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An assessment of water quality along the rivers loading to the Manado Bay, North Sulawesi, Indonesia

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Abstract—In the city of Manado, rivers are used for water drainage and sewer system of various wastewater discharges, including from toilets; these rivers discharge their load to Manado Bay. Therefore it is extremely important to know the water quality of these rivers. In this study three selected rivers, Sungai Bailang (SB), S. Maasing (SM), and S. Tondano (ST), were assessed in regard to 5-days Biochemical Oxygen Demand (BOD_5), nitrate (NO_3^-), ortho phosphate (PO_4^{3-}), total coliform (TC), *Escherichia coli* (EC), and total mercury (Hg-tot) to indicate loads of organic matter, inorganic nutrients, bacteria, and metals, respectively. Existing concentrations, variations with seasons (dry and wet), and pollution status of the rivers, are presented and discussed in this paper. Except the levels of TC and EC, which were high in all rivers and seasons, these parameters varied according to space (within the river and among the rivers) and the seasons. Average levels loaded to the bay for (1) organic were 15.30 mg/l of BOD_5 in the dry season and 7.52 mg/l of BOD_5 in wet season; (2) inorganic of NO_3^- and PO_4^{3-} were 2.01 mg/l of NO_3^- and 1.71 mg/l of PO_4^{3-} in the dry season, and 1.44 mg/l of NO_3^- and 2.20 mg/l of PO_4^{3-} in the wet season; (3) Hg-tot in the water and the surface sediment of ST was 0.024 mg/l and 0.133 mg/kg in the dry season, and 0.081 mg/l and 0.130 mg/kg in the wet season. The level of Hg-tot accumulated in the marine bivalve, *Soletellina* sp., ranged between 0.012 and 0.124 mg/kg. Based on these results, the water quality of the rivers was assessed as polluted. This was perhaps attributable to the presence of input of wastewater discharging from residential sources of the city and from the hinterland agricultural area of Minahasa Regency (MR). This condition may further threaten the water quality of Manado Bay; therefore, management measures are also identified and discussed.

Key words: water quality, wastewater management, Manado Bay, Manado, Indonesia

Introduction

Manado Bay (MB) is located in the western part of Minahasa Peninsular Coastal Waters (MPCW), North Sulawesi, Indonesia. The bay creates waterfront to Manado City (MC), a middle-scale city with a population approximately of 418,000 people in 2000 with a growth rate of 3.04% per year in the last decade (Mokat 2003) and having a total area of approximately 160.61 km^2. The bay receives water from land through 21 rivers, and six of them [Sungai Bailang (SB), S. Maasing (SM), S. Malalayang (SML), S. Sario (SS), S. Tondano (ST), and S. Wusa/Paniki (SWP)] are crossing through the city with various widths, lengths, and depths. The source of water flowing through the rivers is mostly from the hinterland agricultural area of MR. Since most of sewage and drainage of the city connect to those rivers, the rivers and the bay are being threatened by decreasing water quality due to untreated city wastewater discharge. Whereas, a good water quality of the bay is significantly important to support subsistence fishery of local people, local tourism activities, and marine ecosystems (coral reefs and other important marine biota) of Bunaken Island (a central point of Marine National Park of Bunaken) that is located at the outer part of the bay (Fig. 1).

Information about the water quality of the rivers and the bay is a matter of importance. However, almost no published information is available, especially in regards to organic, inorganic, bacteria, and metal, except Lasut (2002) on metal accumulation in the bay and the unpublished data of BOD_5 and bacterial load by the PPLH-SDA Unsrat in several selected rivers conducted in 1999. This lack of published information and data is one of the problems that cause difficulty in formulating management measures in order to overcome further impacts on those rivers and the bay. Most domestic wastewater is discharged, untreated and uncontrolled, directly to the rivers. Also, the rivers are used for waste (garbage) disposal systems and also, except SM, for daily activities of people living around the rivers such as washing, bathing, and transportation. Therefore, this study aimed to assess the water quality, including existing concentrations and its variation due to space and season. Besides, this may be used as base-line data for further controlling and monitoring, and it may be used as a guideline for responsible agencies to create management measures to mitigate pollution in MB caused by wastewater discharge from land-based sources.

With regard to domestic wastewater, since it may consist of a wide range of organic, inorganic, bacterial, metal, and other pollutant-containing substances, most authors have reported that such wastewater has been a major environmental concern in coastal waters (Adingra and Arfi 1998, Lee and Arega 1999, Wu 1999, Lipp et al. 2001). Furthermore, Ortiz-Hernandez and Saenz-Morales (1999) suggested that the most important source of water pollution was attributable to wastewater discharge.

Materials and Methods

Water quality indicators assessed

Assessment on the water quality was done using four indicators, i.e., organic, inorganic, bacteria, and metal content. Bacterial level was determined using TC-EC parameters; organic, inorganic, and metal levels were determined using the parameters of BOD_5, NO_3^-, PO_4^{3-}, and Hg-tot, respectively. Measurement of the BOD_5 was conducted using the method presented by Adams (1991) with some modifications for measuring the dissolved oxygen using the portable La Motte DO-4000 and performed at the laboratory of the Pusat Penelitian Lingkungan Hidup & Sumberdaya Alam (PPLH-SDA), Sam Ratulangi University. The NO_3^- and PO_4^{3-} concentrations were measured using cadmium-reduction and ascorbic acid methods respectively (Adams 1991). The TC and EC were measured using the multiple-tube technique (APHA-AWWA-WPCF 1969) with the highest measurement of 2400 MPN (most probable number per 100 ml); this is the only method available in the laboratory of the Balai Laboratorium Kesehatan (BLK), Propinsi Sulawesi Utara, where the samples were analysed. In the same laboratory, an Atomic Absorption Spectrophotometers (AAS) method was used for Hg-tot analysis with the protocol of the APHA-AWWA-WPCF (1990). All methods follow the Indonesian National Standard (INS).

Study area and sampling procedure

Three selected rivers of SB, SM, and ST situated in the urban area of MC (1°30–1°40N and 124°40–124°50E) were observed in this study. Sampling stations were selected in each river and named as #B1-B4, #M1-M4, and #T1-T5, respectively (Fig. 1). Geographical coordinates of the stations

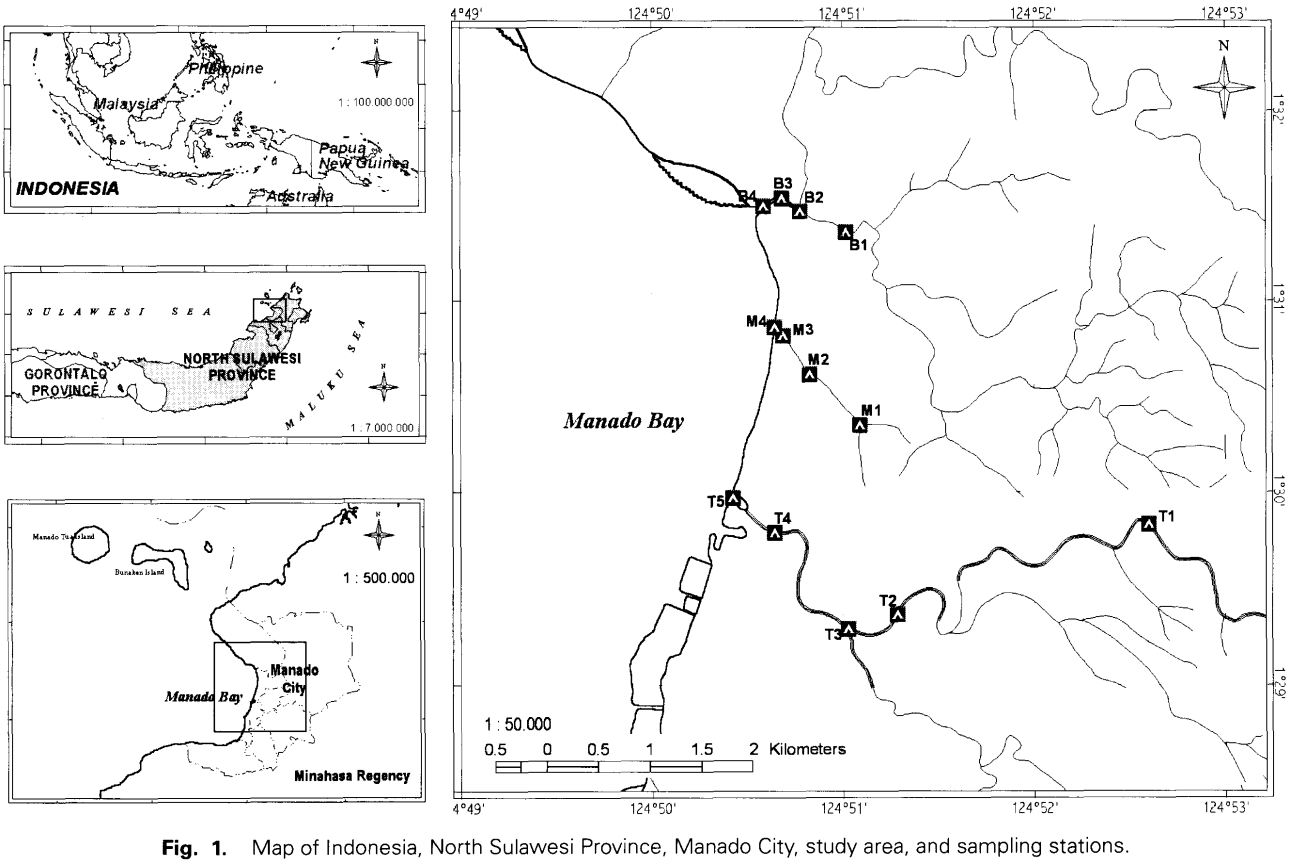

Fig. 1. Map of Indonesia, North Sulawesi Province, Manado City, study area, and sampling stations.

were marked using Global Positioning System (GPS) in order to re-monitor for future activities. The dominant area characteristics and uses of the rivers as well as width and environmental condition (salinity, temperature, and conductivity) of the water in each station during observation were noted.

Sampling was carried out in two different seasons, dry (September–October 2002) and wet (January–March 2003), which had monthly rainfall of 75–136 and 370–376 mm, respectively; 150 mm is usually stated as the end of the dry season. The monthly rainfall data were obtained from the Climatologic Station at Kayuwatu Manado (CSKM). As the rivers' water is flowing continuously, the samplings were set up consecutively from the down to the upstream and conducted in one day per indicator to avoid sampling of the same water. All samplings were done in the procedure of INS. Surface water of 30 cm depth was collected in sterile plastic bottles of 500 ml for BOD_5, NO_3^-, PO_4^{3-}, and Hg-total; glass bottles of 250 ml for TC-EC; and plastic pockets were used for 10 cm depth of surface sediment samples for Hg-tot. The marine bivalve *Soletellina* sp. was sampled for accumulated metal of Hg-tot; the biota were collected haphazardly from five selected sites at the river mouth of ST (T5). The sites were selected so that two stations were to the left and two to the right of the river mouth, and 50 m apart. Except for Hg-tot, the samples were taken in duplicate. All samples were kept in a cooler box with blocked ice during transportation to the laboratories and were analysed within 24 hours of the time of collection.

Statistical analysis

A simple statistical computation of one-way analysis of variance (Fowler and Cohen 1990) was applied to test differences of concentration of each parameter among the rivers and the seasons.

Results and Discussion

General characteristic and environmental condition

The general characteristics of the observed rivers are shown in Table 1. Since the rivers are located in the urban area of MC, the predominant land use in their surrounding area is residential (R), residential in dense urban area (Rdu), and residential mixed with agricultural (MRA). Most sewerage and drainage are directly connected to the rivers; such conditions result in rivers full of garbage, coloring, muddy, smelling, and bad in visual appearance. During the wet season, the rivers are relatively full of water. In contrast, there is a lack of water during the dry season. The width of the rivers measured at each of the sampling stations is in the range of approximately 2.5–30.0, 1.0–2.5, and 30.0–50.0 m, for SB, SM, and ST, respectively.

The salinity values during dry and wet seasons were low at the upstream end (in the range of 0.1–10.0 ppt) and high at the downstream end, close to the river mouth (up to 20.0 ppt) where mixing with marine water occurred. Conductivity showed a similar pattern. The water temperature was in the range of 28.1–34.2°C during the dry and 27.3–28.8°C during the wet season (Table 1).

Organic matter load

Content of organic matter, expressed as BOD_5, during dry and wet seasons in the three selected rivers is shown on Figs. 2 (a–c); high values indicated the high concentration of organic matter. The highest concentration was at sampling stations B1 (21.79 mg/l), M2 (28.20 mg/l), and T3 (15.58 mg/l) during the dry season; and at B2 (8.30 mg/l), M2 (18.36 mg/l), and T4 (5.49 mg/l) during the wet season. These values were most likely attributable to the presence of high amounts of organic matter in domestic wastewater discharged from residences at those sampling stations.

During the dry season, the concentrations showed a pattern with slightly higher values at the upstream than the downstream end. This may be explained if most of the organic matter was degraded during its passage from the upstream area because the river's water was flowing slowly due to lack of water. Conversely, during the wet season, concentration at the river mouths (downstream) of M4 and T5 was higher than those at the upstream end. This indicates that during the season with high amount of water organic matter is flushed and dispersed faster than it can be degraded. Most of the material was trapped and degraded in this area and caused increasing the BOD_5. No statistics could be performed on data within rivers as samples were only collected in duplicate.

Average values of the BOD_5 among the rivers showed that SM (19.34 mg/l)>SB (14.78 mg/l)>ST (12.48 mg/l) in the dry season; however, this was not statistically significant ($p>0.05$). Differences observed during the wet season were statistically significant ($p<0.01$) and SM (14.11 mg/l)>SB (5.10 mg/l)>ST (4.18 mg/l). Concentrations were higher during the dry season than in the wet season in all rivers. This was probably due to dilution. The values obtained in the present study were higher than those reported by PPLH-SDA Unsrat (1999) where BOD_5 in the rivers SB and ST was 7.00 and 16.46 mg/l. However, the actual sampling locations were not reported.

Average organic matter loaded to the bay in the dry season (15.30 mg/l of BOD_5) was significantly higher than in the wet season (7.52 mg/l of BOD_5) ($p<0.01$). These levels may significantly influence BOD_5 concentration of Manado Bay. Ortiz-Hernandez and Saenz-Morales (1999) reported BOD values ranging from 22.61–38.96 mg/l (mean 32.26 mg/l) from Chetumal Bay, Quintana Roo, Mexico, whereas Cheevaporn and Menasveta (2003) reported values between 1.3

Table 1. Characterization and environmental condition (salinity, temperature, and conductivity) of sampling stations during dry (September–October 2002) and wet (January–March 2003) seasons.

Location	Sampling station ID #	Coordinates (UTM)	Predominant land use in surrounding area	Uses	Approx. Width (m)	Salinity[a] (ppt)		Temperature[a] (°C)		Conductivity[a] (μS)	
						Dry	Wet	Dry	Wet	Dry	Wet
Bailang River	B1	51 N 0706427 0167511	MRA	Transportation	2.5	0.1	0.1	30.4	27.4	275.8	226.0
	B2	51 N 0706041 0168198	MRA	Transportation	15	0.2	0.2	31.9	28.1	470.2	241.0
	B3	51 N 0705652 0168711	R	Toilet	20	10.0	5.1	33.7	28.2	17.9*	8.9*
	B4	51 N 0705099 0168407	MRA	—	30	17.4	15.5	33.1	28.7	28.6*	26.5*
Maasing River	M1	51 N 0705989 0166417	R	Toilet, garbage dump	1	0.3	0.2	31.6	27.7	538.5	448.5
	M2	51 N 0705622 0166788	R	Public Toilet	2.5	0.5	0.2	31.7	27.7	982.0	471.0
	M3	51 N 0705404 0167125	R	Garbage dump	2	0.5	0.4	34.0	28.3	1171.0	666.0
	M4	51 N 0705304 0167254	MRA	—	3	9.0	20.0	34.2	28.8	15.4*	30.3*
Tondano River	T1	51 N 0708992 0165397	R	Transportation, Toilet, washing, bathing	30	0.1	0.1	30.1	27.4	259.8	252.5
	T2	51 N 0706413 0164390	Rdu	Transportation, fish culture, fishing, Toilet, washing	35	0.2	0.2	28.1	28.1	328.5	315.0
	T3		Rdu	Fish culture, fishing, Toilet, washing	35						
	T4	51 N 0705312 0165354	MRA	Bathing, washing, Toilet	50	2.1	0.6	30.4	27.4	4.7*	1.3*
	T5	51 N 0704989 0165630	Rdu	—	50	4.1	1.1	31.1	27.3	9.0*	2.1*

[a] the average of two values
* mS
MRA: mix residential and agriculture
R: residential
Rdu: residential (dense urban)

and 3.2 mg/l at river mouths in the upper Gulf of Thailand. The standard of acceptable BOD_5 for coastal waters is less than 10 mg/l (Clark 1996: 211). In general, BOD_5 values for domestic wastewater range between 100 and 500 mg/l (Ortiz-Hernandez and Saenz-Morales, 1999). This indicates that, especially in the dry season, organic load of rivers in Manado City should be reduced.

Inorganic nutrient load

Levels of inorganic matter measured as NO_3^- concentration is shown on Figs. 3(a–c). The highest concentration during dry season was at sampling stations B1 (2.14 mg/l), M2 (3.46 mg/l), and T2 (3.31 mg/l). During the wet season, the highest concentration was at B3 (2.02 mg/l), M3 (2.30 mg/l), and T2 (2.33 mg/l). The concentration during the dry season was generally high at the upstream and low at the downstream end close to the river mouth for all rivers. This pattern was not evident during the wet season. As the river water flow is slow during the dry season, most of the NO_3^- input must have come from the upstream area beyond the initial sampling station. Moreover, the concentration may have decreased towards the downstream end as the NO_3^- was used as a nutrient source for aquatic plants. However, an input apparently occurred at stations M2 and T2 as indicated by increased concentrations.

The average NO_3^- concentration varied among the rivers as SM (2.37 mg/l)>ST (2.13 mg/l)>SB (1.49 mg/l) during dry season, and ST (1.83 mg/l)>SM (1.46 mg/l)>SB (0.93 mg/l) during wet season; however, this was not statistically significant. In addition, the average level of inorganic matter as NO_3^- loaded to the bay during the dry season was not significantly higher (2.01 mg/l) than during the wet season (1.44 mg/l).

Concentrations of PO_4^{3-} (Figs. 4a–c) showed a pattern

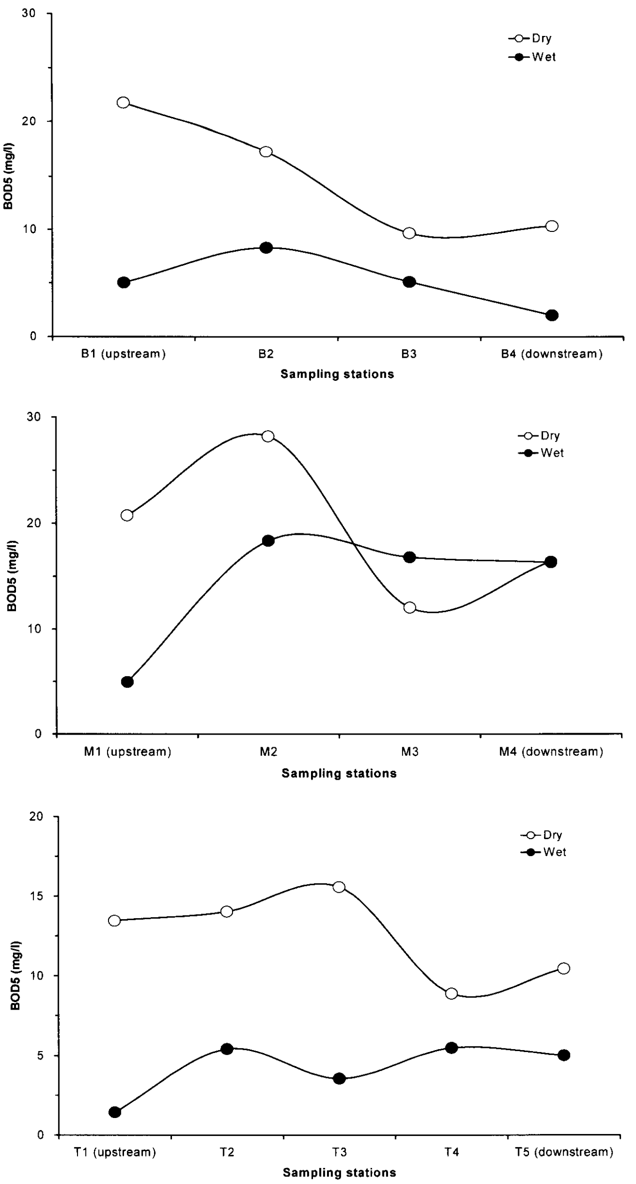

Fig. 2. BOD_5 values for 3 rivers in Manado City, SB (a), SM (b), and ST (c) during dry and wet seasons. Stations are shown on Fig. 1.

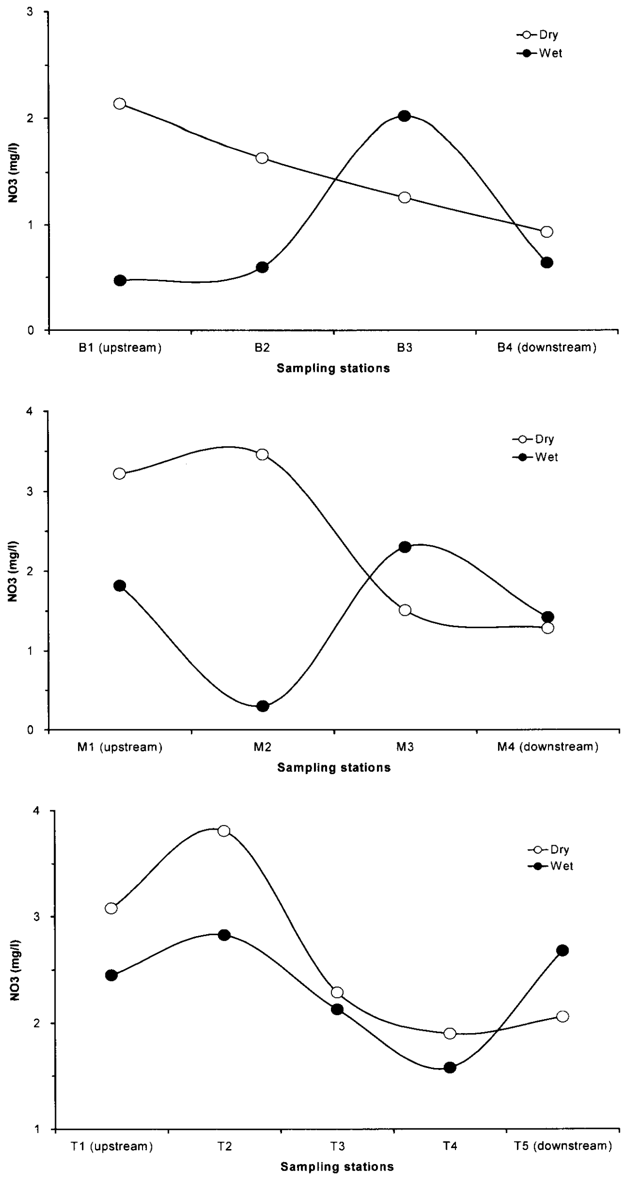

Fig. 3. NO_3^- values for 3 rivers in Manado City, SB (a), SM (b), and ST (c) during dry and wet seasons. Stations are shown on Fig. 1.

of increasing towards the downstream end during the wet season in all rivers. This indicated that there was a significant input from the urban area to the rivers. The highest concentrations in the dry season were found at B2 (2.06 mg/l), M2 (2.98 mg/l), and T2 (1.56 mg/l), and during wet season at B2 (1.81 mg/l), M4 (2.88 mg/l), and T5 (3.52 mg/l), respectively.

The average concentration in the river SM was highest during the dry season, and in ST during the wet season; this was statistically significant ($p<0.05$). The PO_4^{3-} loaded to the bay was significantly ($p<0.05$) higher during the wet season (2.20 mg/l) than the dry season (1.71 mg/l).

Levels of NO_3^- and PO_4^{3-} in the 3 rivers were one to two orders of magnitude higher than those recorded from river mouths discharging to the upper Gulf of Thailand (0.006–0.64 mg/l for NO_3^- and 0.09–0.36 mg/l for PO_4^{3-}) (Cheevaporn and Menasveta, 2003). High nutrient levels (eutrophication) are likely to cause massive algal blooms, possibly with toxic (harmful) algal species, and subsequently oxygen depletions.

Bacterial load

All observed rivers were contaminated by bacteria. This was indicated by high concentrations of TC and EC, which mostly exceeded the maximum measurable concentration of 2400 MPN (Table 2). Concentrations of EC vary within the rivers in the range of 11 to 2400 MPN during the dry season and 15 to 2400 MPN during the wet season. Since the value of 2400 MPN is not an absolute value, no statistical test was applied to test the differences among the rivers and seasons. Previous measurements showed that both *E. coli* and *Vibrio*

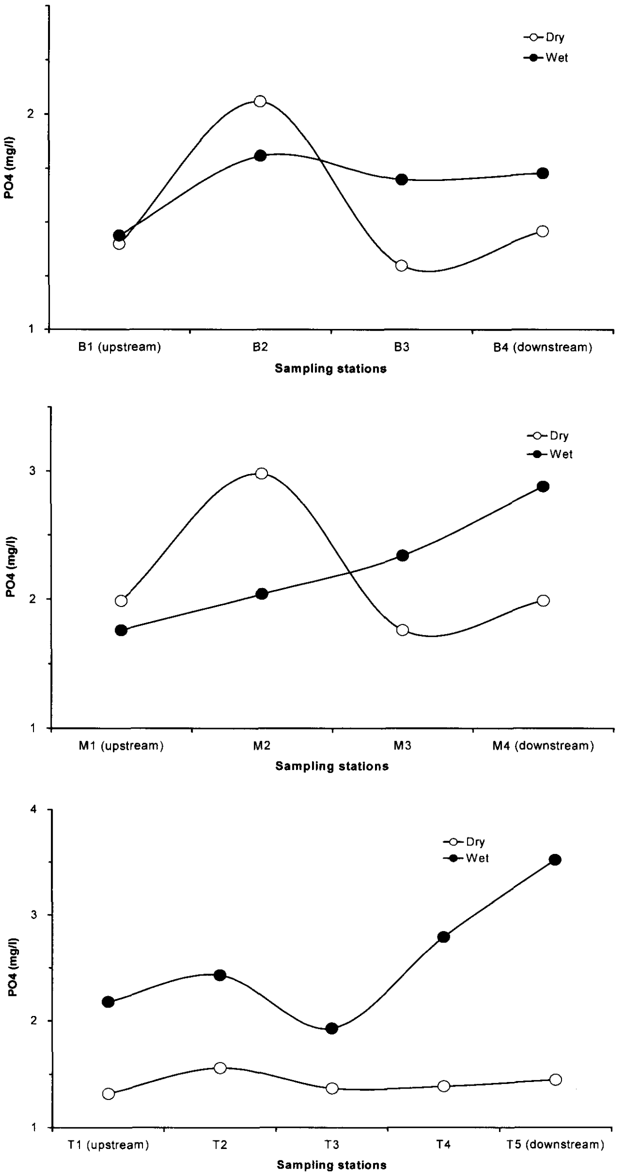

Fig. 4. PO_4^{3-} values for 3 rivers in Manado City, SB (a), SM (b), and ST (c) during dry and wet seasons. Stations are shown on Fig. 1.

sp. were detected in the river ST (PPLH-SDA Unsrat 1999).

As coliform bacteria are associated exclusively with mammal intestinal tracts (Rees 1993), the high levels of bacteria must be attributable to the presence of untreated wastewater discharge from toilets or domestic animals, for instance pig husbandry that has been observed in those areas.

Metal load

Metal concentration, as Hg-tot, was only measured in the river ST. The concentration in water and surface sediment slightly varied according to the sampling stations (space) and the season. The level in water during the dry season was low at the upstream and slightly higher at the downstream end close to the river mouth; in contrast, during the wet season it was high at the upstream and much lower at the downstream

Table 2. Concentration of Total coliform (TC), and *Escherichia coli* (EC) during dry (September–October 2002) and wet (January–March 2003) seasons.

Location	Sampling Station ID #	TC (MPN)[a]		EC (MPN)[a]	
		Dry	Wet	Dry	Wet
Bailang River	B1	1100	>2400	15	>2400
	B2	>2400	>2400	23	17
	B3	>2400	>2400	>2400	>2400
	B4	>2400	>2400	11	>2400
Maasing River	M1	>2400	>2400	1100	>2400
	M2	>2400	>2400	1100	>2400
	M3	>2400	>2400	210	>2400
	M4	>2400	>2400	23	15
Tondano River	T1	>2400	>2400	>2400	7.4
	T2	>2400	1100	23	240
	T3	>2400	>2400	>2400	558
	T4	>2400	>2400	>2400	93
	T5	>2400	>2400	210	17

[a] the highest value from the two values
MPN (most probable number per 100 ml of sample)

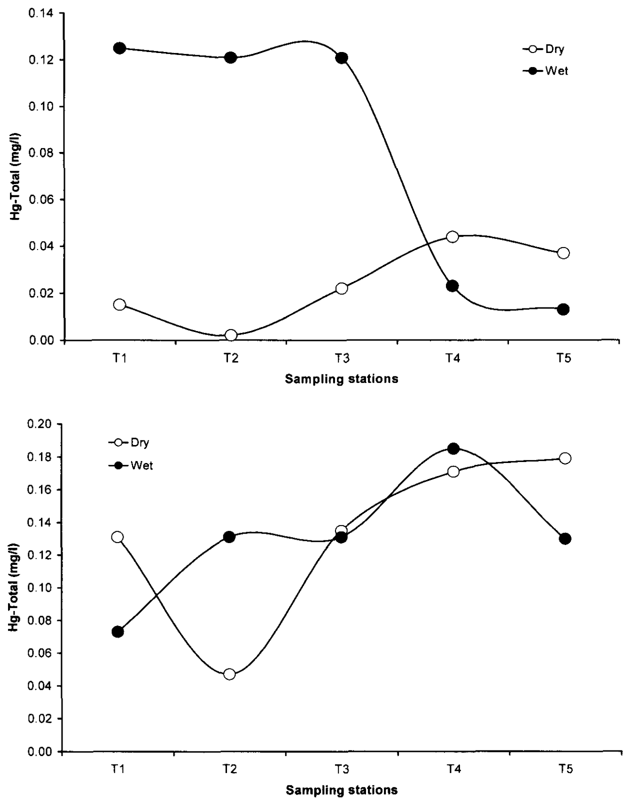

Fig. 5. Concentration of Hg-tot in water (a) and sediment (b) of ST during dry and wet seasons. Stations are shown on Fig. 1.

end (Fig. 5a). The high concentration at the upstream sampling stations (T1–T3) during the wet season was perhaps due to the high volume of water bringing suspended, particle-bound mercury from the hinterland area of MR where elemental mercury is used in artisanal gold mining practices (pers. obs.). The concentration decreased when the water mixed with water from a tributary and estuary close to the river mouth at sampling stations T4–T5. The concentration during the dry season was 0.002–0.044 mg/l, with the highest value at station T4 (0.044 mg/l), and 0.013–0.125 mg/l during the wet season, with the highest value at station T1 (0.125 mg/l) (Fig. 5a). The average concentration in the wet season (0.081 mg/l) was slightly higher than in the dry season (0.024 mg/l), though this was not statistically significant ($p>0.05$).

The same pattern of slightly higher concentrations at the downstream end was also shown for Hg-tot in surface sediment during both seasons, dry and wet (Fig. 5b). The suspended, particle-bound mercury brought out from the hinterland area tends to settle at the area close to the river mouth (T4 and T5). This was probably the reason why the concentration in the surface sediment at these stations was slightly higher than the others. The concentration during the dry season was 0.047–0.179 mg/kg with the highest at station T5 (0.179 mg/kg), and 0.073–0.185 mg/kg during the wet season with the highest at station T4 (0.185 mg/kg). The average concentration in the dry season (0.133 mg/kg) was slightly higher than in the wet season (0.130 mg/kg) though this was not statistically significant ($p>0.05$).

Comparing the Hg-tot concentration in the water and in the surface sediment within the season showed that the concentration in the surface sediment was significantly higher ($p<0.01$) during the dry season, and also ($p<0.05$) during the wet season than in the water (Figs. 6a and 6b, respectively). Seasonal variations for metals (Al, Cr, and Fe) in water and surface sediment have been reported from Richards Bay Harbor, South Africa (Vermeulen and Wepener 1999). Cheevaporn and Menasveta (2003) reported mercury concentrations of 0.01–847 μg/l in seawater and 0.003–2.8 μg/g in sediment of the upper Gulf of Thailand.

The concentration of Hg-tot accumulated in the bivalve, *Soletellina* sp., ranged between 0.012 and 0.124 mg/kg. The concentration was higher to the right (North) than to the left (South) of the river mouth (Fig. 7). Unfortunately, no statistical test could be applied due to the single measurement obtained from each station. The observed distribution can be explained as water current in the MB runs continuously from South to North. Lasut (2002) reported that Hg-tot accumulated in gastropods, *Littoraria* sp. and *Nerita* sp., from the same area was 0.045 and 0.344 mg/kg, respectively. Marine biota accumulate metals from the sediment. Chen and Chen (1999) reported that grey mullet (*Liza macrolepis*) accumulated the metals Cd and Cu in their body from contaminated harbour sediment and the liver had levels at least 2–5 times higher than those found in the sediment. In the present study, the concentrations of Hg-tot in the surface sediment and in the bivalve found at the river mouth of ST were of the same magnitude.

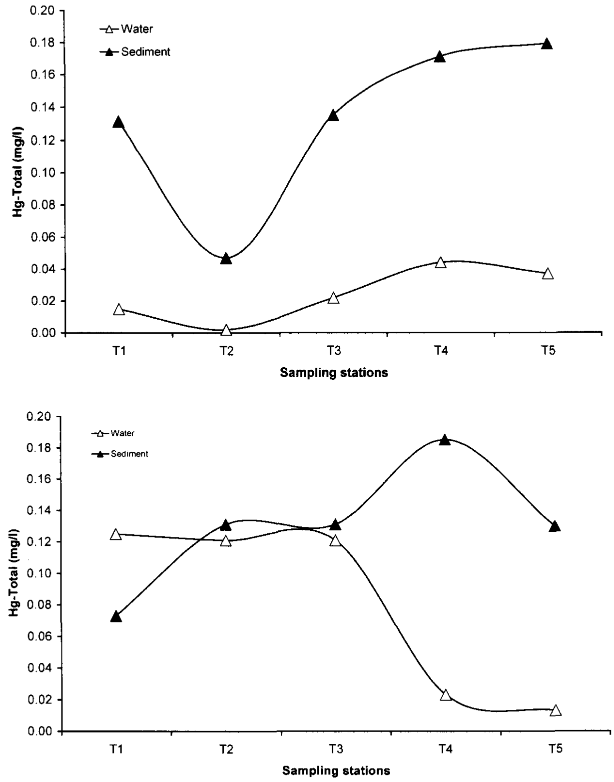

Fig. 6. Concentration of Hg-tot in water and sediment of ST during dry (a) and wet (b) seasons. Stations are shown on Fig. 1.

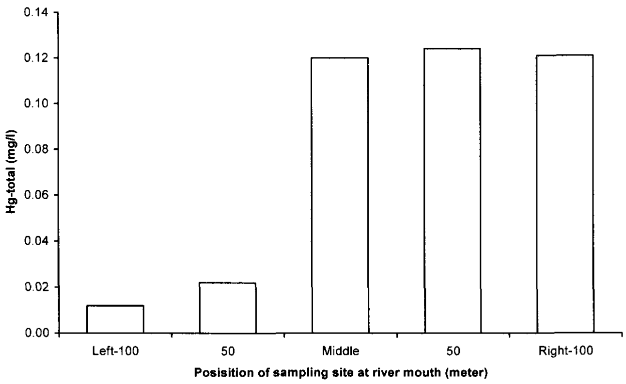

Fig. 7. Concentration of Hg-tot accumulated in the marine bivalve *Soletellina* sp. at the mouth of the river ST.

Pollution status and challenge to management

Based on the observed levels of the above parameters status of the rivers must be considered to be in condition of pollution for organic matter, inorganic nutrients, bacteria, and metal (mercury). The level of BOD_5 in all rivers exceeded the WQC-GRRI for water that may be used for recreational activities, fisheries, livestock, and irrigation, while those for NO_3^- and Hg-tot exceeded the ASEAN-MWQC for protection of aquatic life and the WQC-GRRI for water that may be used for recreational activities, fisheries, livestock, and irrigation, respectively. The level of PO_4^{3-} exceeded the WQC-GRRI and the ASEAN-MWQC for protection of aquatic life in estuaries and coastal areas (Table 3). All ob-

Table 3. Water quality status of the river of S. Bailang (SB), S. Maasing (SM), and S. Tondano (ST).

Parameters	Indonesia (mg/l)[a]		ASEAN (mg/l)[b]		Present study results			
					Rivers	Concentration (mg/l)[c]		Status
	a	b	c	d		Dry season	Wet season	
BOD_5	3				SB	14.78	5.10	Exceed: a
					SM	19.34	14.11	Exceed: a
					ST	12.48	4.18	Exceed: a
Nitrate (NO_3^-)	10	20	0.060		SB	1.49	0.93	Exceed: c
					SM	2.37	1.46	Exceed: c
					ST	2.13	1.83	Exceed: c
Phosphate (PO_4^{3-})	0.2[c]	1[d]	Estuaries: 0.045		SB	1.56	1.67	Exceed: a, b, c
			Coastal: 0.015		SM	2.18	2.26	Exceed: a, b, c
					ST	1.42	2.57	Exceed: a, b, c
Mercury (Hg-tot)	0.002	0.002	0.16 μg/l	21 μg/l	ST	0.024	0.081	Exceed: a, b, c, d

[a] Water Quality Criteria of Government Regulation of Republic of Indonesia (WQC-GRRI), No. 82, 2001 (Tunggal, 2002)
[b] Proposed ASEAN Marine Water Quality Criteria (ASEAN-MWQC) (Jusoh, 1999)
[c] Average values
[d] Phosphate total
a: Class II, water that may be used for recreational activities, fisheries, livestock, and irrigation.
b: Class III, water that may be used for fisheries, livestock, and irrigation.
c: Criterion for protection of aquatic life.
d: Criterion for protection of human health (recreational activities).

served rivers were in the status of pollution with regard to bacterial levels, since the level of TC and EC greatly exceeded those of the International Standard for recreational contact waters, typically 200 MPN coliform (Clark 1992).

NOAA (1995) suggested that wastewater is not a pollutant *per se*. It can be categorised as a pollutant if it has negative impact to environment. From our results, obviously, the water quality of the observed rivers was highly problematic. Water quality is significantly impacted by input of wastewater discharged from residential areas. Therefore, it is extremely important to overcome and mitigate further impact. In this regard, a management plan integrating all sectors and community stakeholders is an appropriate way, as it will involve all parties who have role in this problem. In addition, as the condition of water in MC is influenced by runoff from hinterland agricultural area of MR, the management should be transboundary, involving the MR authority where the upstream rivers are located.

Conclusion

Our results showed that the water quality of SB, SM, and ST had high levels of BOD_5, NO_3^-, PO_4^{3-}, TC, EC, and Hg-tot concentration. Variations in concentration occurred among the sampling stations within the rivers, among the rivers, and the seasons. The poor condition was attributable to input of wastewater discharged from residential areas in the urban area of MC and from the hinterland agricultural area of MR. Since some of the concentration levels exceeded the WQC-GRRI and the ASEAN-MWQC, they were in a state of pollution that needs to be managed to overcome further impacts to MB. The present data can be used as a baseline to monitor improvements or further deterioration of water quality of the rivers running through MC.

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