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Influence of Coastal Land Use on Soil Heavy-Metal Contamination in Pattani Bay, Thailand

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ABSTRACT

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Expansion of land use in coastal areas results in natural resources being degraded, particularly by soil and water pollution. The objectives of this study were to assess land-use patterns and determine the influence of land-use types on soil heavy-metal contamination in Pattani Bay, Thailand. In studying land use, high-resolution SPOT satellite images were used and analyzed using ArcView GIS 3.2a and ENVI 3.5 software. Collections from 16 soil-sampling sites with topsoil and subsoil layers (0–20 and 21–50 cm in depth) from nine land-use types were carried out during March and April 2006. The heavy metals mercury, lead (Pb), cadmium, arsenic (As), and zinc were analyzed using a Perkin Elmer Optima 2100 DV. Results found that land uses in 2006 were mainly dominated by agricultural, residential, and mangrove-forest areas. In agricultural areas, paddy field were the main land use, followed by shrimp farms. In residential areas, most land was used for living, infrastructure, and industry. Land-use types affected soil pollution in different ways. Municipality areas, industrial zones, and dockyard areas had the highest potential for soil contamination by heavy metals, particularly Pb and As, while shrimp farming and traditional land uses such as salt flats, paddy fields, orchards, and mangrove forests showed low levels of metals. At the dockyard and Pattani River–mouth sampling sites, Pb was recorded in high concentrations of 385.77 and 557.15 mg/kg, respectively; the latter exceeds the soil quality standards of the United States Environmental Protection Agency soil screening levels for residential areas (400 mg/kg). A high concentration of As was found at the dockyard, Pattani River mouth, and industrial zone (4.46, 4.75, and 3.48 mg/kg, respectively), while the EPA standard is not to exceed 4.0 mg/kg. The results indicate that using coastal lands without planning and good management negatively influences soil resources degradation, especially in the area of soil pollution.

ADDITIONAL INDEX WORDS: *Coastal land use, heavy metals, soil and water pollution, Pattani Bay.*

INTRODUCTION

Land use is the management of land to meet human needs. This includes rural land use and also urban and industrial use (FAO, 1993). Human needs, in terms of land use, are material, spiritual, or both; this point is very important because most human needs are not finite, but the land is limited. Typical categories for land use are dwellings, agriculture, industry, transport, recreation, and nature-protection. Land resources have been used by humans for a long time, and this has resulted in degradation, especially degradation in soil quality due to soil pollution. For land, degradation is a well-known process (Bridges *et al.*, 2001). Land degradation threatens environmental well-being and is a growing global issue (Zhang *et al.*, 2006). High population-growth rates and development during the last three decades has resulted in lands being used in different ways without planning and good management and has caused land degradation. There are many land-use activities that affect soil and water quality such as mining, unplanned urban growth, industrial development, and chemical use in agriculture. It is estimated that as many as 1.8 billion people live in areas with some noticeable land and water degradation, which reduces livelihoods and household food security. Degradation occurs in some or many parts of nearly all developing countries. Moreover, the rate of degradation of land and water resources is accelerating, and the consequences for food security are becoming increasingly clear (Wood, Sebastian, and Scherr, 2000).

In Thailand, Pattani Bay is one of thousands of developing sites planned by the government. Establishment of an industrial zone at the Pattani River mouth in 1977 has resulted in more than 200 factories being located near the sea, but no wastewater treatment plant is in operation. Agricultural and industrial pollution release large amounts of heavy metals into the atmosphere, surface water, soil, and plants (Cruz-Guzmán *et al.*, 2006). The environment and natural resources around Pattani Bay are being threatened by government policies and the free-trade system. Coastal ecosystems, which typically include wetlands, mangroves, and estuaries, are very fragile environments. These valuable ecosystems are being destroyed

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by many activities, such as excavation for shrimp ponds, wastewater from communities and industries, construction of service roads, and discharge of shrimp-pond effluents into freshwater and coastal areas. Many activities can have a significant impact on these resources (Pradhan and Flaherty, 2008).

Pattani Bay is one of 350 intertidal mudflat sites in the world (Deppe, 2000). The International Union for Conversation of Nature identified Pattani Bay as a worthy coastal wetland for conservation in Asia. Wealth and the good geographic location of Pattani Bay caused many activities to be developed, particularly economic activities such as industrial-zone expansion, coastal aquaculture, seafood-bank establishment, and seaport development. These activities need a huge volume of natural resources, and they also generate a large volume of pollution. Different land uses in Pattani Bay and its watershed produce different kinds of pollution. For example, excess sediment may come from farming, heavy-metal contamination from mining, sewage from urban areas, and wastewater from industrial estates. Therefore, Pattani Bay is being affected by these land-use activities. At present, most wastes around Pattani Bay are not treated, which means treatment will be conducted only by natural processes. Solid waste or wastewater contaminated with heavy metals from land-use activities around the bay may harmful to the environment, especially to marine organisms.

Soil pollution is mainly caused by chemical products used in agriculture, mineral solid waste, mining, garbage accumulation, and industrial dust deposition. Large amounts of waste accumulate on land and find their way into the soil. Gangue from mining, solid wastes from industries, and waste residues are also dumped; even wastewater and dust from factories are discharged. All the above activities cause chemical, physical, and biological pollution in the soil, particularly contamination by heavy metals of river and marine sediments. Sediments act as a dynamic site for biological and chemical reactions and as a food source for marine organisms (Muir *et al.*, 1999); if these food sediments became very polluted, especially by heavy metals, it would cause health hazards to both humans and other organisms.

Soil and water pollution in the Pattani River Basin has occurred for the last 50 years. In particular, tin mining at the upper basin in Yala Province has caused contamination of lead (Pb) in water and sediment. The contamination was found to be from two sources: lead as galena (PbS) from mine-waste piles from a disused 50-year-old tin mine, and lead oxide (Pb_3O_4) from boat-repairing activities at the Pattani River mouth (Simachaya, Navickaphum, and Leelapanang, 2003). In 1986, the Pattani River was found to contain high lead concentrations in places such as water sediment and marine flora, and the resulting health effects were seen in children (Varathorn, 1997). Many land-use types around Pattani Bay have released heavy metals into the soil, river, and marine sediments, but no research has been done on this matter. The purposes of this study were to assess present land-use patterns and to determine the influence of each land-use type on degradation of soil resources, especially soil heavy-metal contamination in Pattani Bay.

METHODS

Study Area

The study was conducted in Pattani Bay and a radius of 3 km from the shoreline out into the land, in Pattani Province, Thailand (Figure 1). The study area covers 167.75 km^2 in two districts of Pattani Province: Muangpattani and Yaring. Pattani Bay, situated along the southernmost part of Thailand's east coast along the Gulf of Thailand, is an estuarine wetland of international importance. It is a shallow bay, with a maximum depth of 3.2 m below mean sea level (MSL) (Royal Thai Navy Hydrographic Department, 1997), except in the dredged channel at the bay mouth, which is more than 4 m deep. The geographic location of the bay is between latitude 6°51′N and 6°57′N and longitude 101°13′E and 101°25′E. The bay is protected on the northeast side by a sand spit 15 km long, called "Laem Pho" (Cape Pho), and covers an area of about 67 km^2: 56 km^2 of tidal open bay and 11 km^2 of mangrove forest. Areas of mangrove forest, salt marsh, and mudflat are found along the shores of the bay, interspersed with salt flats, shrimp ponds, and areas of small private holdings. Valuable sea grass (*Halophila ovalis*) and seaweed (*Gracilaria fisheri*) beds occur at the bottom of the bay. The bay is important in sustaining the region's fisheries production, as well as for thousands of migratory shorebirds and other wildlife.

Most of the mangrove forest area is publicly owned, mostly as state forest land. The water regime is complex, with tidal influences from the Gulf of Thailand, runoff from the landward side, and water drainage from the two major rivers. The tidal amplitude varies from 130 cm at spring tides to 30 cm at neap tides. The bay is characterized by a tropical monsoonal climate with an average annual rainfall of 1645 mm, 63.2% of which falls during the months of November and December. Pattani Bay provides the resource base that supports the livelihoods of approximately 70,000 local villagers who live in 18 villages scattered in two districts around the bay. Threats to the coastal wetlands of Pattani Bay are characteristic of most of Thailand's coastal areas; they include reclamation for intensive shrimp aquaculture (and related conversion and pollution), major port developments (and related dredging), industrial expansion (and pollution), and destructive fishing by commercial trawling and by boats equipped with push nets (Ruttanadakul, Chutadesh, and Srichai, 1993).

Land Use Mapping

We used SPOT-5 high–geometric resolution (HRG) multispectral and panchromatic images in GeoTIFF format with processing level 2A, taken on March 7, 2006, and May 4, 2006, with 5- and 2.5-m resolution (images were acquired from the Geo-Informatics and Space Technology Development Agency of Thailand). Satellite images were geo-referenced to Universal Transverse Mercator projection, Everest spheroid (Indian *datum*), using ENVI 3.5 software. Aerial photos at 1:4000 scale for cadastral maps from the Department of Lands of Thailand were used as geo-reference coordinates. Standard False Colour Composite (FCC) (images with bands 234 in blue-green-red) and panchromatic images of SPOT-5 HRG were analyzed and converted to ArcView format using ENVI 3.5. Manual (on-

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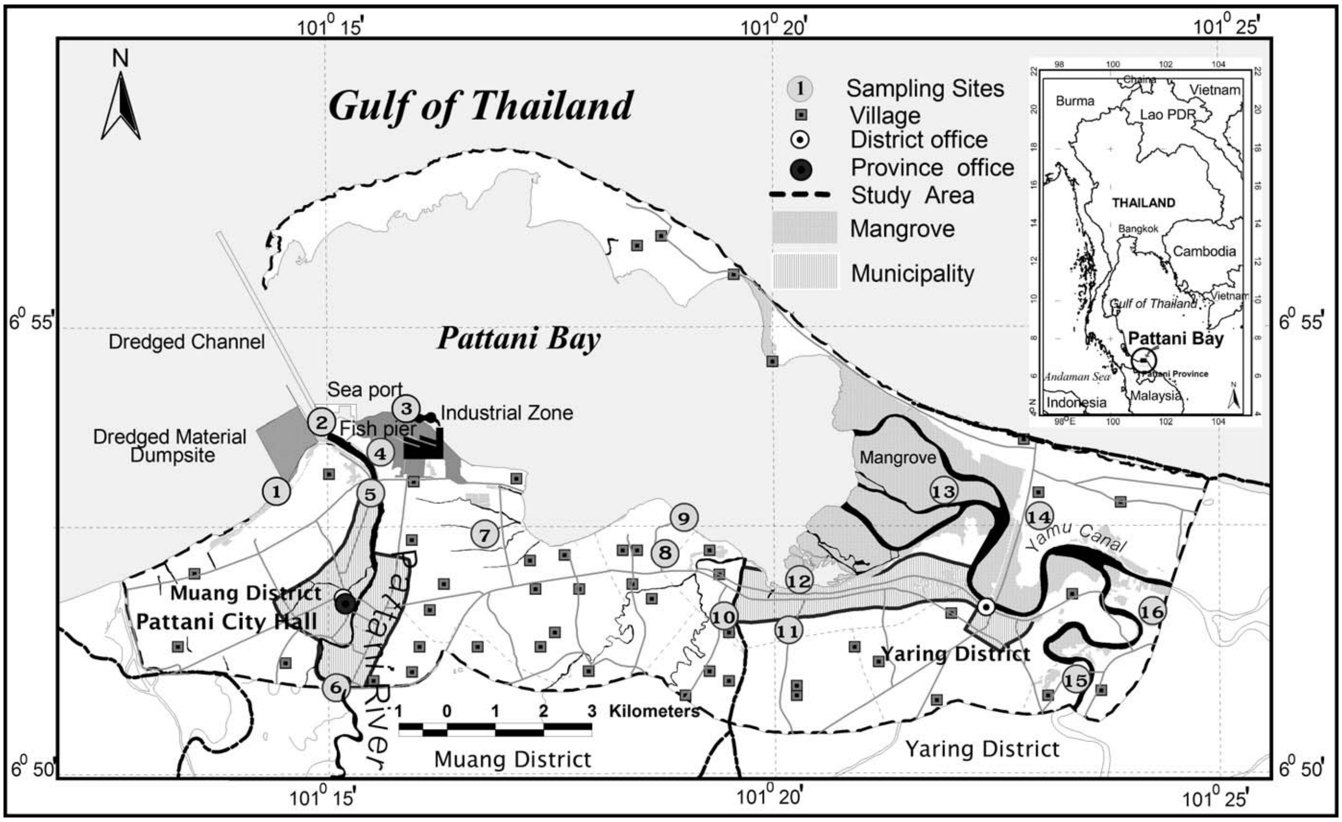

Figure 1. The study area showing sampling sites.

screen digitization) techniques were employed using ArcView 3.3. Visual interpretation indicators such as color, size, shape, and texture were extensively used in identifying land use and other features from the images. Visual interpretation by skilled interpreters in appropriate operational contexts is often the most accurate technique. For this reason, visual interpretation of imagery (on-screen) is useful, especially for its direct compatibility with geographic information system layers. The classification system for land use was adopted from the Anderson *et al.* (1976) classification system level IV (USGS, 2001).

Soil Samples and Analysis

Field work and sampling were carried out from March to June 2006. Sixteen soil-sampling sites were collected based on the main land use and its geographical distribution, as shown in Figure 1 and Table 1. Subsamples were collected at 0–20 and 20–50 cm by using a soil auger (inland) and a polyvinyl chloride pipe with a 4-in diameter and 50-cm length (sediment). All samples were stored in polyethylene bags and were air dried for about two weeks before being transported to the laboratory. A total of 32 air-dried soil samples were ground using a porcelain mortar and pestle and sieved with a 2-mm sieve.

Analytical Methods

Metals in soils and sediments of main land-use types, including mercury (Hg), lead, cadmium (Cd), zinc (Zn), and arsenic (As), were analyzed using different methods. For Pb, Cd, Zn, and As, 2 g of each soil sample were weighed and digested by an acid using a modified U.S. Environmental Protection Agency (EPA) method 3050B (EPA, 1996); composition of these samples was determined using inductively coupled plasma optical emission spectrometry (ICP-OES) with an Optima 2100 DV (PerkinElmer, Waltham, Massachusetts).

To determine Hg concentration, 2 g of air-dried soil was placed in a Biochemical Oxygen Demand (BOD) bottle and frozen for 1 hour. After that, 15 mL of $KMnO_4$ was added to the BOD bottle for 15 minutes until the purple color disappeared. The sample was then placed in an oven at 60°C for 2 hours. After cooling the sample to room temperature, 5 mL of $K_2S_2O_8$ was added, and the closed bottle was left for 24 hours. Finally, 6 mL NH_2OH–HCL was added to the sample until the brown color of manganese oxide and permanganate disappeared. The sample was then filtered and diluted to a volume of 50 mL with distilled water. The digested samples were then analyzed for total mercury by ICP-OES, after reducing Hg with a stannous chloride solution (Gambrell, 1991). Soil texture and organic

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Table 1. *Soil-sampling sites.*

Site No.	Site Name	Land-Use Description	Remark
1	Mangrove A	Planted mangrove forest	Sediment
2	Pattani River mouth	Pattani River mouth at seaport	Estuarine sediment
3	Industrial zone	wastewater disposal site at industrial zone	Estuarine sediment
4	Dockyard A	Dockyard at fish pier area	Soil
5	Dockyard B	Dockyard in the private area	Soil
6	Pattani River	Pattani River at Talubo bridge	River sediment
7	Shrimp pond A	Shrimp pond at Yu Yo village	Soil
8	Salt flat	Salt flat at Tanyong Lu Lo village	Soil
9	Shrimp pond B	Shrimp pond at Tanyong Lu Lo village	Soil
10	Paddy field A	Paddy field at Bandi Village	Soil
11	Orchard	Orchard (mainly coconut)	Soil
12	Community A	Community at Ba La Du Wo village	Soil
13	Mangrove B	Natural mangrove forest	Soil
14	Community B	Community at Ta Lo A Ho village	Soil
15	Shrimp pond C	Shrimp pond at Thung Kha village	Soil
16	Paddy field B	Paddy field at Nong Raet village	Soil

matter were also analyzed by gravimetric and wet-oxidation methods, respectively.

RESULTS AND DISCUSSION

Land-Use Patterns

In 2006, the study area land-use types were mainly dominated by agricultural areas (29.24%), residential areas (27.25%), and forest areas (19.33%), as shown in Table 2 and Figure 2. In agricultural areas, paddy fields were the main land use, followed by shrimp farms and mixed horticultural areas. Most of the land in residential areas was used for dwellings, businesses, institutions, infrastructure, and industrial zones. There are many communities and villages around the bay with a combined population of more than 70,000. In forest areas, the mangrove forest is the most important and largest area compared to other types. Most of the mangrove forest is in a conserved forest area (Yaring Mangrove Forest). However, in the residential area, abandoned areas and paddy fields are becoming built up, expanding the city area. The areas outside the municipality are abandoned due to the younger generation not wanting to be farmers and low profit from agricultural products. Land use in the Pattani River mouth area is very important because there are many land-use types, such as communities, factories, institutional places, sea ports, and other infrastructure from government projects. Most land utilization at the river mouth and around the bay has expanded without planning and good management or without following the plan. Although there are many laws and regulations, this is a big problem for the government. In the future, agricultural and abandoned areas, and even the mangrove forest area around the city, may become residential areas to support socioeconomic growth.

Utilization of Marine Resources in the Bay

Since Pattani Bay is the basic resource for the livelihood of local fishermen, there are many activities in the bay besides the fishery. The bay supports fishermen in many dimensions, such as economic, cultural, and community relationships. Figure 3 shows that at present all areas in the bay are used for fisheries, aquaculture, and seaweed stock. There are many fertile resources in the bay, such as mangrove forests, water birds, aquatic animals, seaweed, and sea grass. There are 22 mangrove species at Yaring Mangrove Forest, 48 waterbird species around the bay, and 143 species of aquatic animals. Hajisamae, Yeesin, and Chaimongkol (2006) reported that 108 fish species were collected between March 2003 and February 2004 from 11 study sites in Pattani Bay, indicating that the bay was important as a nursery ground for fishes. The study of Ruangchuay, Lueangthuwapranit, and Pianthumdee (2007) on characteristics and taxonomy of macroalgae from February 2004 to March 2005 found that there were 12 species in three divisions of macroalgae. In addition, seaweed, sea grass, dolphins, dugong, and many waterbirds were found in many sites, especially the sea grass *H. ovalis*. Results from a survey of sea-grass beds in the southern Gulf of Thailand in 1996 found that there were 10 sea-grass beds (Ruangpatikorn, Siripech, and Randorn, 1996). These sea-grass beds covered an area of 4.5 km^2. Five genera of seven species of sea-grass were noted: *Halodule uninervis*, *H. beccarii*, *H. ovalis*, *Halodule pinifolia*, *Ruppia maritima*, *Enhalus acoroides*, and *Thalassia hemprichii*. The largest sea-grass bed in the southern Gulf of Thailand is the sea-grass bed in Pattani Bay (Ruangpatikorn, Siripech, and Randorn, 1996). The presence of very fertile *H. ovalis* in Pattani Bay suggests that there were dugongs in this area in the past since dugongs are aquatic herbivores that feed on the phangerogamous sea grasses of the families Photomogetonaceae and Hydrocharitaceae, especially *H. ovalis*. In Pattani Bay, a dugong was last found in 2004 at the coastline of Budi Village in the northern part of the study area.

Aquaculture is very important, especially cockle and green mussel farming. Cockle farming has been conducted for many years, so soil and water quality in this area should be considered due to the bay being the waste-disposal site of all basins from the upper part. Contamination of pollutants in soil and water will cause the accumulation of metals in marine life. Cockle culture in Thailand was first practiced 82 years ago at Bantaboon District in Petchaburi Province. It has since expanded to other maritime provinces such as Samut Songkram, Surathani, Nakhon Si Thammarat, Pattani, Satun, Trang, and Ranong. In Pattani Bay, cockle culture came with C2

Table 2. *Land use in the study area in 2006.*

Land Use	Area (ha)	%	Land Use	Area (ha)	%
Residential	18,581.25	27.25	Demonstration farms	13.75	0.02
Residential (high density)	1869.38	2.74	Fish farms	459.38	0.67
Residential (medium density)	1455.63	2.13	Shrimp farms	4421.88	6.48
Residential (low density)	1976.25	2.90	Mixed perennial	879.38	1.29
Residential (rural)	6352.50	9.32	Para rubber	306.88	0.45
Central business district	363.13	0.53	Forest	13,181.25	19.33
Commercial strip development	101.25	0.15	Plantations	631.25	0.93
Isolated commercial establishments for goods and/or services	32.50	0.05	Old fields	753.13	1.10
Isolated commercial office buildings	73.75	0.11	Shrub land	1946.25	2.85
Resorts, hotels, motels, and related facilities	23.13	0.03	Swamp forests	978.13	1.43
Educational institutions	1220.00	1.79	Mangrove forests	8740.63	12.82
Health institutions	43.13	0.06	Beach forests	131.88	0.19
Correctional institutions	63.13	0.09	Water	3440.00	5.04
Government centers	820.63	1.20	Streams and canals	2536.88	3.72
Military installations	3.75	0.01	Irrigation canals	36.25	0.05
Other institutional	25.63	0.04	River sediment deposit	15.00	0.02
Mixed commercial and services	4.38	0.01	Construction	4.38	0.01
Small shops	1.25	0.00	Drainage canals	10.00	0.01
Showrooms	14.38	0.02	Water bodies	159.38	0.23
Industrial zone	1105.00	1.62	Farm ponds	118.75	0.17
Bus and truck terminals	11.25	0.02	Sea (open sea)	560.63	0.82
Port facilities	415.63	0.61	Wetlands	3437.50	5.04
Water treatment facilities	2.50	0.00	Saline marshes	421.88	0.62
Other transportation, communication, and utilities	1668.75	2.45	Vegetated dune communities	1333.75	1.96
Cemeteries	125.63	0.18	Herbaceous wetlands	1682.50	2.47
Inactive land with street patterns	256.25	0.38	Barren Lands	9787.50	14.35
Open areas	387.50	0.57	Open beach	581.25	0.85
Community recreation areas	18.13	0.03	Other sandy areas	16.88	0.02
Parks	146.88	0.22	Salt flats	2584.38	3.79
Agriculture	19,942.50	29.24	Mud beach	358.13	0.53
Paddy fields	9760.00	14.31	Solid waste disposal	40.00	0.06
Orchards	212.50	0.31	Dredge material disposal sites	647.50	0.95
Coconut	653.75	0.96	Seawalls	19.38	0.03
Horticulture	10.00	0.01	Undifferentiated barren lands	5540.63	8.12
Mixed horticulture	3178.75	4.66	Total land area	68,193.75	100.00
Truck crops	28.75	0.04	Sea area	37,268.75	35.55
Specialty farms	17.50	0.03			

villagers from outside and was promoted by the Department of Fisheries for economic reasons. Nowadays, the Pattani Bay area is used by many groups, such as the government for promoting the aquaculture fishery industry and other industries, villagers for aquaculture and fishing, and outside persons for fisheries. At the river mouth there are more than 500 fishing boats at anchor each day, and there were more than 7000 arrivals and departures of fishing boats in 2008 at the Pattani fish pier.

Soil Heavy-Metal Contamination

Basic characteristics of soil samples, including pH, organic matter (OM) content, and soil texture, are presented in Table 3. Most of the topsoil samples had a clay fraction greater than 40%. The soil-sampling sites that have a low percentage of clay were dockyard A, dockyard B, the industrial zone, and community B, due to these areas being filled with sand and, for some, being naturally sandy. Soil textures of subsoils were a little bit different from topsoils. The land uses that had greater differences in percentage of clay between topsoil and subsoil were salt flats and orchards.

However, topsoils of these samples contain more fine-textured soils than coarse-textured soils. Organic matter of topsoil at all sites was in the range of 0.53%–4.5%, while for the subsoil it was 0.43%–3.36%. High contents of organic matter were found at mangrove areas, the Pattani River mouth, and shrimp ponds in both topsoil and subsoil. However, organic matter content of topsoil was greater than subsoil and was different among the land-use types. Soil pH varied from 5.4 to 7.89 for topsoils and from 5.31 to 7.43 for subsoils.

The results from soil analysis show that many land-use types were contaminated with high concentrations of heavy metals, especially in dockyard areas at the Pattani River mouth and at shorelines near the industrial zone, as shown in Table 4. Cadmium concentration in soil samples from different land-use types ranged from 0.09 to 0.63 mg/kg and 0.12 to 0.81 mg/kg for topsoils and subsoils, respectively. All soil samples were lower than the soil quality standards in the EPA soil-screening levels for residences (70 mg/kg dry soil); the maximum concentration was 0.81 mg/kg in subsoil at the dockyard area near the Pattani River mouth (Figure 4). Cadmium levels in most of the subsoils were higher than those in the topsoils. Results indicate that none of the land uses in the study released cadmium to the environment. Since sources of cadmium include soil (at concentrations of about 0.1–0.5 mg/kg in the earth's crust), fossil fuel combustion, iron and steel production, chemical fertilizers (phosphate fertilizer contains 5–100 mg/kg), polluted

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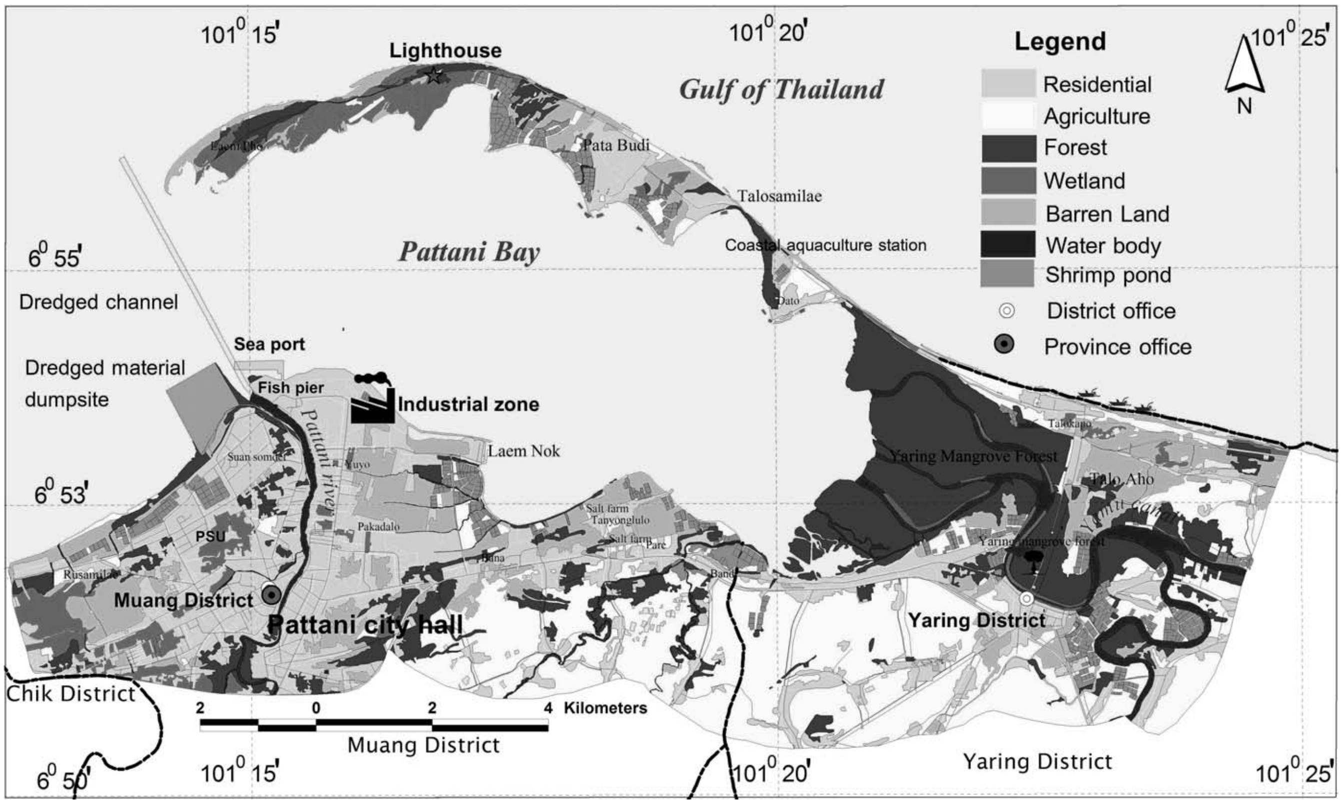

Figure 2. Land use in Pattani Bay, Thailand, 2006.

groundwater, household batteries, sewage-sludge disposal, and plastic bags, avoiding or wisely using these sources can solve the problem of these contaminations in the environment. In Thailand, pollution from cadmium in the environment is less than lead or arsenic; however, the increasing number of factories, particularly in the electronics and chemical industries, may affect the environment in the future.

Mercury concentration found in all soil samples was not more than the soil quality standard (23 mg/kg). The maximum concentration was 156.64 μg/kg in the shoreline of the industrial zone (Figure 5). This site is the disposal site of wastewater from the industrial zone, so this study analyzed only the topsoil. The results indicated that none of the land-use types cause the contamination of soil with mercury corresponding to the study of Vibunpant *et al.* (2006) on heavy metals (Hg, Cd, and Pb). In some marine organisms along the southern coast of the Gulf of Thailand, the contamination levels of heavy metals are still lower than the contamination standard limitation level in food issued by the Ministry of Public Health of Thailand. However, at the industrial-zone site the concentration was quite high when compared to other land-use types, which indicates that in the future this area may be harmful for aquatic animals such as fish, shrimp, cockles, and green mussels, since this area is also a fishing and farming area.

Concentrations of arsenic in all soil samples ranged from 0.14 to 4.76 mg/kg; it was highly concentrated at the dockyard and Pattani River mouth sites (Figure 6), which are over the EPA soil quality standard (4 mg/kg). Concentration of As in the surface layer of soil samples ranged from 0.14 to 4.76 mg/kg, while in subsurface samples it ranged from 1.01 to 4.75 mg/kg. There was variation of As content in soil samples among the land-use types. Concentration of As was very high in land-use areas near the river mouth and in high-density residential areas such as mangrove A (located near Prince of Songkla University), dockyard A (located at the fish pier where many fishing boats are repaired), and the industrial zone (located nearby the fish pier). Subsoil of many land-use types had greater As concentration than topsoil, including natural mangrove areas (mangrove B), at the Pattani River mouth, the shoreline near the industrial zone, residential areas, and paddy fields. The mangrove A sampling site was an afforestation in the mudflat area located in front of Prince of Songkla University. More than 20,000 persons live and work at the university, including students, staff, and others. Untreated wastewater from the university was discharged to this site every day. The mangrove B sampling site is a natural mangrove forest with no large community located nearby, so the concentration of As was low. For other land-use types, the concentration of As in soil samples was quite low and not over the soil quality standard. However, there is a relationship between concentrations of As and Pb in the same land-use type, especially in the dockyard area and river mouth.

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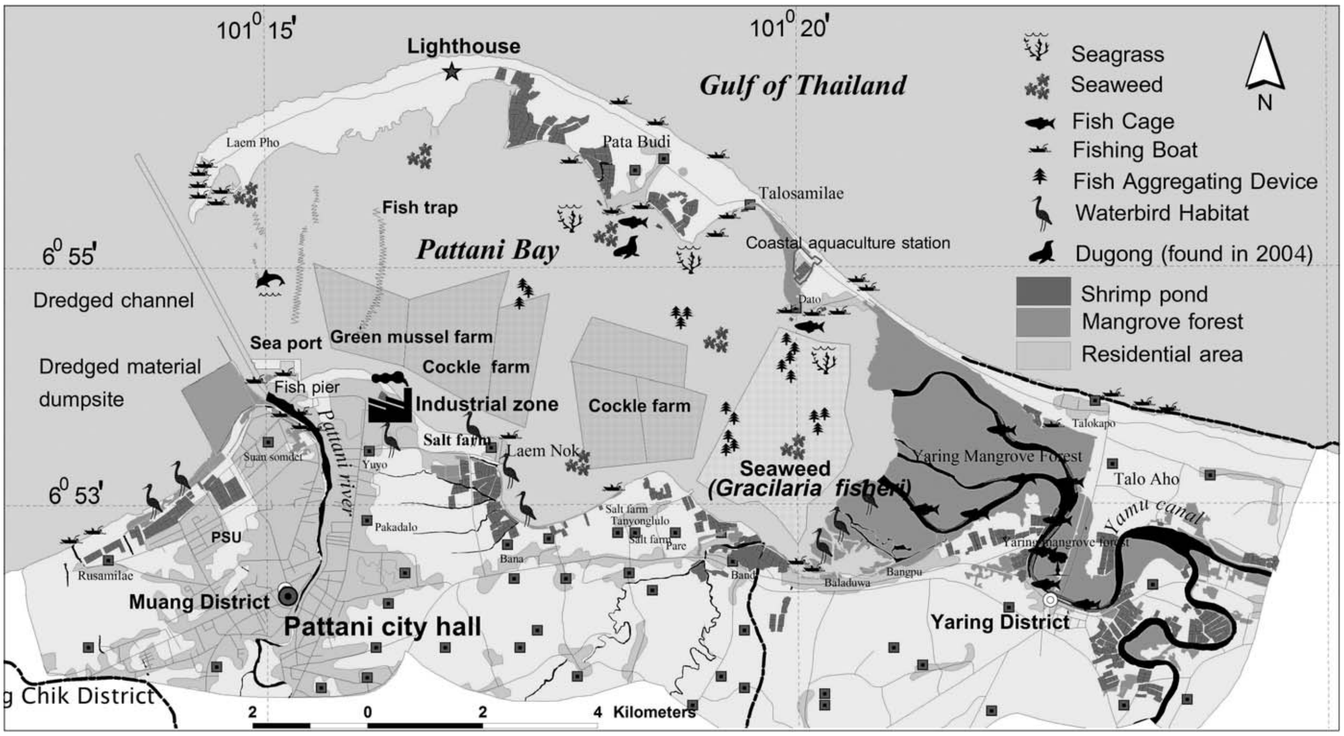

Figure 3. Utilization of marine resources in Pattani Bay.

In the past we were worried about lead contamination, but this study raises a new interest in As, and we have to investigate the sources and effects of arsenic in this area. In Thailand, the first report on arsenic contamination in a consumptive pond emerged in the late 1980s at Ronpibul District in Nakhon Si Thammarat Province and at Bannang Sata District in Yala Province, where the concentration of As in soil ranged from 21–16,000 mg/kg. (Visoottiviseth, Francesconi, and Sridokchan, 2002). From a review of that study it can be concluded that the main source of As contamination in soil and water in Thailand is tin mining. Arsenic contamination in the environment is harmful to humans and aquatic animals, both in freshwater and seawater, as reported by Jankong *et al.* (2007), who showed for the first time a clear effect of water arsenic concentrations on

Table 3. *Soil-sample characteristics (pH, OM, and soil texture).*

	pH		OM (%)		Soil Texture					
					Topsoil (0–20 cm)			Subsoil (20–50 cm)		
Site Name	Topsoil (0–20 cm)	Subsoil (21–51 cm)	Topsoil (0–20 cm)	Subsoil (0–20 cm)	Sand (%)	Silt (%)	Clay (%)	Sand (%)	Silt (%)	Clay (%)
Mangrove A	6.58	7.12	3.50	2.42	5.43	57.26	37.31	4.64	49.80	45.56
Mangrove B	5.82	5.57	4.50	3.36	3.26	34.62	62.12	14.29	48.12	37.59
Dockyard A	5.70	6.15	1.41	0.66	50.90	32.70	16.40	47.47	45.99	6.54
Dockyard B	5.40	5.62	0.53	0.43	53.83	42.81	3.36	50.99	42.47	6.54
Pattani River mouth*	7.96	7.34	3.42	3.34	18.90	22.39	58.71	8.90	54.70	36.41
Pattani River†	6.71	6.82	2.12	1.85	32.31	42.97	24.72	4.29	59.31	36.40
Industrial zone*	6.85	7.12	1.71	2.54	53.83	27.40	18.77	32.47	42.81	24.72
Orchard	5.89	6.31	0.99	0.72	4.02	25.74	70.24	38.49	42.97	18.90
Salt flat	7.34	5.67	1.15	1.74	5.00	25.17	69.83	58.71	22.40	18.89
Shrimp pond A	6.62	5.31	1.98	1.21	2.20	33.61	64.19	2.36	27.40	70.24
Shrimp pond B	7.68	7.43	2.55	2.63	14.29	48.12	37.59	4.43	25.74	69.83
Shrimp pond C	6.81	5.61	3.58	2.43	2.68	39.48	57.84	28.80	33.61	37.59
Community A	7.89	7.31	2.25	3.18	10.20	36.92	52.87	10.64	25.17	64.19
Community B	6.47	5.89	0.85	0.72	46.07	47.52	6.41	53.36	34.62	12.02
Paddy field A	6.14	5.62	1.41	1.22	7.93	38.71	53.36	7.27	45.61	47.12
Paddy field B	6.72	6.83	1.98	2.01	7.45	40.68	51.87	5.71	52.13	42.16

* Estuarine sediment
† River sediment

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Table 4. *Concentration of metals in soil samples (mg/kg dry weight).*

Site Name	Cd		Hg		As		Pb		Zn	
	Topsoil*	Subsoil†	Topsoil	Subsoil	Topsoil	Subsoil	Topsoil	Subsoil	Topsoil	Subsoil
Mangrove A	0.63	0.42	7.3×10^{-3}	-	2.18	2.03	41.70	7.74	19.54	19.02
Mangrove B	0.09	0.14	5.51×10^{-3}	-	0.14	1.19	6.43	3.76	9.69	31.31
Dockyard A	0.42	0.81	14.21×10^{-3}	-	**4.76**	**3.18**	**385.77**	**19.36**	46.19	9.01
Dockyard B	0.27	0.38	5.64×10^{-3}	-	2.19	2.03	50.15	4.27	29.94	14.42
Pattani River mouth	0.15	0.21	6.56×10^{-3}	-	**0.33**	**4.75**	**557.15**	**11.04**	40.89	11.42
Pattani River	0.09	0.22	4.07×10^{-3}	-	2.25	2.23	9.20	7.63	8.07	12.27
Industrial zone	0.31	0.20	156.64×10^{-3}	-	0.89	3.48	69.49	5.01	11.93	16.03
Orchard	0.33	0.41	24.31×10^{-3}	-	1.73	1.07	27.06	5.21	15.26	24.00
Salt flat	0.34	0.17	2.98×10^{-3}	-	1.13	0.87	18.26	9.66	16.43	14.59
Shrimp pond A	0.33	0.16	9.44×10^{-3}	-	2.89	2.88	24.54	3.41	15.23	5.09
Shrimp pond B	0.17	0.18	34.57×10^{-3}	-	1.85	1.06	19.05	2.50	17.11	7.84
Shrimp pond C	0.26	0.23	11.74×10^{-3}	-	1.88	0.87	8.03	6.85	8.33	6.07
Community A	0.17	0.18	5.35×10^{-3}	-	2.73	2.87	12.30	5.03	26.41	10.85
Community B	0.23	0.27	3.36×10^{-3}	-	0.52	1.81	15.41	3.50	8.89	9.68
Paddy field A	0.10	0.12	3.20×10^{-3}	-	0.24	1.48	15.10	1.70	13.32	8.60
Paddy field B	0.09	0.40	4.05×10^{-3}	-	1.88	1.01	17.10	1.36	24.08	16.82
EPA standard§	70 mg/kg		23 mg/kg		4 mg/kg		400 mg/kg		2300 mg/kg	

* 0–20 cm depth
† 20–50 cm depth
§ EPA soil-screening levels, human health-screening criteria for residences (EPA, 2001)

natural fish-tissue arsenic concentrations. However, there are many sources of As, including both natural and anthropogenic activities. Arsenic is widely found in nature: there are over 150 known arsenic-bearing minerals. Commercial end uses of arsenic include wood preservatives, electronics, medicinals and botanicals, and agricultural products (*e.g.*, fungicides, herbicides, pesticides, and silvicides) (EPA, 1998). All sources of As contribute to the significant influx of As to the environment.

High concentrations of lead were recorded in topsoils of soil samples from the Pattani River mouth and dockyard A sampling sites, as shown in Figure 7. Lead content in the topsoils of all sampling sites was higher than in the subsoils. At the Pattani River mouth, Pb concentration was over the EPA standard, and dockyard A also had a high level. Since both areas are located at the river mouth, this result indicates that pollution from lead contamination in soil and water in Pattani Bay is a risk to aquatic animals and local people. A report of Thailand's Pollution Control Department (PCD, 2002) concluded that dockyard workers who use lead oxide (Pb_3O_4) for boat-repairing activities were at the highest risk; therefore, lead oxide use should be reduced or a lead substitute should be used in order to decrease the risk from using lead in dockyard areas. Simachaya, Navickaphum, and Leelapanang (2003) found that lead levels in the blood of dockyard workers and in dust samples were high. Lead concentrations in the blood of dockyard workers were found in the range of 14.20–32.89 µg/dL and highest among three populations groups. Lead concentrations in the blood of the population within 1 km of the dockyard, and in the population outside the dockyard were in the range of 5.74–7.94 and 3.06–7.64 µg/dL, respectively. The EPA soil quality standard for residences limits the concentration of Pb to 400 mg/kg; therefore, the area at the Pattani River mouth and the dockyard area are still at risk. Government authorities who are responsible in this area must take some action. Results from this study indicate that pollutants from dockyards and wastewater from the community may be important sources of Pb contamination. This is a change from the past, when the source of Pb contamination was tin mining at Bannang Sata District, Yala Province.

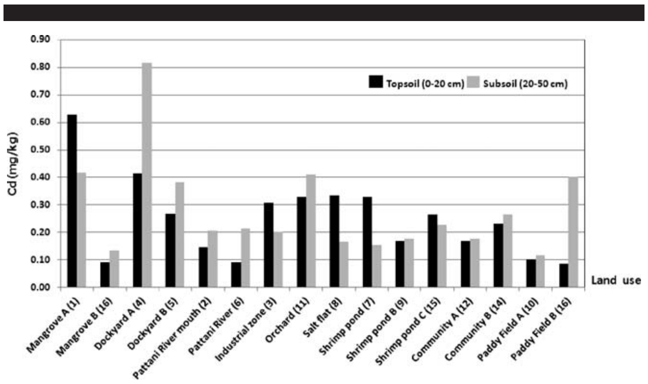

Figure 4. Cadmium concentration (mg/kg) in soil samples of different land-use types.

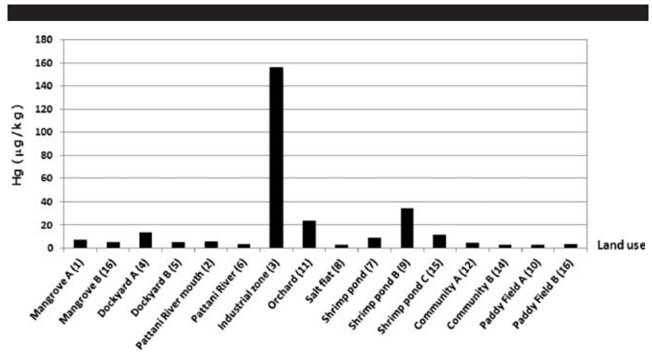

Figure 5. Mercury concentration (µg/kg) in soil samples of different land-use types.

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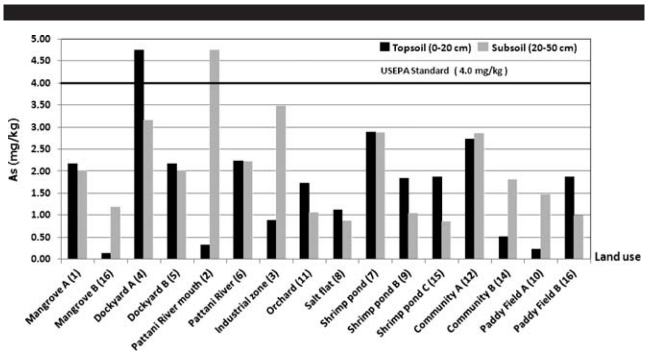

Figure 6. Arsenic concentration (mg/kg) in soil samples from different land-use types.

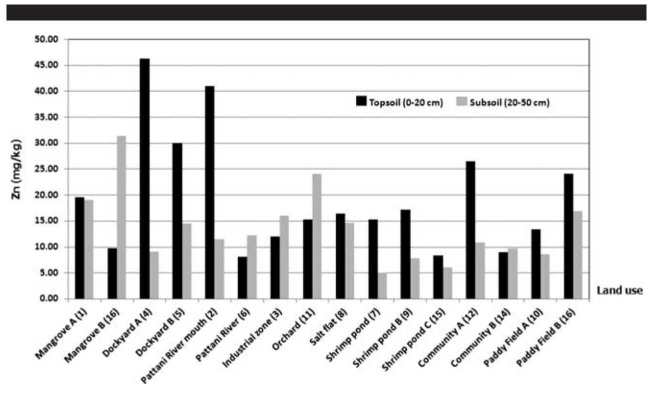

Figure 8. Zinc concentration (mg/kg) in soil samples.

The problem of Pb contamination in water and sediment in the Pattani River has existed for a long time and still exists due to authorities, whether government or nongovernment, taking no action to solve the problem. Pattani River was found to contain high lead concentrations in 1986. Follow-up studies investigated the high lead concentrations in water sediment and marine flora and the resulting health effects in children. Metal concentrations in sediments were higher than in water and fish tissues, as reported by Ayas *et al.* (2007). The study of Geater *et al.* (1997), which examined lead contamination among schoolchildren in two primary schools in Bannang Sta, one primary school in Am-phoe Muang Yaha District, Yala Province, and two primary schools in Muang Pattani District, Pattani Province, found that primary-school children living in the Pattani River Basin have high lead levels compared with international standards. The principal source of lead in the Pattani River is a group of abandoned tin mines in the province. Other sources of lead are industries along Pattani Bay, especially shipyards that use lead-based plumboplumbic oxide in ship building and repair work (Varathorn, 1997). Kietpawpan (2001) found that the lead contamination evaluated using multiple ecological-risk indices was at a heavily polluted level in the Pattani Dam Reservoir, according to sediment quality guidelines. The contamination factors ranged from moderate to very high contamination (2.4–6.3). The hazard quotients were greater than 1 for all sites (4.8–12.5), indicating that the aquatic ecological risk from lead-contaminated sediment exposures in the Pattani Dam Reservoir was not negligible. At present, tin mines in Yala Province are almost all closed. The report of the Yala Industrial Office found that only one tin mine operated in 2008, and a report on water quality in the upper Pattani River from government authorities (Ministry of Industry, 2007) found that lead contamination in the river had decreased except at the Pattani River mouth. The report of Cheewasedtham *et al.* (2003) on the lead contamination situation in the Pattani River Basin found lead in sediments (particle size < 53 μm) in streams at Tum Ta Lu Subdistrict (a disused tin mining area) at a very high concentration, in the range 390–28,679 mg/kg dry weight. Direct contact with sediment in this area should be avoided. However, the concentration of lead in Pattani River sediments was found to decrease as the distance from the mine increased. The concentration of lead in the samples of Pattani River sediments collected from Pattani Dam to the Pattani River mouth were found at lower than 250 mg/kg dry weight. Lead concentration in streams and Pattani River water was lower than 20 μg/L; this water can be treated to reach the standard level of drinking water at 5 μg/L. However, data from this study show the contamination of lead was not as high as in the past due to it being localized to the dockyard and river mouth, which are very close together, while contamination outside this area is quite low.

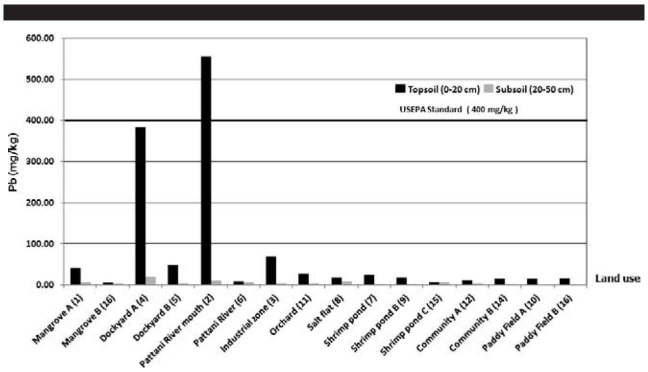

Figure 7. Lead concentration (mg/kg) in soil samples.

Our lab analysis showed that zinc concentration ranged from 5.09 to 46.19 mg/kg, and the concentration in topsoil is greater than in subsoil for all land-use types except the mangrove B, Pattani River, Industrial zone, orchard and Community B sampling sites (Figure 8). The results show that in the study area no land-use type was affected by Zn contamination due to its low concentration (below the EPA soil quality standard). Normally, the use of land as a dumping site for sewage, industrial waste, metal, paint, cosmetics, fertilizer, and pesticides can cause zinc contamination of the soil. However, in this study, these land-use activities did not produce Zn contamination in the environment. Although zinc is an important supplement for living organisms, it can also do harm if it is taken at high doses.

More-concentrated sources of zinc in aquatic environments include urban runoff, mine drainage, and municipal and

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industrial effluents. Metal corrosion and tire abrasion also contribute to urban runoff. Industries that directly discharge zinc into water include iron and steel foundries, zinc smelting, plastics, and electroplating. Municipal wastewaters are major contributors of zinc in estuarine environments (EPA, 1991). Zinc mining is also a source of zinc released to marine environments (Mance and Yates, 1984). The concentrations of zinc measured in sediment (on a dry-weight basis) in the Gulf of Thailand were 4.82–113.8 μg/g (Cheranbamrung, 1994).

Results from this heavy-metal contamination study indicate that some land-use types were affected by soil degradation at different levels. Increasing population and expansion of the city (including socioeconomic development) increased soil pollution due to generation of waste products and the lack of a treatment system before discharge to the environment. In this study, residential areas, the industrial zone, and dockyard areas in the fish pier had high potential for soil heavy-metal contamination, while shrimp farming and traditional land uses such as paddy fields, mangroves, orchards, and salt fields had no increase from the natural content in soil heavy-metal contamination (especially in salt farming lands, where the soil is still in a natural condition). The Pattani River mouth, its surrounding area, and high-density residential areas are the highest-risk areas for metal contamination, particularly Pb, As, and Hg. This study demonstrates that land use caused by socioeconomic development, without good planning and responsibility by all stakeholders in the area, affected the environment in a negative way.

CONCLUSIONS

The main land-use types in Pattani Bay and its 3-km shoreline are agricultural, residential, and forest area (mangrove forests). Paddy fields are the main land use in the agricultural area, followed by shrimp farming and mixed horticulture. Most land-use activities are controlled by the physical and chemical properties of land and by government policies. Traditional land uses such as paddy fields, mixed horticulture, and para rubber areas still exist, particularly in the countryside, while the area around Pattani city was abandoned. Shrimp farming is one of the special problems in this study area due to many land-use types, such as mangrove forests, salt flats, salt marshes, and paddy fields, being converted to shrimp ponds. Land use at the Pattani River mouth area is rapidly expanding with communities, factories, institutional places, the seaport, and other infrastructure from government projects. Most land utilization at the river mouth and around the bay has expanded without planning and good management, or without following the plan. Although there are many laws and regulations, this is a big problem for the government. In the future, agricultural and abandoned areas (even the mangrove forest area around the city) may be changed to residential areas to support socioeconomic growth.

This study found land-use types were affected by soil heavy-metal contamination at different levels. Residential areas, especially in the municipality area, industrial zones, and dockyard areas in the fish pier have high potential for heavy-metal contamination, while shrimp farming and traditional land uses such as paddy fields, mangrove forests, fruit trees, and salt fields show no effect from soil heavy-metal contamination. The Pattani River mouth and its surrounding high-density residential area is the highest-risk area for contamination with heavy metals, as shown by the high content of heavy metals such as Pb, As, and Hg. At the dockyard and Pattani River mouth stations, Pb was recorded in high concentrations of 385.77 and 557.15 mg/kg, respectively the latter exceeds the soil quality standards of the EPA soil-screening levels for residences (400 mg/kg). High concentrations of As were found at the dockyard, Pattani River mouth, and industrial-zone stations (4.46, 4.75, and 3.48 mg/kg, respectively), while the EPA standard is not to exceed 4.0 mg/kg. High concentrations of Hg were found at the industrial-zone station (156.64 μg/kg), but no samples had a concentration higher than the soil quality standard (23 mg/kg). The results indicate that socioeconomic development without planning and good management has influenced the land-use type and affected the environment.

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