Chemical assessment of sediment along the coastal belt of Nagapattinam, Tamil Nadu, India, after the 2004 tsunami

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Concentration levels of Cr, Ni, Zn, Pb and Cu in relation to those of the nutrients – total phosphates, exchangeable nitrates, total organic carbon, etc. have been investigated in the sediments of Nagapattinam beach after the 2004 tsunami. The maximum values in the study area were 3204, 75, 71, 57 and 18.5 $\mu g\ g^{-1}$ for Cr, Ni, Zn, Pb and Cu respectively; Cd was below detectable level. All the trace elements were relatively high in the near-shore sediments and the distribution pattern of the metals in the study area was in the order: Cr > Ni > Zn > Pb > Cu. The present study shows that the tsunami has brought the clayey sediments from the sea-bottom that were settled for years together in inland areas as well as from the offshore sediments. The event has changed the chemical composition of the beach sediments and is threatening fishing grounds even in trace concentrations.

Keywords: Metal pollution, nutrients, shore sediments, total organic carbon, trace metals.

AN earthquake of greater magnitude occurred in the west coast of northern Sumatra, Indonesia (3.4°N, 95.7°E) on 26 December 2004. Giant tidal waves of 3–10 m in height, resulting from the earthquake hit various locations along the east, southeast and southwest coast of India. Approximately 2260 km of the coastal districts of Andhra Pradesh, Kerala, Tamil Nadu and Puducherry were affected by the tsunami. Nagapattinam in Tamil Nadu was the worst affected district (Figure 1); it has been estimated that 6051 people died here due to this deluge.

Ramasamy and Kumanan[1] have recorded ark sonic sediment grain transported by the tsunami to the land. Metal concentrations in aquatic organisms are typically several orders of magnitude (Table 1) higher than those in water, and results in biomagnification. This prompted a survey of a restricted area in the east coast of India to delineate the water quality of the Nagapattinam region (lat. 10°46′N, long. 79°50′E) in the Bay of Bengal. Since this area was worst affected by the tsunami, we have made an assessment of chemical quality of the coastal sediment. The chemical parameters estimated were trace metals like Cr, Ni, Zn, Pb, Cu and Cd, and nutrients (total phosphate, orthophosphate, exchangeable nitrate, etc.) along with total organic carbon (TOC) and C, H and N ratios.

Four different sampling sites (Figure 2) reflecting the variability in the effect of the tsunami were chosen. Transect parallel to the coast of Nagapattinam District, namely Nagapattinam beach (T1 and T2), Tarangambadi temple site (T3 and T4); the temple was completely damaged due to tsunami (Figure 3), Tarangambadi beach (T5 and T6) and Danish Fort, Tranquebar (T7 and T8). Originally Tarangambadi was a port city on the Coramandal coast. The Danish Fort was constructed during AD 1629.

Sample collections were made three weeks after the tsunami (January 2005). From each station two sediment samples were collected in sealed plastic bags parallel to the coast, one from the shoreline (T1, T3, T5 and T7) and the other from 10 to 20 m inland across the beach (T2, T4, T6 and T8) area. The sediments were clayey sand-type, though the sampling was made on the beach area. Samples were frozen and preserved till further analyses.

Sediments were dried, finely powdered and homogenized thoroughly. Samples were analysed for concentration of the trace metals – Cr, Ni, Zn, Pb, Cu and Cd; TOC, percentage carbon, hydrogen and nitrogen (%CHN) and nutrients (total phosphate, orthophosphate and exchangeable nitrate). For the determination of trace metals, 2 g of the sediment was digested at 90°C with HNO_3 + $HClO_4$ + HCl mixture in the ratio 1 : 1 : 3 for about 10 h. The acidic solution was centrifuged at 5000 rpm and made up to 25 ml with dil HCl. Blanks were set up concurrently. All the samples and blanks were then analysed by Atomic Absorption Spectrophotometer (Perkin Elmer model 3110) using air-acetylene flame and the nutrients were estimated spectrophotometrically as described by Grasshoff *et al.*[2]. TOC was determined using wet digestion followed by back titration with ferrous ammonium sulphate and %CHN analyses were carried out using Vario EL III CHN Analyzer.

Marine sediments fringing the coast of India exhibit well-defined patterns in their texture, chemical and min-

Figure 1. Complete devastation of the coastal belt in Nagapattinam.

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Table 1. Maximum trace metal concentration in the study area and some regions of the east coast of India along with guidelines for marine sediments given by NOAA

Station	Cr ($\mu g\ g^{-1}$)	Ni ($\mu g\ g^{-1}$)	Zn ($\mu g\ g^{-1}$)	Pb ($\mu g\ g^{-1}$)	Cu ($\mu g\ g^{-1}$)	Cd ($\mu g\ g^{-1}$)
Pulicat Estuary, east coast of India[11]	n.d.	n.d.	n.d.	n.d.	n.d.	8.6
Puducherry Harbour, east coast of India[15]	n.d.	n.d.	n.d.	n.d.	42	2.5
Ennore, Chenni, southeast coast of India[14]	138	55	36.5	17.5	52	n.d.
Nagapattinam beach (T1)	148	65	33	24	9.0	n.d.
Tarangampadi temple (T3)	3204	18.4	71.7	33	2.9	n.d.
Tarangampadi beach (T5)	241.9	75.8	58.0	57.0	18.5	n.d.
Danish Fort (T7)	30	n.d.	14.0	15.0	2.0	n.d.
Threshold effect level, TEL	52.3	15.9	124	30.24	18.7	0.6
Probable effect level, PEL	160.4	42.8	271	112.2	108.2	4.21
Apparent effect level, AEL	62E	110EL	410I	400E	390MN	30.0N

E, Echinoderm larvae; L, Larval max; I, Infacenal community impacts, and M, Microtox.

Figure 2. Sampling location (not to scale) of Nagapattinam District.

Figure 3. Tarangampadi temple site after the tsunami.

eral composition[3]. Most of the sediment depositions were observed 0.2 km away from the coast and maximum sediment inundation was noticed at the coastal beaches of Nagapattinam. These sediments were fine in nature and contained appreciable quantities of clay deposits. The analyses revealed predominance of whitish or brownish sand in all the stations. The thickness of the deposits varied from 1 to 90 cm. The tsunami-laid deposits have been studied for their types and characteristics by various workers[4–7].

An examination of the constituents like TOC, total phosphate, orthophosphate, exchangeable nitrogen, %CHN and trace metals like Cr, Ni, Zn, Pb, Cu and Cd (Figure 4 *a–g*) of the deposit revealed a quantum jump in their distribution when compared with the available secondary data (Table 1).

The dissolved and particulate organic carbon content of the waters in the southeast coast of India is generally low owing to the presence of fine coral sand, which adsorbs these constituents making the water less marshy. Therefore, the low TOC recorded supports this assumption. All the samples showed a low TOC in the range 0.2–0.5 $\mu g\ g^{-1}$ (Figure 4 *a*). The low organic carbon value in the sample may be the result of new marine sediment induction and mixing process in the beach as well as the high rate of degradation by the microbial-mediated process[8]. The shallow sandy nature of the coastal region supports this observation. Total organic phosphate, orthophosphate and exchangeable nitrate are high compared to TOC (Figure 4 *b–d*). Srinivasalu *et al.*[9] described these tsunami-deposited sediments as layer type, consisting of well-sorted, fine sand intercalated with non-marine black organic mixed with plant roots, as found in the present study.

The total metal content exhibited higher concentrations at stations T1, T3 and T5 that were severely affected by the tsunami. Among these stations, a high value of Cr was reported at station Tarangambadi temple (T3; 3204 $\mu g\ g^{-1}$), Tarangambadi beach (T5; 241 $\mu g\ g^{-1}$) and Nagapattinam beach (T1; 148 $\mu g\ g^{-1}$), and a low value (30 $\mu g\ g^{-1}$) at Danish Fort (the Fort was not damaged due to tsunami). High concentration of Ni was reported at the Tarangambadi beach (75 $\mu g\ g^{-1}$) and it was below detectable range in the Danish Fort. All metals showed a low value in Danish Fort station. Overall, the maximum trace metal concentration was found at the Tarangambadi shore

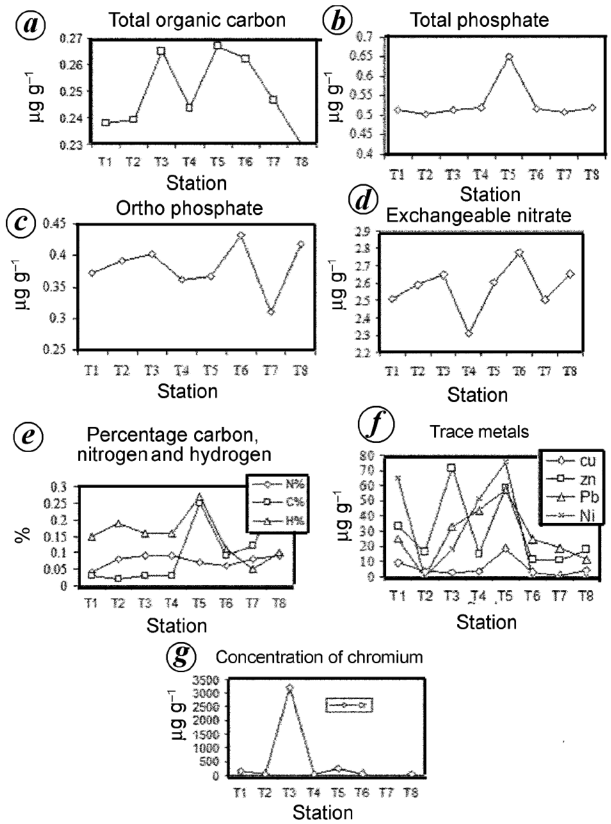

Figure 4. Distribution pattern of chemical constituents in the coastal belt of Nagapattinam.

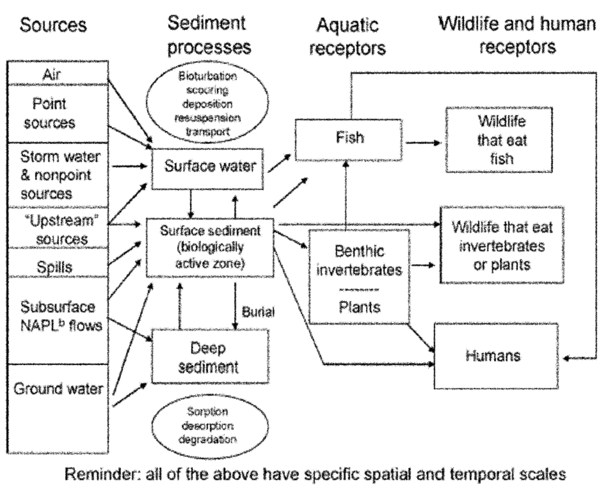

Figure 5. Biogeochemical cycle of trace metals in the coastal environment[22].

region, T3 and T5; Cr (3204 µg g^{-1}) and Zn (71 µg g^{-1}) at T3 and Ni (75 µg g^{-1}) Pb (57 µg g^{-1}) and Cu (18.5 µg g^{-1}) at T5 (Figure 4*f* and *g*). Although most of the above-mentioned metal concentrations were above the threshold effect level (TEL), they were below the probable effect level (PEL) and apparent effect level (AEL) of some tested animals (Table 1)[10].

Metal concentration was higher in the shoreline region (T1) compared to the vertical region for Cr, Ni and Zn (148, 65 and 33 µg g^{-1} respectively). It is inferred that enrichment of all the analysed trace elements of near-shore sediments occurred (T1, T3, T5 and T7) when compared with the other regions (T2, T4, T6 and T8). This is due to the clayey nature of the sediments originated from the marine environment. Sediments in the near-shore area move along the coast due to the action of waves, which generate long shore currents and cause sediment transport of chemical constituents[9].

On the east coast of India, the available information on the concentration of heavy metals in the sediments is limited[7,11–14]. Comparison of our results with SQuiRT[10] and previous studies in the east coast of India, Pulicat Lagoon[11], Puducherry Harbour[15] and Ennore Estuary[14], showed that the sediments brought by the tsunami have high metal concentration in the east coast region (Table 1).

High metal concentration in Nagapattinam beach, Tarangambadi temple site and Tarangambadi beach compared with that of Danish Fort may be due to domestic and sewage waste in these regions. The variation of metal concentrations was drastic, caused by churning of the bottom sediments and their deposition along the shore by the waves, bringing changes in the beach profile and chemical concentrations. This remobilization contributes environmental disturbance and likely to have a far-reaching effect on the life and activities of marine biota in general and pelagic fishery in particular. Figure 5 schematically represent the biogeochemical cycle of metals in the coastal sediments.

The distribution of copper showed a noticeable reduction at all stations (2–9 $\mu g\ g^{-1}$), except at station T5. The Tarangambadi beach showed an elevated concentration (18.5 $\mu g\ g^{-1}$) when compared to the earlier values reported in the east coast region[11,12,14]. It was also noticed that at all sites Cd concentration showed a distinct spatial distribution pattern below detectable limit (Table 1). The concentration of Zn and Pb remained almost the same (10–33 $\mu g\ g^{-1}$) in all the stations studied.

The distribution pattern of metals was Cr > Ni > Zn > Pd > Cu > Cd and it outweighs the presence of metals associated with the bottom sediments contaminated with anthropogenic inputs (M. P. Jonathan, unpublished)[13,16–21]. Various river channels which may act as pathways for sediment inundation to the nearby lands with heavy mineral content, were observed in the tsunami deposits in Karaikkal, Kalpakkam and Tarangambadi areas; our results corroborate the above findings[9].

In conclusion, the present study showed the distribution of trace metal at Nagapattinam after the 2004 tsunami. Cr showed the highest concentration (3204 $\mu g\ g^{-1}$) at the Tarangambadi temple area compared with other stations. The Tarangambadi beach showed elevated concentrations of Ni (75 $\mu g\ g^{-1}$), Pb (57 $\mu g\ g^{-1}$) and copper (18.5 $\mu g\ g^{-1}$) compared to the other three stations. The high metal content may affect the productivity of this area in the near future. The tsunami has clearly interfered with the well-set pattern by which sea has controlled the trace metal cycle by the biogeochemical processes.

1. Ramasamy, S. M. and Kumanan, C. J., *TSUNAMI: The Indian Contest*, Allied Publishers Pvt Ltd, Chennai, 2005.
2. Grasshoff, K., Ehrhard, M. and Kremling, K., *Methods of Seawater Analysis*, Verlag Chemie, Weinheim, Second Revised and Extended Edition, 1998.
3. Murthy, P. S. N. and Veerayya, M., Studies on the sediments of Vembanad lake, Kerala State: PART IV – Distribution of trace elements. *Indian J. Mar. Sci.*, 1981, **10**, 165–172.
4. Satapaty, K. K., Impact of tsunami on meiofauna of Marina Beach, Chennai, India. *Curr. Sci.*, 2005, **89**, 1646–1647.
5. Kumaraguru, K., Jayakumar, K., Wilson, J. and Ramakritinan, C. M., Impact of the tsunami of 26 December 2004 on the coral reef environment of Gulf of Mannar and Palk Bay in the southeast coast of India. *Curr. Sci.*, 2005, **89**, 1729–1741.
6. Negendra, N., Kamalakannan, B. V., Sajith, C., Sen, G., Reddy, A. N. and Srinivasalu, S., A record of foraminiferal assemblage in tsunami sediments along Nagappattinam coast, Tamil Nadu. *Curr. Sci.*, 2005, **89**, 1947–1952.
7. Chandrasekar, N., Saravanan, S., Immanuel, L. and Rajamanickam, J. M., Classification of tsunami along the southern coast of India. An initiative to Safeguard the coastal environment from debacle. *Science of Tsunami Hazards*, 2005, vol. 24, p. 3.
8. Canuel, E. A. and Martens, C. S., Seasonal variations in the sources and alternations of organic matter associated with recently deposited sediments. *Org. Geochem.*, 1993, **20**, 563–577.
9. Srinivasalu, S., Nagendra, R., Rajalakshmi, P. R., Thangadurai, N., Arun Kumar, K. and Achyuthan, H., Geological signatures of sediments of *M9* tsunami event along Tamil Nadu Coast. In *Tsunami: The Indian Context* (eds Ramasamy, S. M. and Kumanan, C. J.), 2005, pp. 171–181.
10. Buchman, M. F., NOAA Screening Quick Reference Tables, NOAA, HAZMAT Report 99-1, Seattle WA, Coastal Protection and Restoration Division, National Oceanic and Atmospheric Administration, 1999, p. 12; accessed on 15 September 2006.
11. Padma, S. and Periakali, P., Physico chemical and geo chemical studies in Pulikkat Lake, east coast of India. *Indian J. Mar. Sci.*, 1999, **28**, 434–437.
12. Senthilnathan, S. and Balasubramanian, T., Heavy metal distribution in Pondicherry Harbour, southeast coast of India. *Indian J. Mar. Sci.*, 1999, **28**, 434–437.
13. Jonathan, M. P. and Ram Mohan, V., Heavy metals in sediments of inner shelf off the Gulf of Mannar, southeast coast of India. *Mar. Pollut. Bull.*, 2003, **46**, 263–268.
14. Thangadurai, N., Srinivasalu, S., Jonathan, M. P., Rajeshwara Rao, N. and Santhosh Kumar, R., Pre-tsunami chemistry of sediments along the inner continental shelf off Ennore, Chennai, southeast coast of India. *Indian J. Mar. Sci.*, 2005, **34**, 274–278.
15. Balachandran, K. K., Ph D thesis, Cochin University of Science and Technology, Cochin, 2001, p. 148.
16. Zingde, M. D., Trivedi, S. K. and Desai, B. N., Physicochemical studies on pollution off Bombay. *Indian J. Mar. Sci.*, 1979, **8**, 271–277.
17. Sweeny, M. D. and Naidu, A. S., Heavy metals in sediments of the inner shelf of the Bean fort sea, Northern Artic Alaska. *Mar. Pollut. Bull.*, 1989, **20**, 140–143.
18. Raman, A. V., Pollution effects in Visakhapatanam Harbour, India: An overview of 23 years of investigations and monitoring Hegolander Meeresunters 49, 1995, pp. 633–645.
19. Bothner, M. H., Buchholtzten Brink, M. and Manheim, F. T., Metal concentrations in surface sediments of Boston harbour changes with time. *Mar. Environ. Res.*, 1998, **45**, 17–55.
20. Mohan, P. M., Trace element geochemistry of modern sediments of the Vellar river and its surrounding environments. *Indian J. Mar. Sci.*, 1997, **26**, 150–157.
21. Seralathan, P. and Seetharamaswamy, A., Clay minerals in the modern deltaic sediments of Cauvery river. *Indian J. Mar. Sci.*, 1982, **11**, 167–199.
22. Wenning, R. J. and Ingersoll, C. G., Use of sediment quality guidelines and related tools for the assessment of contaminated sediments. In Executive Summary of a SETAC Pellston Workshop, Montana, USA, 2002.

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