 Saipan dumpsites examined in present study

Site categorization and map ID no.	Location and brief description	Sample
Cliffline dumpsites:		
1	Agingan Point: former ammunition dump, general waste repository, and ocean disposal tipping point	Surface soil
6	Naftan East: former cliffline dumpsite and unexploded ordnance (UXO) detonation site	Surface soil
7	Naftan East: former cliffline dumpsite and UXO detonation site	Surface soil
16	Laolao Bay: former cliffline sinkhole dumpsite and burn-pit	Surface soil
31	Banzai Cliff: former cliffline dumpsite, UXO detonation site, and ocean disposal tipping point	Surface soil
32	Banzai Cliff: cliffline sinkhole dumpsite and burn-pit	Surface soil
Inland dumpsites:		
3	Naftan Point: ravine dumpsite, UXO detonation area and burn-pit	Surface soil
4	Naftan Point: ravine dumpsite, UXO detonation area and burn-pit	Surface soil
5	Naftan Point: ravine dumpsite, UXO detonation area and burn-pit	Surface soil
23	Hospital Dump: located on 'Kingfisher Golf Course' at base of small cliff, medical wastes	Surface soil
29	Department of Public Safety (DPS) Firing Range formerly used by US military	Surface soil
34	Dogas Dump: aircraft parts, UXO, bitumen drums, construction waste: downstream of impacted area	Stream sediment
35	Dogas Dump: aircraft parts, UXO, bitumen drums, construction waste: upstream of impacted area	Stream sediment
Drainage pathways from known or suspected inland dumpsites:		
9	Laolao Bay Road: stormwater gulley on seaward side of beach access road	Surface soil
10	Laolao Bay Road: natural drainage pathway on seaward side of beach access road	Surface soil
11	Laolao Bay Road: small undocumented dumpsite in jungle area on landward side of beach access road	Surface soil
12	Laolao Bay Road: natural drainage pathway on seaward side of beach access road	Surface soil
13	Laolao Bay Road: natural drainage pathway on seaward side of beach access road	Surface soil
14	Laolao Bay Road: natural drainage pathway on seaward side of beach access road	Surface soil
19	Old Man by the Sea Beach: unimpacted southern stream on jungle trail to beach	Stream sediment
21	Old Man by the Sea Beach trail: impacted northern stream (undocumented dumpsite) on jungle trail to beach	Stream sediment
26	Flemming: drainage pathway from DPS Firing Range	Surface soil
27	Flemming: drainage pathway from DPS Firing Range	Surface soil
28	Liyang: drainage pathway from DPS Firing Range	Surface soil
Coastal discharge points from known or suspected inland dumpsites:		
15	Laolao Bay: stormwater discharge point	Beach sediment
17	Tank Beach: stormwater discharge point from Kagman Dump	Beach sediment
18	Marine Beach: stormwater discharge point from Kagman Dump	Beach sediment
20	Old Man by the Sea Beach: stream discharge point from previously undocumented inland dump	Beach Sediment
22	Talafofo Bay: major stormwater discharge point	Beach sediment
24	Hidden Beach: stormwater discharge point	Beach sediment
25	Nanasu Beach: stormwater discharge point	Beach sediment
30	Bird Island Beach: stormwater discharge point	Beach sediment
Submerged sites impacted by ocean disposal:		
2	Agingan Point: directly below cliffline tipping point	Subtidal sediment
8	Dandan Point: suspected ocean disposal site	Subtidal sediment
33	Banzai Cliff: directly below cliffline tipping point, UXO detonation site	Subtidal sediment

'Bird Island Beach' (sites 25–30) were of particular interest and imply rather widespread Cd contamination along this stretch of coastline. Cadmium was used extensively during WWII to protect artillery shells and gun barrels from corrosion and pitting (Woodford 1933). This would have been especially important on small tropical islands like Saipan where the high

Table 2 Heavy metals in soils and sediments from Saipan dumpsites

Site	Heavy metal levels (μg g^{-1} dry weight)									
	Ag	Cd	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Zn
1	<0.2–0.6	<0.4	9.0–13	948–1617	13,052–14,600	0.024–0.025	102–136	3.9–5.3	1846–2000	919–960
2	<0.2–0.4	<0.2	4.1–13	98–157	3506–6245	0.056–0.136	15.2–77.9	2.0–5.4	1460–1822	49–87
3	1.4–1.5	21–23	111–115	11,580–11,864	42,994–45,000	0.142–0.143	1459–1542	78–96	1555–1582	8924–9019
4	36–42	16–18	94–100	2220–2360	50,400–50,800	0.604–0.624	2400–2492	73–74	1960–2000	5660–5760
5	23–24	15–16	60	1403–1647	24,706–26,688	0.421–0.425	960–969	19–22	1696–1787	2805–2882
6	<0.2	0.6	6.3–6.7	17	3974–4184	0.088	320–336	2.5–2.7	7.0–8.2	21–23
7	0.6	1.6–1.8	33–37	161–180	49,608–50,329	0.058–0.064	875–882	13	72–73	371–407
8	<0.2	<0.2	2.9–3.3	0.4–5.1	172–740	0.004–0.007	3.44–5.49	1.0–1.4	<1.0	0.6–2.9
9	<0.2	0.6	8.2–11	8.9–9.6	7288–9460	0.012–0.013	173–186	2.9–3.5	<1.2	12–13
10	<0.2	<0.4	4.9–5.8	6.4–6.7	4935–5112	0.016–0.019	103–109	2.4–2.5	<1.0	9.5–10
11	<0.2	0.6	10–12	32–37	29,600–30,397	0.031	1313–1438	5.5	<1.0	42–45
12	<0.2	<0.4	12	44–45	51,513–51,800	0.048–0.055	2298–2372	7.4–7.5	<1.0	47–52
13	<0.2	<0.4	8.0–8.6	39–41	39,935–40,701	0.036	1052–1122	4.4–4.8	<1.0	41–43
14	<0.2	<0.4	8.2–8.5	50–56	44,503–46,065	0.016–0.018	2921–3534	4.5–4.8	<1.0	49–51
15	<0.2	<0.2	4.2	14–15	15,860–16,519	0.009	678–680	1.4–1.9	<1.0	16–18
16	<0.2	3.0–3.2	87–93	56–57	51,800–52,595	0.092–0.106	2718–2947	16–18	7.8–8.2	91–92
17	<0.2	0.6	23–27	34–35	44,118–46,200	0.048–0.053	2622–2966	6.0–6.3	<1.0	41
18	<0.2	0.8	26–27	40–43	46,839–47,171	0.012	3345–4318	7.3–14	<1.0	38–39
19	<0.2	<0.2	8.9–11	21–22	25,063–27,115	0.010–0.011	518–621	1.9–2.4	<1.0	28–32
20	<0.2	<0.2	17–18	515–614	24,909–24,423	0.007	363–442	2.0–2.4	<0.7–9.9	52–57
21	<0.2	1.0–1.2	25–26	47–48	38,481–38,487	0.050–0.052	808–855	8.3–8.4	118–149	110–146
22	<0.2	<0.2	5.9–6.2	10–11	16,000–17,032	0.003–0.004	205–224	1.0–1.5	<1.2	13–14
23	<0.2–4.3	0.6–2.6	5.3–64	23–126	6616–52,931	0.172–0.741	358–3078	3.7–28	0.8–187	49–1559
24	<0.2	<0.4	20	26–27	36,711–38,289	0.021–0.023	1731–1916	8.3–8.4	<1.2	37
25	<0.2	1.2–1.4	14–15	21–23	22,745–25,232	0.023–0.028	1533–1546	6.4–6.5	<1.0	35–36
26	<0.2	1.0	32–33	30–31	30,000–32,293	0.021–0.028	1189–1208	11–12	2.0–3.8	54–55
27	<0.2	1.6–1.7	60–70	40–42	53,377–58,462	0.067–0.076	1256–1312	15	<1.0	54–59
28	<0.2	2.8–2.8	7.3–8.4	58	14,503–15,497	0.099–0.109	1683–1941	7.0–7.5	<1.0	78–83
29	<0.2	3.4–3.5	11	12–13	19,935–20,265	0.036–0.037	1144–1283	7.0–7.3	<1.0	29–30
30	<0.2	1.6–1.7	12–14	37	30,764–31,176	0.038–0.039	1027–1168	6.9	<1.0	35–38
31	<0.2	3.9	46	46–47	43,529–43,548	0.901–1.040	1425–1519	10–11	18–26	194–195
32	0.4–0.6	4.1–4.2	93–94	146–148	43,026–43,846	0.049–0.055	1954–2129	15–18	329–331	748–758
33	<0.2	<0.2	19–73	352–3190	4591–5549	0.013–0.017	39.9–79.8	9.5–48	58–142	122–368
34	<0.2	<0.2–0.4	4.5–13	4.7–18	6020–25,098	0.015–0.027	131–810	1.3–6.7	<0.9	20–38
35	<0.2	<0.2–1.2	6.5–16	11–32	13,283–26,682	0.005–0.080	440–1039	3.0–5.4	<0.9–36	20–117

humidity and salt laden atmosphere greatly accelerates the deterioration of unprotected ferrous metals (Morrow 2003). Northern Saipan was literally covered with thousands of UXO after WWII and decades passed before any recovery attempts were initiated (AMPRO 2005). Thus, the gradual sacrificial loss of the protective Cd coating on lost munitions over time may well account for the Cd footprint left behind in this part of the island. It is perhaps worth mentioning here that no attempts have ever been made to commercially recycle metals associated with the huge trove of abandoned munitions left behind on Saipan after WWII. Instead, recovered explosives are stockpiled in safe areas and eventually destroyed by mass detonation.

Conclusion

While the majority of dumpsites visited are reasonably far from the general population, many Saipan residents hunt and forage for food in such remote places. Therefore, the degree of metal uptake by food organisms in these areas may be of

Table 3 Selected background data for heavy metals in soils and sediments from Saipan and elsewhere

Region	Type	Number	Mean[a] and range of heavy metal concentrations (μg g^{-1} dry weight)										Reference
			Ag	Cd	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Zn	
Saipan soils													
Chalan Kanoa	Limestone	3	nc All <0.021	0.23 <0.18–0.32	8.25 7.4–9.6	– –	– –	nc All <0.021	– –	– –	nc <1.3–1.3	– –	Woodward–Clyde FS (1998)
Kobler	Limestone	3	nc All <1.5	nc 0.73–1.2	36.9 16.5–169	– –	– –	nc All <0.15	– –	– –	33.4 11.7–59.0	– –	Woodward–Clyde FS (1999a)
Tanapag	Limestone	7	nc <2.04–4.70	nc <1.19–1.6	7.23 1.41–108	– –	– –	nc All <0.142	– –	– –	5.05 2.47–12.6	– –	Woodward–Clyde FS (1999b)
Tanapag	Limestone	8	– –	– –	21 11–110	– –	13,259 4900–50,000	– –	305 88–1100	– –	7.6 1.4–43	– –	USACE (2015)
Kagman	Limestone	22	0.05 0.01–0.30	1.8 0.28–4.20	76.6 11.0–276	– –	– –	0.09 0.05–0.14	– –	– –	11.6 2.50–23.0	– –	Woodward–Clyde FS (1999c)
Kagman	Limestone	[b]	0.02 –	0.28 –	52 –	31 –	– –	0.05 –	– –	10 –	3.9 –	31 –	WCP–SCSE (1998)
Edoni	Limestone	3	nc All <0.49	1.10 0.43–4.9	7.90 3.6–28.0	2.99 0.58–11.0	– –	nc <0.038–0.040	– –	nc <0.94–4.4	1.24 <0.14–5.50	7.39 1.6–18.0	URS Corp. (2001)
Tanapag	Volcanic	6	nc <2.08–2.11	nc All <1.33	11.7 4.81–37.3	– –	– –	nc All <0.144	– –	– –	6.0 3.6–13.3	– –	Woodward–Clyde FS (1998)
Kagman	Volcanic	71	0.05 <0.01–1.95	1.01 All <0.04-7.0	84.6 3.00-439	– –	– –	0.07 <0.05-0.36	– –	– –	12.2 2.70–47.0	– –	Woodward–Clyde FS (1999c)
Guam Soils													
Northern Guam	Limestone	1	<3	7.1	730	46	140,000	–	5600	320	77	57	Miller et al. (2002)
Southern Guam	Volcanic	24	nc All <3	0.2 <0.1–0.4	85 14–620	47 20–380	54,700 33,000–130,000	–	1159 780–2300	46 12–380	10.5 <0.8–26	96 70–140	Miller et al. (2002)
Southern Guam (badlands)	Volcanic	8	– –	– –	354 317–390	170 147–188	94,655 82,229–105,148	– –	1114 829–1798	296 274–320	– –	125 107–143	Siegrist et al. (1997)
US State averages	–	6–48	0.6 0.5–1.2	0.3 0.1–0.9	48 14–122	21 5.0–96	22,045 3705–50,147	0.03-0.06[c]	471 85–1112	18 3.8–48	18 5.0–39	55 12–233	USEPA (2005)
Western US soils	Volcanic	36	nc All <3	0.3 <0.1–16	73.6 15–670	47.2 8.0–280	40,400 9700–120,000	– –	915 180–5100	36.4 6.6–410	10.7 0.90–97.0	83 10–160	Miller et al. (2002)
Marine sediments													

Table 3 (continued)

Region	Type	Number	Mean[a] and range of heavy metal concentrations (μg g^{-1} dry weight)										Reference
			Ag	Cd	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Zn	
Saipan Lagoon (beach)	Carbonate	5	nc All <0.2	nc All <0.2	2.9 2.4–3.1	0.6 0.6–1.0	125 83–219	0.007 0.004–0.018	4.0 2.4–5.2	nc All <0.4	0.8 <0.4–2.8	3.8 2.7–5.0	Denton et al. (2014)
Saipan Lagoon (1000 m offshore)	Carbonate	21	nc All <0.2	nc All <0.2	2.2 1.5–3.4	nc All <0.2	45 21–63	0.001 <0.001–0.013	2.0 1.2–7.6	nc All <0.4	nc All <0.4	nc <0.2–0.4	Denton et al. (2014)
Pago Bay, Guam 0–100 m offshore)	Carbonate	27	nc All <0.2	nc All <0.2	2.5 1.8–4.9	0.8 0.6–2.6	292 148–600	0.003 <0.001–0.007	13.5 10–23	0.8 <0.2–2.1	0.5 <0.2–1.0	0.9 0.6–1.8	Denton and Morrison (2009)

Dashes indicate no data

nc not calculable

[a] Geometric mean

[b] Lowest values selected from 77 soil samples analyzed

[c] Average US soil Hg levels reported by Sell et al. (1975) and Melton et al. (1971)

Table 4 Saipan dumpsites exhibiting heavy metal screening level exceedances in adjacent soils or sediments

Metal	Soil screening levels[a]	Site soil screening level exceedance factors		
		1–10	10–100	>100
Saipan soil screening levels ($\mu g\ g^{-1}$)[b]				
Ag	78	–	–	–
Cd	14	3–5	–	–
Cr	1100[c]	–	–	–
Cu	630	1, 4, 5, 20, 33	3	–
Hg	4.7[d]	–	–	–
Ni	760	–	–	–
Pb	400	1–5	–	–
Zn	1000	1, 3–5, 23	–	–
USEPA eco-screening levels ($\mu g\ g^{-1}$)[e]				
Ag	4.2	5, 23	4	–
Cd	0.36	6, 7, 9, 11, 16–18, 21, 23, 25–30, 34, 35	3–5, 31, 32	–
Cr	26	3–5, 7, 16–18, 23, 26, 27, 31-33	–	–
Cu	28	2, 7, 11–14, 16–18, 21, 23, 26–28, 30-32, 35	1, 4, 5, 20	3, 33
Hg	0.1[f]	2–5, 16, 23, 28	31	–
Ni	38	3, 4, 33	–	–
Pb	11	7, 31, 35	21, 23, 32, 33	1–5
Zn	46	2, 7, 12, 16, 20, 21, 26–28, 31, 33, 35	1, 5, 23, 32	3, 4

Note 1: Submerged sediment metal levels were also compared with the numerical sediment quality guidelines developed by MacDonald et al. (1996) for calcium carbonate sediments in Florida coastal waters. 'Threshhold Effects Levels' (TEL) for Hg (0.13 $\mu g/g^{-1}$) and Cr (52.3 $\mu g/g^{-1}$) were exceeded at sites 2 and 32, respectively, while 'Probable Effects Levels' (PEL) for Cu (108 $\mu g/g^{-1}$) and Pb (112 $\mu g/g^{-1}$) were exceeded at sites 2 and 32. PEL exceedances were also noted for Ni (42.8 $\mu g/g^{-1}$) and Zn (271 $\mu g/g^{-1}$) at the latter site

Note 2: Persaud et al. (1992) developed SQG for Fe and Mn in aquatic sediments but values given for both elements were well in excess of those encountered in submerged sediments during the present study

Dashes indicate no benchmark exceedances

[a] Establishing specific benchmarks for Fe and Mn in soils is difficult because the biological availability of these elements depends upon site-specific soil conditions (pH, Eh, soil water conditions). In the well-aerated limestone soils encountered during this investigation, Fe and Mn exist largely in insoluble forms (Fe^{3+}, Mn^{3+}, and Mn^{4+}). Because of this, both elements are likely to be limiting to plants rather than present in oversupply, and toxicologically insignificant to other soil dwelling organisms

[b] For unrestricted land use on shallow soils overlying usable groundwater resources;

[c] Total Cr

[d] Total Hg

[e] For most sensitive receptor

[f] Inorganic mercury (after Friday 1999)

concern from a public health standpoint. This is particularly true for the more toxic elements like Ag, Cd, Hg, and Pb, which were found in relatively high concentrations in soils from some of the sites examined. These contaminants have no known biological function and are readily accumulated by certain types of animals and plants (Phillips 1980; Baker and Walker 1990). It is therefore important to determine the metal loadings of any biotic components harvested for food in these areas. Land crabs, including coconut crabs and hermit crabs, are obvious terrestrial candidates for such an assessment, as are wild fruits, coconuts, wild peppers, and medicinal plants used by traditional herbal doctors or 'healers.' In coastal waters impacted by contaminated runoff or submerged debris fields, fish, crustaceans, mollusks, and seaweeds are the main contenders.

The alarmingly high Pb values found in and around the old dump site at 'Agingan Point' (sites 1 and 2) is another issue of concern here, especially considering the gross levels of contamination found in sediments immediately offshore. This area and the adjacent waters of Saipan Lagoon are popular recreational and subsistence fishing spots. Local residents also harvest bivalves and seaweed for consumption from these waters. Preliminary follow-up analysis of sediments in this part of the lagoon has so far indicated widespread Pb contamination that extends from the point northwards for about 500 m and covers an area in the adjacent lagoon of approximately 0.1 square km. Determining the impact of this dump on aquatic communities in the area is obviously important as are the implications of the findings from a human health perspective.

Other sites of similar interest include 'Hospital Dump' (site 23), which encroaches on a public golf course and has drainage pathways into an artificial lake fished by some of the course employees, and 'Laolao Bay' and 'Old Man by the Sea Bay', which serve as drainage discharge points for several undocumented inland dumps and are popular fishing and recreational spots for locals and tourists alike. The relatively high levels of Cd found inland at the old 'DPS Firing Range' (site29) and further down gradient at 'Liyang' (site 28), and all coastal sites between 'Nanasu Beach' (site 25) and 'Bird Island' (site 30), also concern us and require additional studies to determine impacts on aquatic fisheries and other popular food items in these areas. As an addendum to this recommendation, we recently demonstrated a progressive increase in Cd concentrations in limpets inhabiting this stretch of coastline. These intertidal organisms are excellent indictors of Cd pollution in the marine environment and have long been used for such purposes (Butterworth et al. 1972; Noël-Lambot et al. 1980). It is therefore noteworthy that average Cd levels in limpets from Bird Island were at least an order of magnitude higher than found at most other sites south of Nanasu Beach (unpublished data).

Although preliminary in nature, then, this investigation clearly shows that several sites on Saipan could present a significant risk to local residents and wildlife, with a number of soil and sediment associated metals occurring at levels that are currently considered unacceptable. Follow-up studies involving more detailed sampling in potentially high risk areas are now appropriate in order to delineate the extent of the contamination identified, minimize data uncertainties, and better assess any associated human and ecological health risks. To this end, the discrete sampling strategy adopted in the current work should be replaced by a more intensive, statistically rigorous methodology that eliminates, or at least minimizes, sampling error resulting from compositional and distributional heterogeneity. The *decision unit and multi-increment* sampling approach developed by the US Army Corps of Engineers is well suited for such purposes (USACE 2009). Expanding the contaminant database to include other munitions related chemicals (e.g., explosives, propellants (USEPA 2012) and white phosphorus (Sparling 1997)), and other likely WWII legacy contaminants in soil and sediment on the island (PCBs, pesticides, dioxins, petroleum products etc.) is also called for.

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