

Correlation Study between Land Use, Water Quality, and Heavy Metals (Cd, Pb, and Zn) Content in Water and Green Lipped Mussels *Perna viridis* (Linnaeus.) at the Johor Strait

Tony Hadibarata · Faizuan Abdullah ·
Abdull Rahim Mohd Yusoff · Razali Ismail ·
Shamila Azman · Norliyana Adnan

Received: 25 November 2011 / Accepted: 18 January 2012 / Published online: 8 March 2012
© Springer Science+Business Media B.V. 2012

Abstract In order to observe the variation in land use changes, satellite images from the Landsat Thematic Mapper (TM) and the Enhanced Thematic Mapper (ETM) for 1991, 2000, 2005, and 2008 were used to compare the differences between selected water quality parameters, including heavy metal (Cd, Pb, and Zn) content in both water and green mussels or *Perna viridis* (Linnaeus.) before and after the increase in land use activities beginning from 2006. The samples were collected at 11 points for water and 4 points for green mussels between the Second Link and the Causeway Link at the Johor Strait in 2009 and were analyzed for pH, temperature degrees Celsius, dissolved oxygen, ammoniacal nitrogen, and heavy metal (Cd, Pb, and Zn) content.

Electronic supplementary material The online version of this article (doi:10.1007/s11270-012-1095-7) contains supplementary material, which is available to authorized users.

T. Hadibarata (✉) · F. Abdullah · A. R. M. Yusoff ·
R. Ismail · S. Azman · N. Adnan
Institute of Environmental and Water Resource
Management (IPASA), Universiti Teknologi Malaysia,
81310 UTM,
Johor Bahru, Johor, Malaysia
e-mail: hadibarata@utm.my

F. Abdullah · A. R. M. Yusoff · R. Ismail
Department of Chemistry, Faculty of Science,
Universiti Teknologi Malaysia,
81310 UTM,
Johor Bahru, Johor, Malaysia

Keywords Land use · Satellite images · *P. viridis* ·
Johor Strait · Water quality · Heavy metals

1 Introduction

The Johor Strait is located along the west coast of Peninsular Malaysia. This area is rich in renewable resources owing to its productive coastal ecosystems, and it has extensive culture fisheries, aquaculture, and intertidal mollusks. Among intertidal mollusks, *Perna viridis* (Linnaeus) is one of the species that can be found along the west coast of Peninsular Malaysia (Yap et al. 2003a, b). Green mussel belongs to Mytilidae family; matured *P. viridis* is dark green and widely distributed along Indo-pacific tidal area from Arab Gulf the South Japan including Southeast Asia. Generally, green mussel lives at littoral and sub-littoral area and muddy area especially with high salinated (Ayako et al. 2003; Rajagopal et al. 2006; Sivalingam 1977). Green mussel exist in high density of group, attached to the floating substances, especially human made such as buoy, cage, rope, jetty, and son using the fine hairy organ called byssus (Rajagopal et al. 1998; Sivalingam 1977).

Bivalves' species including green mussel will be selected as bioindicator for the toxic contaminant level monitoring. The specialty of green mussel to be selected as monitoring agent for the Asia Pacific Mussel

Watch Program, started since 1994, sponsored and organized by International Mussel Watch—Asia Pacific Phase is due to their wide distribution, sessile lifestyle, easy sampling, and tolerance to a considerable range of salinity, high accumulation of various type of chemicals compounds, and resistance to stress (Monirith et al. 2003). Naturally, the special factor of green mussel as it is always chosen as a biomonitoring agent is because they accumulate many pollutants to levels slightly higher than actual concentration in water (Nicholson and Lam 2005).

Recently, there are rapidly growing land use activities for development near the sea coast of Johor Strait. The effects of changing land use on marine communities are of concern as coastal populations increase at tremendous rates (Hertler et al. 2009). Land use areas generate both nonpoint and point sources of pollutants. Metals, industrial organic chemicals, nutrients, and pesticides are the main pollutants in the Johor Strait owing to the anthropogenic activities of the agricultural and chemical industries (Bayen et al. 2003). As areas of natural vegetation are increasingly being used as agricultural and urban land, it is important to check the effect of these transformations on seawater quality. Pollution of natural environment by the toxic chemicals is recently a worldwide serious tragedy, which could give bad impact to human and wildlife via bioaccumulations (Tanabe et al. 2000).

The Landsat Thematic Mapper (TM) is an advanced, multispectral scanning, earth resources sensor designed to achieve higher image resolution, sharper spectral separation, improved geometric fidelity, and greater radiometric accuracy and resolution. This sensor images a swath that is 185-km wide with each pixel in a TM scene representing a 30×30 m ground area except in the case of the far-infrared band 6. Band 6 uses a larger 120×120 m pixel resolution. The TM sensor has seven bands that simultaneously record reflected or emitted radiation from the earth's surface. Landsat Enhanced TM (ETM) provides data continuity with the Landsat-5 TM. The characteristics and number of bands are similar to those in the case of Landsat TM. However, a panchromatic band was added to Landsat ETM, giving it a total of eight bands. The wavelength of this band is 0.52–0.90 μm , and it has a 15-m resolution. The development of remote sensing technologies has led to the improvement of mapping and interpretation techniques for acquiring environmental data as a means of understanding and effectively managing available resources for sustainability (Ding et al. 2007).

The main focus in this research is the change in the Tebrau Strait water quality due to the nearby sea coast development by the Iskandar Region Development Authority (IRDA), Johor, Malaysia. Nutrients and sediments are largely transported to marine systems through surface runoff. Nitrogen is usually the limiting nutrient in marine systems. Changes in land use also affect the levels of heavy metals like Cd, Pb, and Zn in marine systems. Metals in sediment are filtered through storm water by marginal ecosystems (Hertler et al. 2009; Qishlaqi et al. 2009).

Green mussels occur widely in shallow waters along the west coast of Peninsular Malaysia. They have become a food resource especially in Malaysia, which, at one time, exported them. Green mussels are harvested commercially in the Indo-Pacific region as a human food resource owing to their dense and fast growth. Moreover, the harvesting of green mussels can have economic, ecological, and human health impacts. Green mussels are used as a biomonitoring agent for heavy metals because they are commercially important seafood species worldwide (Sivalingam 1977; Farrington et al. 1987). The objective of this research is to assess the effect of land use on the water quality and heavy metals (Cd, Pb, and Zn) content in the water and in green mussels in the Johor Strait.

2 Materials and Methods

2.1 Study Sites

The sampling sites for this study involved 11 points located at Johor Strait, between the Second Link and the Causeway Link. These sampling points were selected due to the criteria as an estuary and as the main area for fisheries and aquaculture activities as the focus of the study. All of the sampling point locations, coordinates, and sampling frequencies are represented in Table 1.

As shown in Fig. 1, the sampling area included 11 targeted sites along the strait. Green mussel samples were collected at S3 (Sg. Danga Estuaries) to compare with the previous years (1991, 1998, 2000, and 2006) data for heavy metals (Cd, Pb, and Zn) content. The present sampling session was conducted three times between February and November in 2009. All of the water samples were collected in polycarbonate bottles and directly transferred to an ice box maintained at 4°C

Table 1 Sampling point's locations and coordinate at Danga-Pendas straits

No.	Sampling stations	Coordinate	Code
1	Sungai Skudai estuaries	N 01 28.265 E103 43.039	S1
2		N 01 28.011 E103 43.150	S2
3	Sungai Danga estuaries	N 01 28.108 E103 43.433	S3
4		N 01 27.662 E103 43.855	S4
5	Sungai Melayu estuaries	N 01 27.454 E103 43.459	S5
6		N 01 27.328 E103 41.719	S6
7	Nusajaya	N 01 27.574 E103 41.308	S7
8	Tebing Runtuh	N 01 26.825 E103 41.603	S8
9		N 01 26 348 E103 40.640	S9
10	Tanjung Kupang	N 01 24.544 E103 39.440	S10
11	Second Link	N 01 22.225 E103 38.139	S11

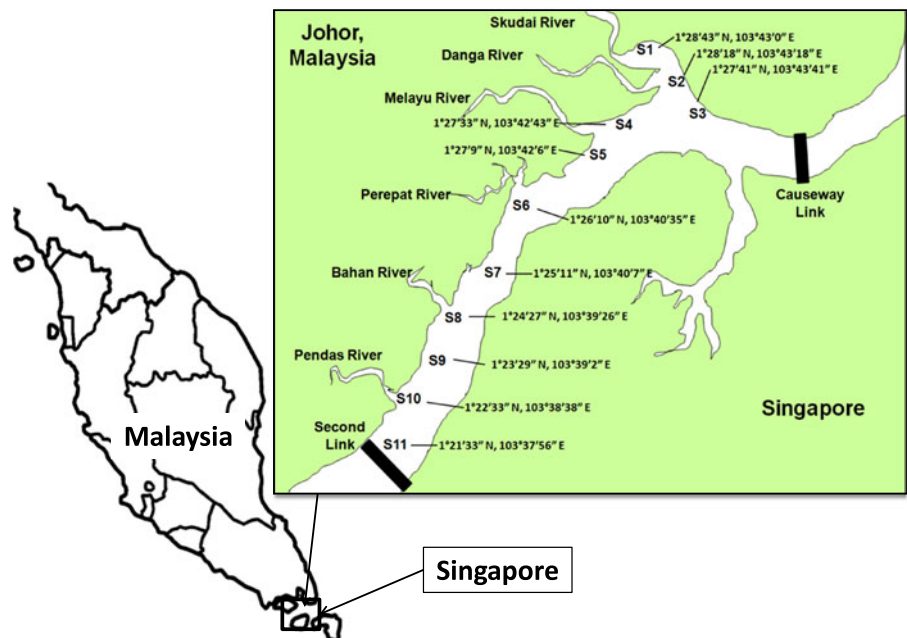
where they were stored until further analysis at the laboratory.

2.2 Sample Preparations

To prepare the water samples for analysis, they were collected in three bottles. The first bottle contained only the water samples, the second bottle contained the water samples and 1 ml L⁻¹ of sulfuric acid (for analyzing nutrients), and the third bottle contained the water samples and 1 ml L⁻¹ of nitric acid (for analyzing metals). The green mussel samples were then collected and grouped according to size. Before the mussels were

shucked, the external shell surface was thoroughly cleaned with a brush and water to remove all the sand and dirt adhering to the shell to prevent the contamination of composite samples. The mussels were then thawed and shucked, and the flesh was collected in a clean dish and homogenized by mixing. The green mussels (2 g) were weighed and digested on a wet basis, using a modified reflux system by digesting the samples overnight with a hot plate. The digested samples were filtered and diluted using double distilled deionized water to ensure that the acid in the samples was <5%. The digestion method used was adopted from the American Public Health Association (APHA) 3030E,

Fig. 1 Sampling locations of seawater and green mussel in Strait of Johor



which is a nitric acid digestion method. In this study, only the heavy metal content of adult mussels (7–9 cm) was analyzed on a dry weight basis. For water quality analysis and comparison with previous years data, the water quality data was only considered for the Danga area representing the Sg. Danga Estuaries (S3 and S4) and the Pendas area representing Tanjung Kupang and the Second Link sites (S10 and S11).

2.3 Water Quality and Heavy Metals Content Analysis

For the process of analyzing the water quality parameters, the temperature, pH, and dissolved oxygen (DO) were analyzed in situ at the sampling site using a multiparameter water quality probe. Measurement of the ammoniacal nitrogen (AN) and heavy metals content was done at the laboratory using the HACH DR4000 spectrophotometer and the Perkin Elmer atomic absorption spectrophotometer. Table 2 shows the parameters, methods, and equipment used to analyze the samples (Yap et al. 2003b).

2.4 Identification of Land Use Satellite Images

Remote sensing data for selected years from 1991 to 2008 were gathered from the Malaysia Remote Sensing Agency (MACRES) to see the land use changes at the study area. Landsat TM and ETM images were used as the main remote sensing data sources in this study. The Landsat TM and ETM were selected because the resulting data has a large spatial resolution of 30 m, which can capture the study area with a fine spectral resolution. They have seven bands, which can aid in the analysis from the ground and can be used for land use extraction and for the analysis of water. Scenes of Landsat satellite images and the specification used by the Landsat TM

was shown in Fig. S1 and Table S1. For the extraction of land use data, the processing of satellite images was carried out in several stages. Each image was processed using methods such as geometric correction, atmospheric correction, subsets to particular coordinates, and region of interest selection before becoming an image used to extract land use information (Ding et al. 2007).

2.5 Land Use Change Detection

For the change detection process, both land use classification images selected for changes that have occurred were used. The process involved the use of the designated features for change detection with post-classification comparison images. The post-classification comparison change detection method is the most commonly used quantitative method. It requires the rectification and classification of each remotely sensed image. These two maps are then compared on a pixel-by-pixel basis using a change detection matrix to identify the land use changes in the satellite images (Klema 2001).

3 Results and Discussion

3.1 Land Use Classification Images

For the four different years, land use classification processes were carried out according to the relevant changes in land use along the Johor Strait area. The classification of the satellite images for land use information consisted of six types of major land use: mangrove area, urban and developed area, open area, forest and scrub area, cultivation, and water bodies.

Table 2 Parameters, method, and instrument used to analyze the samples

Parameters	Methods	Equipments
pH	AWWA 4500- H ⁺	YSI Multiparameter
DO	AWWA 4500-O	YSI MULTiparameter
Temperature	APHA 2550 B	YSI Multiparameter
Ammoniacal-Nitrogen	HACH 10031	HACH DR/4000 colorimetric
Cd	APHA 3111 B	Perkin Elmer AAnalyst 400 Flame
Cu	APHA 3111 B	Perkin Elmer AAnalyst 400 Flame
Pb	APHA 3111 B	Perkin Elmer AAnalyst 400 Flame
Zn	APHA 3111 B	Perkin Elmer AAnalyst 400 Flame

Land use classes were selected based on the most applicable and main land use observed. The illustration of the land use classification images was processed using remote sensing software (Erdas Imagine Software) (Fig. S2). The brown color indicates the developed areas, which are mostly in Johor Baharu and Singapore. Meanwhile, most of the Johor state lands are covered with cultivation area, which is consistent with rubber and palm oil plantation estates, some of which are secondary forests with mixed plant species. Open area can be seen at several locations considered to be urban. When compared with the previous land use image of 1991 with land use image of 2000, which was processed with same land use classifications, the changes are clearly seen especially in urban and developed areas and scrub areas. The lines that appear represent the new road and open areas of developing region. The main difference was the construction of the Second Link connecting Malaysia and Singapore through Pendas. Most of the open area in 2000 was replaced with developed area for the 2005 classification. Compared to 2000, there were dense areas of urban development, which also illustrates that Johor Bahru had more intense development, as represented by the brown color that shows the land use for the most recent year, which is a 2008 image of the Johor Bahru area (Fig. S2).

The satellite image of 2008 has several striped lines indicating interference, which implies that no data was detected under the lines. The error is due to the mistake of the scanner or the detector of the Landsat satellite because it failed to detect and scan the ground for specific lines. However, this error did not affect other scan lines, and the land use map can still be processed. For the land use image of 2008, there were many differences in land use classification as compared with 2005. The IRDA region was considered as an open area due it being in the early stages of development with activities such as site clearing, earthwork, demolition, and also the development of new buildings.

As the images clearly show, there were changes in the satellite land use images from 1991 to 2008. The urban and developed area was clearly increasing from 1991 to 2008 because of the rapid development. There is a corresponding decrease in the mangrove area from the 1991 to 2008 satellite images. Digital change detection is the process that helps in determining the changes associated with land use and land cover properties with

reference to geo-registered multi temporal remote sensing data (Yacauba et al. 2009)

3.2 Statistical Differences in Land Use Areas and Analysis of Water Quality Data

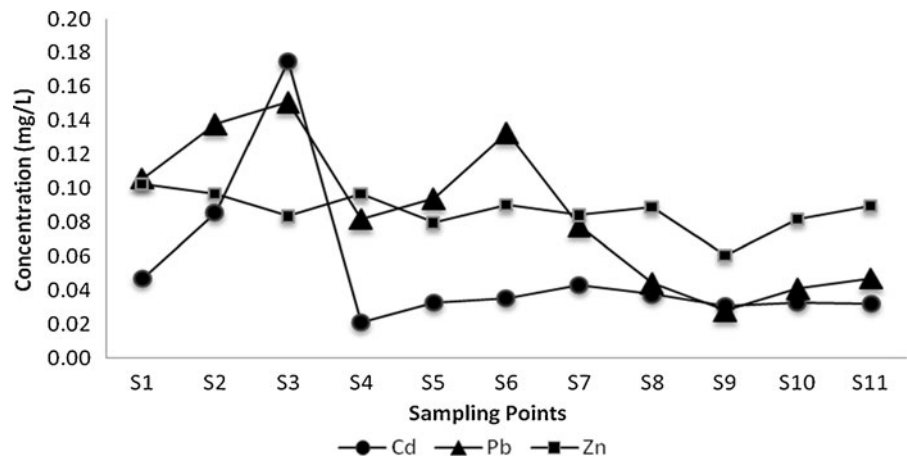
Land use changes can also be evaluated in terms of statistics. In order to see the value of the differences, the land use areas are represented in Table S2, indicating the area with changes and the initial area for each class for each year. It is very important to draw a comparison between the period before 2005 and the period from 2005 to 2008 because the development of the IRDA region was started in 2006.

The standard concentrations for heavy metals in natural water according to the Interim National Water Quality Standards for Malaysia (INWQS) are the following: 0.1 mg L⁻¹ for Cd, 0.02 mg L⁻¹ for Cu, 0.1 mg L⁻¹ for Pb, and 0.5 mg L⁻¹ for Zn. The heavy metal content in water and sediment correlates with the biological activities in the water (Yap et al. 2002). In addition, surface water quality can be estimated based on bioassays monitoring (Klemas 2001). As shown in Fig. 2, most of the metals have high concentrations at the Danga sites (S1, S2, and S3), which can be related to the high land use activities in these areas as shown in the satellite images in Fig. S2. Heavy metals are sometimes added to the water through the leaching process from mineral-bearing rock and soil, but in recent years, they have increasingly reached water from industrial emissions.

Water quality data have been obtained from several studies previously conducted in this area. The significant 1991 and early 2006 water quality data have been used in analyzing the status of water quality along the Johor Strait coastal area. The two most significant areas along the Johor Strait were selected in order to evaluate the variations in water quality in these selected years. The first was in Danga Station, while another was in Pendas Station. Danga Station was significant because a great deal of development has occurred there from 1991 up to the present. The greatly urbanized Danga Bay, which is located near the Sg. Danga Estuaries, and the surrounding areas were predicted to have a high impact on water quality in this area. On the other hand, Pendas Station was significant, as this area underwent less development than the Danga area (Table S3, Figs. S5, S6).

As illustrated in Fig. 3a and b, the pH and temperature trends for 1991 through 2009 were constant and

Fig. 2 Heavy metals (Cd, Pb, and Zn) content for water samples from every sampling station



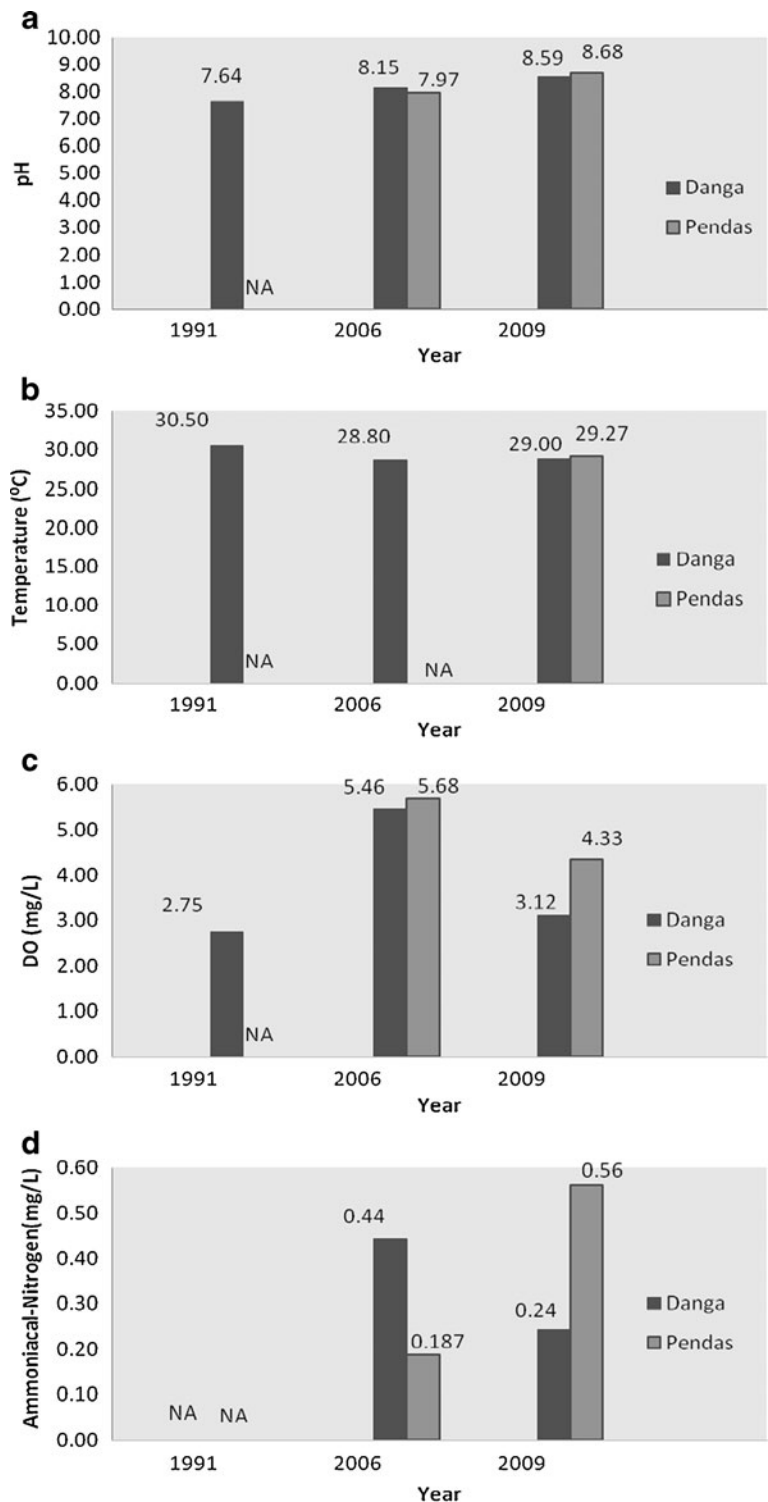
increasingly similar. However, there were small increases in pH through from 1991 to 2009. The lowest pH for the Danga estuaries area ranged from 7.64 in 1991 to 8.59 in 2009. The same trends were also observed in the Pendas area, where the pH values increased from 7.97 in 2006 to 8.68 in 2009. On the other hand, the variation by year for temperature can only be observed for the Danga Station because there were not enough data acquired for temperature in the Pendas area. Temperatures recorded in 1991 were a bit high (30.5°C) compared to those recorded in 2006 and 2009. The value then decreased a little to 28.8°C in 2006 before increasing in 2009. In 2009, the temperature values for Danga and Pendas were not much different with only a 0.28°C difference.

Figure 3c and d represents the concentrations of dissolved oxygen and AN in water by year for 1991, 2006, and 2009. As illustrated by the graph, the concentration of dissolved oxygen in water was higher in 2006 compared to both 1991 and the present. However, the lowest DO values recorded in 1991 at the Danga area were only 2.75 mg L⁻¹ showing that the area was greatly polluted at that time. During the same time, the concentration of DO levels in both the Danga and the Pendas areas increased to 5.46 and 5.68 mg L⁻¹ before decreasing back to 3.12 and 4.33 mg L⁻¹, respectively, in 2009. Although the concentration of DO was higher in 2006, that level still only satisfies the requirements of Class II of the INWQS. At present, the DO concentration only satisfies class III of the INWQS, which indicate that the water quality level for the area is average. In contrast to the DO trend, the trend in the AN concentration showed yearly differences by station area. In Danga, the

concentration decreased from 0.433 mg L⁻¹ in 2006 to 0.242 mg L⁻¹ in 2009, while there was an increasing trend for the Pendas area from 0.187 mg L⁻¹ in 2006 up to 0.56 mg L⁻¹ in the present. Danga Station recording a high AN concentration might be due to the discharge of industrial and domestic waste from the developed Danga Bay, Johor Bahru, and the surrounding area. In addition, there were discharges of agricultural effluents from the cultivated area near the Danga estuaries. The greater number of human activities in Danga, rather than in the less-developed Pendas, may have caused the higher AN levels.

Figure 4 shows the graph of Zn, Cd, and Pb concentrations in water. Generally, the overall trend in metals concentrations was very similar. As observed through the years of 1991, 2006, and 2009, the concentrations of metals recorded at Danga Station were higher compared to those recorded at Pendas Station. Moreover, the concentrations for most of the metals were highest in 2009 compared to 1991 and 2006. For Zn and Cd, there were similar trends observed for all the recorded data. The concentration of Zn in the Danga area was highest in 1991 with 31.428 ppm and then decreased to 0.243 ppm in 2006 and 0.339 in 2009. The concentration of Zn for the Pendas area also showed a decreasing trend from 16.092 ppm in 1991 to 0.753 ppm observed in 2009. The trend in reduced concentrations of Zn might be due to the decreased influence of agricultural effluents caused by agricultural erosion of the land. Conversely, overall concentrations of Cd demonstrate that the higher concentration was recorded on 2009. In Danga Station, the concentration ranged from 0.0001 ppm in 2006 to

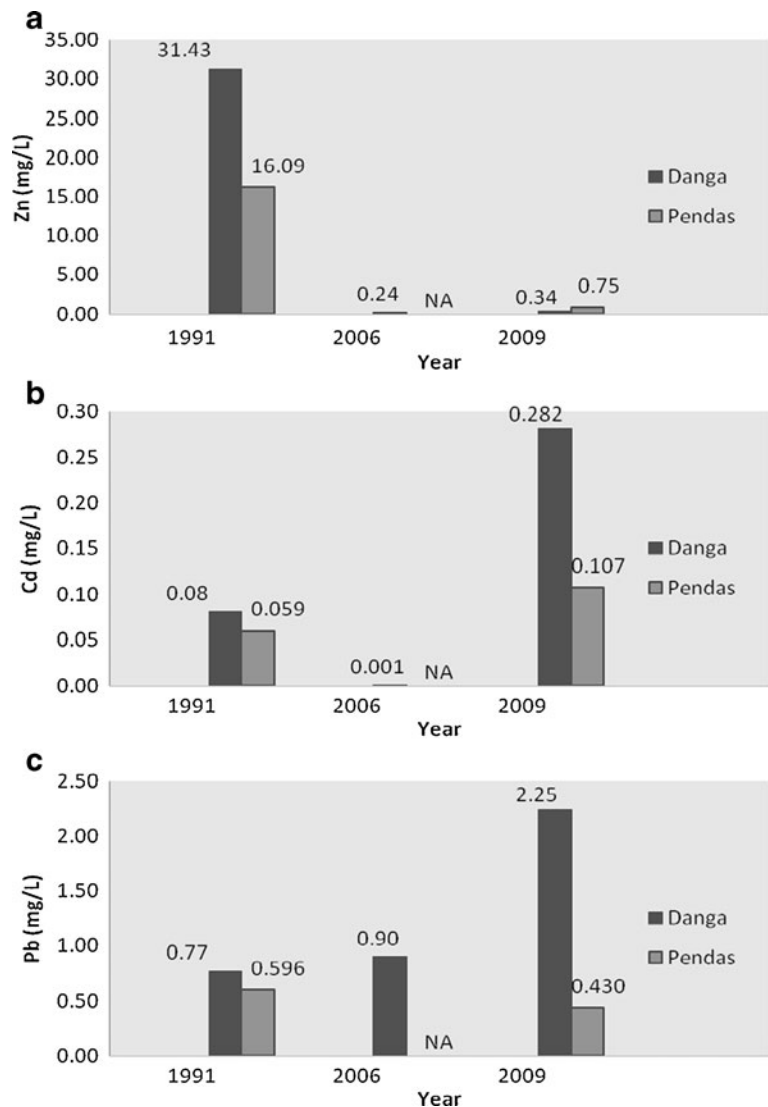
Fig. 3 Graphs of comparison in physical and chemical water quality against year 1991, 2006, and 2009: **a** pH, **b** temperature, **c** DO, and **d** ammoniacal nitrogen (AN)



0.082 ppm in 1991. Then, the concentration increased significantly up to 0.282 ppm in 2009. Although the

concentration was much lower than that observed in Danga, the concentration of Cd in Pendas also

Fig. 4 Graphs of comparison in heavy metals concentration against year of 1991, 2006, and 2009: **a** Zn, **b** Cd, and **c** Pb



increased from 0.059 ppm in 1991 up to 0.107 ppm in 2009. Unlike the 1991 and 2006 data, the latest observed concentration data do not comply with the INWQS limit, which is 0.1 mg L^{-1} . The trend for Pb concentration was similar to the Cd concentration. For the Danga Station, the lowest level was recorded in 2006 with 0.773 ppm, and the Pb levels increased in 2009 with a concentration of 2.253 ppm. However, Pendas Station showed a decreasing trend with a higher level in 1991 and a lower in level in 2009. Regarding the INWQS limits, the observed levels for all years apart from 2009 were lower than and therefore satisfied the standard. However, most of the 2009 data exceeded the required permissible level of 0.1 mg L^{-1} for Pb concentrations.

3.3 Analysis of Land use Effects on Water Quality Changes

There is a long history of studies on the land use and land cover-water quality relationship. Such studies have revealed that the type and severity of water contamination often is directly related to human activities, which can be quantified in terms of the intensity and type of land use in the source areas of water that flows into streams and aquifers. One of the most important factors that can affect the quality of a water body is the land use within its watershed. Urban sprawl (particularly the paving of large segments of the landscape) can have significant and usually negative impacts on water resources. Although growth and

land use change may be inevitable in many communities, the way in which growth takes place affects its impact on water quality (Reth et al. 1996; Allan et al. 1997; Johnson et al. 1997; Basnyat et al. 1999; Yunus et al. 2003).

Based on the results obtained from both integrated land use and observed water quality data, the negative effects of land use changes on water quality cannot be denied. As years pass by, we can see the reduction in natural land surface. The mangrove and forested areas have significantly decreased with increases in construction and developed agricultural areas. At the same time, a decline in the coastal water quality has occurred. Specifically, extensive increases in the water concentrations of metals have been recorded with the increasing build-up of an area. This phenomenon is significantly related to the land-based activities that produce domestic and industrial wastes. Increases in the development of industries and agriculture will also increase the accumulation of heavy metals in the water (Yunus et al. 2003).

3.4 Analysis of Heavy Metals (Cd, Pb, and Zn) in Green Mussels (*P. viridis* (L.))

Three major heavy metals were analyzed in this study: Pb, Cd, and Zn. Most of the studies done both internationally and specifically in Malaysia regarding green mussels used these three metals in their main analysis (Yap et al. 2002, 2003a, 2004; Aminah et al. 2003; Liu and Kueh 2005). Cd, Pb, and Zn are widely distributed in the coastal environment, both from natural geological processes and anthropogenic activities. This is of great interest to public health because the metals readily accumulate in the soft tissues of the green mussel (Yap et al. 2002).

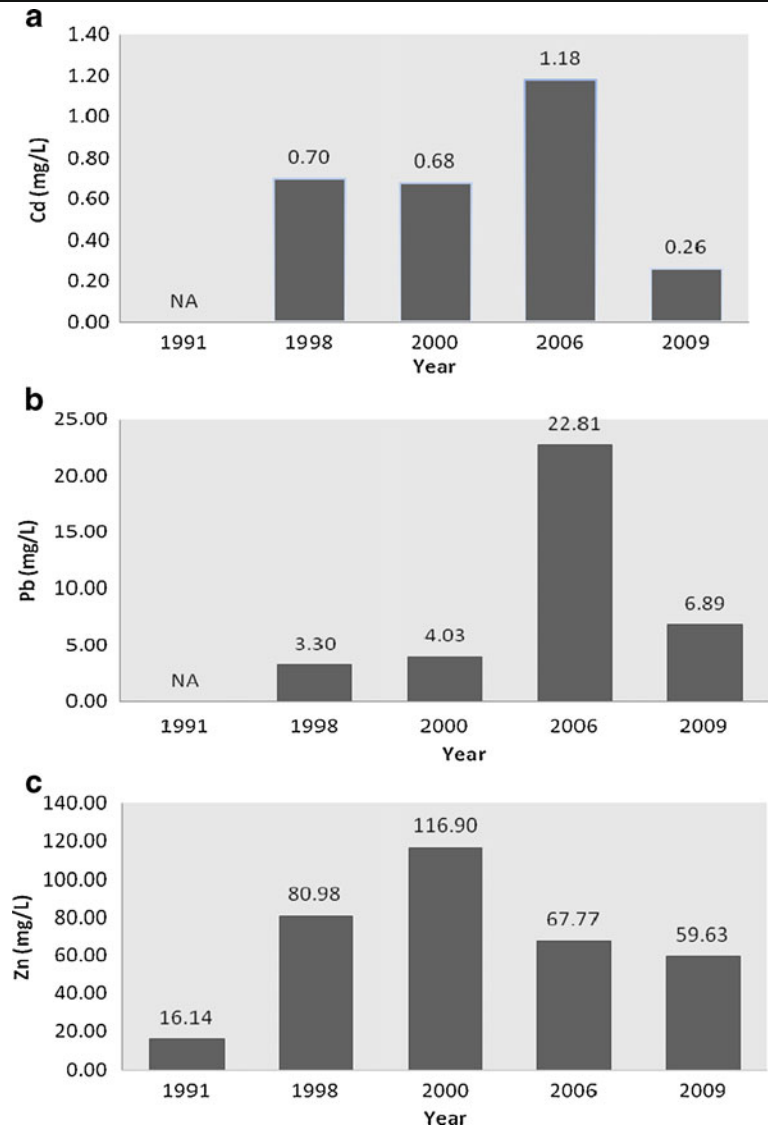
In order to see the variation in heavy metals concentrations in the green mussel, data for Cd, Pb, and Zn concentrations from a series of years were gathered. The list of the maximum permissible limits for heavy metals in seafood from different countries was shown in Table S4. The list can be used as a guideline to evaluate the quality of Malaysian seafood, especially the green mussel. Table 3 compares the metal concentrations in the mussels collected in this study with those from the earlier studies (Yap et al. 2002, 2003b; Chee et al. 2009). A detailed analysis of the variation in concentrations of Cd, Pb, and Zn in the *P. viridis* (L.) collected in S3 can be clearly performed with the graphs of Cd, Pb, and Zn concentrations against the year, as shown in Fig. 5.

Figure 5 also shows the concentration of Cd in *P. viridis* against the year. The concentration increased to 1.18 ppm in 2006 and decreased to the lowest level of 0.26 ppm in 2009. The early years (1998–2000) show more constant Cd concentration levels with an average of 0.68–0.70 ppm. The increase observed in 2006 may be due to the discharge of domestic and industrial wastes entering this area from the Sg. Skudai and Sg. Danga estuaries. Moreover, 2006 is the year that the IRDA development area started. The aggressive and massive development might have contributed to the higher Cd concentrations in this area. However, the present study shows a drastic drop in Cd concentrations in the green mussels for this area, which is possibly due to the intensive IRDA development prevention program implemented by the developers and the government. Although most of the concentrations were quite high, they were still under the permissible limit of the Malaysia Food Regulation, which is $1.0 \mu\text{g g}^{-1}$. Only samples in 2006 recorded Cd concentration more than that the permissible limit. In comparison with regulations from other countries, the concentrations of Cd were under the limits.

Table 3 Mean concentration of Cd, Pb, and Zn in *P. viridis* collected from S3 in present and previous studies: year 1991 (Ibrahim 1993), year 1998 (Yap et al. 2002), year 2000 (Yap et al. 2003a, b), year 2006 (Chee et al. 2009), and year 2009 for this study

Year	Cd (ppm)	Pb (ppm)	Zn (ppm)	Reference
1991	NA	NA	16.143±1.107	Ibrahim (1993)
1998	0.70±0.07	3.30±0.27	80.89±2.24	Yap et al. (2002)
2000	0.68 (0.36–1.53)	4.03 (1.83–8.98)	116.9 (68.1–165)	Yap et al. (2003a, b)
2006	1.179 (0.86–1.53)	22.812 (6.47–35.2)	67.767 (47.6–92.8)	Chee et al. (2009)
2009	0.26 (0.041–0.39)	6.89 (4.30–8.43)	59.632 (45.2–76.52)	This study

Fig. 5 Graph of metal concentration in *P. Viridis* (L.) against year. **a** Cd, **b** Pb, and **c** Zn



The trend in Pb concentrations in *P. viridis* was very similar to the trend observed for Cd concentrations where the values increased from 1998 to 2006 and then decreased in 2009. The highest Pb value recorded in 2006 was 22.8 ppm, and the lowest Pb value obtained in early 1998 was 3.30 ppm. Due to a very similar trend for both heavy metals, the possible reasons for the Pb concentrations may be similar to the reasons for the Cd concentrations. Even though the trend was very similar, the Pb concentrations in the green mussel were much higher. This can be seen when comparing the Pb concentrations to the Malaysian Food Regulation limits, where none of the samples were under the limit ($2.00 \mu\text{g g}^{-1}$). The Pb concentrations seemed very

critical when matched against the regulations and guidelines provided by other countries. The concentration values were observed to be within or above the prescribed limits.

The Zn concentrations started to increase from 1991 to 2000 and gradually decreased in 2006 and 2009. The highest concentration obtained for Zn was 116.90 ppm in 2000, while the lowest level recorded was 16.14 ppm in 1991. Although the concentrations of Zn were higher for most of the year, they were still under the permissible limit set by the Malaysian Food Regulation, which is $100 \mu\text{g g}^{-1}$. In comparison to other guidelines, the Zn concentrations in the green mussels were significantly below the

prescribed limits, which indicate that they were safe as a food source.

4 Conclusion

The reduced water quality is mainly due to the increase in pollutants, nutrients, and heavy metals. Thus, these factors also directly or indirectly have an effect on green mussels. Along with the increase in developed areas and the decrease in vegetated areas (forest, cultivation, and mangrove), there were reductions in water quality levels, where the most psychochemical water quality parameters satisfied class II and III of the INWQS and most of the heavy metals exceeded the INWQS limits. The degradation of water quality level due to land use might also give significant impact to *P. viridis* since they can accumulate high concentration of pollutants such as metals, thus making it hazardous to human as food sources.

Acknowledgments We acknowledge the financial support received from the Ministry of Higher Education, Malaysia (MOHE); the Research Management Centre, Universiti Teknologi Malaysia (UTM); Johor Bahru under vote number Q.J13000.7122.00H90; and the Department of Environment, Malaysia for the research data pertaining to the studied area.

References

- Allan, J., Erickson, D., & Fay, J. (1997). The influence of catchment land use on stream integrity across multiple scales. *Freshwater Biology*, *37*, 149–161.
- Aminah, M. Y., Yanta, N. F., & Wood, A. K. H. (2003). The use of bivalves as bio-indicators in the assessment of marine pollution along a coastal area. *Journal of Radioanalytical and Nuclear Chemistry*, *259*, 119–127.
- Ayako, N., Kousaku, O., Ikuo, U., & Hiroyuki, Y. (2003). Green mussel *Perna viridis* L.: attachment behavior and preparation of antifouling surfaces. *Biomolecular Engineering*, *20*, 381–387.
- Basnyat, P., Flynn, K., & Lockaby, B. (1999). Relationship between landscape characteristic and nonpoint source pollution inputs in coastal estuaries. *Environmental Management*, *23*, 539–549.
- Bayen, S., Thomas, G. O., Hian, K. L., & Obbard, J. P. (2003). Organochlorine pesticides and heavy metals in green mussel, *perna viridis* in Singapore. *Water, Air, and Soil Pollution*, *155*, 103–116.
- Chee, K. Y., Franklin, B. E., Ismail, A., & Soon, G.T. (2009). Interspecific Variation of Heavy Metal Concentrations in the Different Parts of Tropical Intertidal Bivalves. *Journal of Water Air Soil Pollution*, *196*, 297–309.
- Ding, H., Wang, R. C., Wu, J. P., Zhou, B., Shi, Z., & Ding, L. X. (2007). Quantifying land use change in Zhejiang coastal region, China using multi-temporal Landsat TM/ETM+images. *Pedosphere*, *17*, 712–720.
- Farrington, J. W., Davis, A. C., Tripp, B. W., Phelps, D. K., & Galloway, W. B. (1987). Mussel Watch Measurements of chemical pollutants bivalves as one indicator of coastal environmental quality. In T. P. Boyle (Ed.), *New approaches to monitoring aquatic ecosystem*, ASTM STP 940. *Philadelphia: American Society for Testing and Materials*.
- Hertler, H., Boettner, A. R., Ramirez-Toro, G. I., Minnigh, H., Spotila, J., & Kreeger, D. (2009). Spatial variability associated with shifting land use: water quality and sediment metals in La Paguera, Southwest Puerto Rico. *Marine Pollution Bulletin*, *58*, 672–678.
- Johnson, L., Richards, C., Host, C., & Arthur, J. (1997). Landscape influence on water chemistry in midwestern stream ecosystems. *Freshwater Biology*, *37*, 193–208.
- Klemas, V. V. (2001). Remote sensing of landscape-level coastal environment indicators. *Environmental Management*, *27*, 47–57.
- Liu, J. H., & Kueh, C. S. W. (2005). Biomonitoring of heavy metals and trace organics using the intertidal mussel *Perna viridis* in Hong Kong coastal waters. *Marine Pollution Bulletin*, *51*, 857–875.
- Monirith, I., Ueno, D., Takahashi, S., Nakata, H., Sudaryanto, A., Subramanian, A., Karuppiyah, S., Ismail, A., Muchtar, M., Jinshu, Z., Richardson, B. J., Prudente, M., Hue, N. D., Tana, T. S., Tkalin, A. V., & Tanabe, S. (2003). Asia-pacific mussel watch: monitoring contamination of persistent organochlorine compounds in coastal waters of Asian countries. *Marine Pollution Bulletin*, *46*, 281–300.
- Nicholson, S., & Lam, P. K. S. (2005). Pollution monitoring in Southeast Asia using biomarkers in the mytilid mussel *Perna viridis* (Mytilidae: Bivalvia). *Cement Environmental International*, *31*, 121–132.
- Qishlaqi, A., Moore, F., & Forghani, G. (2009). Characterization of metal pollution in soils under two land use patterns in The Angouran Region, NW Iran; a study based on multivariate data analysis. *Journal of Hazardous Materials*, *172*, 374–384.
- Rajagopal, S., Venugopalan, V. P., Nair, K. V. K., Jenner, H. A., & den Hartog, C. (1998). Reproduction, growth rate and culture potential of the green mussel, *Perna līridis* L. in Edaiyur backwaters, east coast of India. *Aquaculture*, *162*, 187–202.
- Rajagopal S., Venugopalan V. P., van der Velde G., & Jenner, H. A. (2006). Greening of the coasts: a review of the *Perna viridis* success story. *Aquatic Ecology*, *40*, 273–297.
- Reth, N. E., Allan, D. J., & Ericson, D. E. (1996). Landscape influences on stream biotic integrity assessed at multiple spatial scale. *Landscape Ecology*, *11*, 181–194.
- Sivalingam, P. M. (1977). Aquaculture of the green mussel, *Mytilus viridis* Linnaeus, in Malaysia. *Aquaculture*, *11*, 297–312.
- Tanabe, S., Prudente, M. S., Kan-atireklap, S., & Subramanian, A. (2000). Mussels watch: marine pollution monitoring of butylenes and organochlorines in coastal waters of Thailand, Philippines and India. *Ocean & Coastal Management*, *43*, 819–839.

- Yacuba, D., Guangdao, H., & Xingping, W. (2009). Applications of remote sensing in landuse/landcover change detection in puer and Simao Counties, Yunnan Province. *Journal of American Science*, *5*, 157–166.
- Yap, C. K., Ismail, A., Tan, S. G., & Omar, H. (2002). Correlation between speciation of Cd, Cu, Pb, and Zn in sediment and their concentrations in total soft tissue of green-lipped mussel *Perna veridis* from The West Coast of Peninsular Malaysia. *Environmental International*, *28*, 117–126.
- Yap, C. K., Ismail, A., & Tan, S. G. (2003a). Assessment of different soft tissues of the green-lipped mussel *Perna viridis* (Linnaeus) as biomonitoring agents of Pb: field and laboratory studies. *Water, Air, and Soil Pollution*, *46*, 1035–1048.
- Yap, C. K., Ismail, A., & Tan, S. G. (2003b). Background concentrations of Cd, Cu, Pb and Zn in the green-lipped mussel *Perna viridis* (Linnaeus) from Peninsular Malaysia. *Marine Pollution Bulletin*, *46*, 1035–1048.
- Yap, C. K., Ismail, A., & Tan, S. G. (2004). Heavy metal (Cd, Cu, Pb and Zn) concentrations in the green-lipped mussel *Perna viridis* (Linnaeus) collected from some wild and aquacultural sites in the west coast of Peninsular Malaysia. *Food Chemistry*, *84*, 569–575.
- Yunus, A. J. M., Nakagoshi, N., & Ibrahim, A. L. (2003). Application of GIS and remote sensing for measuring land use change and its impact on water quality in the Pinang River watershed. *Ecology and Civil Engineering*, *6*, 97–110.