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Assessment of well water quality in Tsunami affected regions of south-west coast of Kerala, India

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Abstract

The quality of well waters, based on 23 parameters of water, at 12 stations of south-west coast of Kerala, India, was assessed during monsoon, 2009 and summer, 2010, to determine their suitability for drinking and other domestic purposes. The stations selected were grouped into four regions *viz*. least, slightly, moderately and severely affected ones based on the severity of 2004 Asian Tsunami at each station. The depths of wells showed variations depending on the seasons and on their distance from the seacoast. The average water temperatures during monsoon and summer seasons were 28.5°C and 30.2°C respectively. The pH of well waters were below 6.5 in least and slightly affected regions and above this value in moderately and severely affected regions. In all the four regions, the well water parameters of electrical conductivity, hardness, fluoride, free chlorine, copper, zinc, calcium and nickel were below, and phosphorus, lead, iron cadmium and manganese were above the standard permissible levels set for them in drinking water. The values of salinity, sodium and potassium in the well waters of moderately and severely affected regions, and the values of nitrate-nitrogen, nitrate and magnesium in the well waters of severely affected regions were above the permissible limits set for them in drinking water. Water quality index calculated on the basis of drinking water standards revealed that the well waters of least and slightly affected regions were moderately polluted in both monsoon and summer seasons and the same of moderately affected region were excessively polluted during monsoon and severely polluted during summer seasons, whereas the well waters of severely affected regions were severely polluted in both seasons. Suitable recommendations were made to improve the quality of well waters of least and slightly affected regions.

Key words

South-west coast of Kerala, Tsunami, Water quality index, Well water

Introduction

A sizeable volume of literature is available on the various aspects of groundwater quality of 2004 Asian Tsunami affected regions in India and Sri Lanka. KSCSTE (2006) gave a geographical description of the groundwater quality of pre-tsunami water of Alappad coast in Kerala, which was severely hit by Tsunami, as a fringe point control and as a reference standard to make evaluations and judgements in the post-tsunami situations and similar coastal disasters in the future. Violette *et al.* (2009) described the tsunami-inducted groundwater salinisation in south-eastern India. Ravisankar and Poongothai (2008) gave an account on the groundwater quality of tsunami-affected areas of Sirkazhi Taluk in Nagapattanam District in Tamil Nadu. Achari *et al.* (2006) furnished an account on the groundwater quality of tsunami-affected Arattupuzha coast of Kerala. A booklet on the impact of Tsunami in the Kerala coast was published by Kerala State Council for Science, Technology and Environment (KSCSTE, 2006). A brief description was furnished by Kurian and Prakash (2005) on the impact of Tsunami on the Kerala coast where they mentioned the quality of groundwater also.

IGRAC (2005) gave an assessment of the impact of 2004 Tsunami on groundwater system and groundwater-based water supplies. The practical guidelines for the control of water pollution due to Tsunami was published by IUCN and IWMI (2005). Clasen and Smith (2005) published a report on the drinking water response to the Indian Ocean Tsunami including the role of household water treatment. Villholth *et al*. (2005) gave a detailed account on the impact of Tsunami on the shallow groundwater and associated water supply on the east coast of Sri Lanka. Anputhes *et al.* (2005) suggested post-tsunami livelihood needs assessment in southern Sri Lanka, which include the improvement in quality of groundwater also. A broad outline on the impact of Tsunami on the groundwater resources of Sri Lanka was furnished by Panabokke and Perara (2005), and the guidelines in well rehabilitation in eastern Sri Lanka were given by UNICEF (2005).

The periodic monitoring of groundwater quality is necessary to safeguard its long-term sustainability, and water quality index is an indicator revealing the composite influence of a number of water quality parameters which are significant for specific beneficial uses (Nair *et al.,* 2005, 2006). The present study was undertaken to evaluate the quality of well waters in 2004 Asian Tsunami affected and neighbouring areas along the south-west coast of Kerala.

Materials and Methods

Study Area: South-west coast of Kerala consists of three districts *viz.,* Thiruvananthapuram, Kollam and Alappuzha. The coastal belts of Kollam and Alappuzha districts are rich in mineral deposits and these were moderately to severely hit by 2004 Asian Tsunami and its impact was felt in their nearby areas of Thiruvananthapuram also. In the present study, a total of 12 stations (Fig.1) located in the three districts were selected. These stations were grouped into four regions depending on the severity of Tsunami at each station. These are least affected, slightly affected, moderately affected and severely affected regions. The names of places under each region, the distance of well from the seacoast, depth of well from surface ground level to well water surface during monsoon 2009 and summer 2010, and the use of well water, are presented in Table 1.

Analysis of well water: Well water samples from each station were collected two times during the monsoon season (July 2009: peak of south-west monsoon period; October, 2009: peak of north-east monsoon period) and two times during the summer season (March, 2010: peak of summer; May, 2010: end of summer). The values of each parameter at each region in a season were pooled and the mean values were taken.

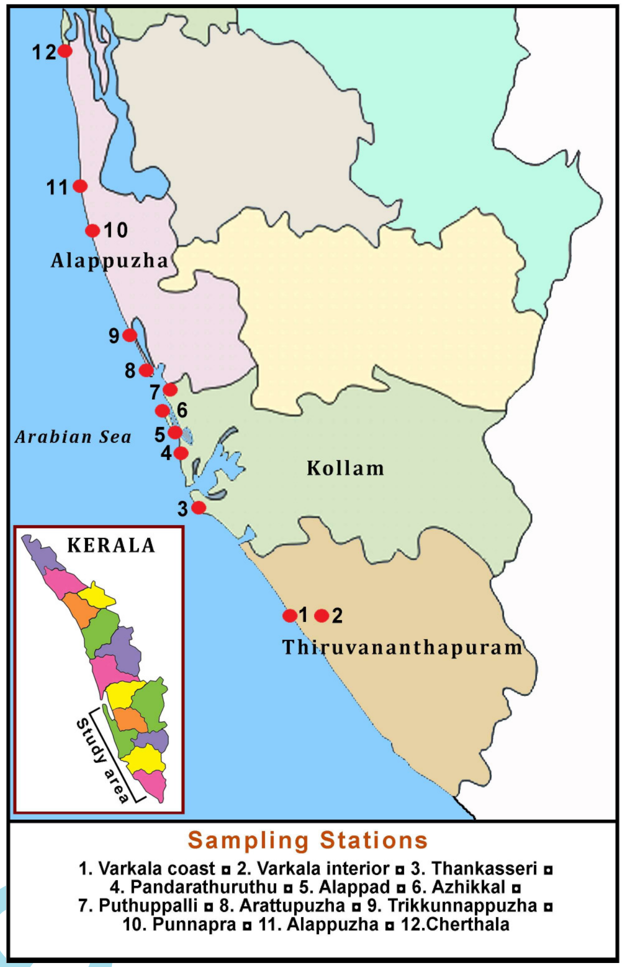

Fig. 1 : Map of south-west coast of Kerala showing the sampling stations

Well water samples (3 l) without any air bubbles were collected from each station in polythene bottles following standard procedures (Nair *et al*., 2006). The date and time (between 7.00 and 11.00 a.m) of collection were recorded and water samples were analysed for 23 parameters. Temperature and electrical conductivity of water were measured on the site itself using Hanna Autoranging Microprocessor EC/^{o}C meter, pH by Beckman pH meter, and salinity by Salinometer. The other parameters were analysed in the laboratory. Total hardness and free chlorine in water were analysed using Hanna Freshwater Analysis Kit. The remaining parameters of water (fluoride, calcium, copper, zinc, phosphorus, manganese, iron, lead, cadmium, sodium, potassium, chromium, nitrate-nitrogen, nitrate, magnesium, mercury and nickel) were analysed using Hanna Multiparameter Bench Photometer and Atomic Absorption Spectrophotometer.

Water quality index : Water quality index of well waters based on 21 parameters of water were calculated following the procedures and equations given by Kaur *et al.* (2001)

Table 1 : Details of well water collection, south-west coast of Kerala

Tsunami affected regions	Site of well water collection		Distance of well from seacoast (Km)	Depth of well (m) from surface ground level to well water surface		Use of well water
				Monsoon 2009	Summer 2010	
Least	a.	Varkala interior	2	19.00	21.25	Drinking, domestic
	b.	Cherthala	3	00.90	01.80	irrigation
Slightly	a.	Varkala coast	< 0.5	05.30	05.25	Drinking,domestic,
	b.	Thankasseri	1	01.41	01.90	irrigation
Moderately	a.	Puthuppalli	< 0.3	01.00	02.60	Drinking,domestic,
	b.	Punnapra	< 0.3	01.42	01.52	washing clothes,
	c.	Alappuzha	< 0.5	01.00	02.50	irrigation
Severely	a.	Alappad	< 0.4	00.83	01.50	
	b.	Pandarathuruthu	< 0.2	01.50	01.70	Drinking,domestic,
	c.	Azhikkal	< 0.2	00.60	01.98	washing clothes
	d.	Trikkunnappuzha	< 0.2	00.30	01.00	
	e.	Arattupuzha	< 0.2	01.75	02.00	

and Nair *et al*. (2006). Parameters are referred here as factors. The unit weight (Wi) of each factor is dependent on the standard limits in drinking water as prescribed by BIS (2010). Factors with low permissible limits have high weightings whereas those with higher permissible limits have low weightings (Kaur *et al*., 2001).

Each factor had been assigned a rating value (Vr) which ranged between 0 and 100. To assign rating value, range of its concentration in water was divided into five intervals, i.e. Vr 0, Vr 40, Vr 60, Vr 80 and Vr 100 (Table 2). The rating Vr = 0 implied that chemical factor exceeded standard (desirable) limit and water was polluted while Vr = 100 implied that chemical factor had the most desirable value and the water was clean. The products of rating (Vr) and unit weights (Wi) of all 21 factors were summated, [WQI = “Vr x Wi] to calculate WQI.

Results and Discussion

There were not much variations in water temperatures between the four regions during monsoon (range: 28.4°C to 28.6°C) which increased marginally during summer (range: 28.6°C to 31.8°C). Water pH of moderately and severely affected regions in both monsoon and summer seasons were above 6.5, whereas the same of least and slightly affected regions were below this value (Table 3a). The pH of groundwater in the whole south-west coastal belt was slightly acidic (Kurian and Prakash, 2005) and the increase in pH in moderately and severely-affected regions might be due to the mixing of seawater with the well water. The normal range of pH in well water was between 6.5 and 8.5 (BIS, 2010) and EPA (2009) recommends this range of pH as a good guide for individual well owners.

The salinity of well waters (Table 3a) of least and slightly affected regions during monsoon and summer seasons ranged between 52 and 98 ppm, which increased sharply reaching 268 to 482 ppm in moderately and severely affected regions. This increase might be due to the salt water intrusion from the sea to the land and its mixing with the well water. The permissible level of salinity in drinking water is 100 ppm, restriction on drinking water is 500 ppm and the maximum limit is 1000 ppm depending upon the proximity of drinking water source to seacoast (Ravishankar and Poongothai, 2008).

The electrical conductivity, hardness, free chlorine, fluoride, calcium, copper, zinc, and nickel concentrations in well waters of all the four regions during monsoon and summer seasons were below the prescribed standard limits (< 1400 m.mho cm^{-1} for EC: < 300 ppm for hardness; < 0.2 ppm for free chlorine; < 1.0 ppm for fluoride; < 75 ppm for calcium; < 0.05 ppm for copper; < 5 ppm for zinc; < 0.07 ppm for nickel) set for them in drinking water(Table 3a, b). However, a comparison of these parameters between the four regions indicated that the values of almost all the above mentioned parameters might have been high in moderately and severely-affected regions soon after Tsunami in 2004 which subsequently came down as years passed by.

The concentrations of phosphorus, manganese, iron, lead and cadmium in the well waters of all the four regions during monsoon and summer seasons were above the normal permissible limits set for them in drinking water (Table 3a, b). The phosphorus content in the well waters of least and slightly affected regions were just above (0.2 to 0.5 ppm) whereas the same in the well waters of moderately and severely affected regions were far above (1.0 to 1.9 ppm)

Table 2 : Rating values (Vr) for different factors to calculate water quality index (WQI)

Factors	**Five intervals**				
pH	6.5-8.5	8.6-8.8 6.4-6.2	8.9-9.0 6.1-5.9	9.1-9.3 5.8-5.6	> 9.3 < 5.6
Salinity	0-100	101-150	151-200	201-250	> 250
EC	0-1400	1401-1500	1501-1600	1601-1700	> 1700
Hardness	0-300	301-350	351-400	401-450	> 450
Free chlorine	0-0.2	0.3-0.5	0.6-0.8	0.9-1.1	> 1.1
Fluoride	0-1.0	1.1-1.3	1.4-1.6	1.7-1.9	> 1.9
Calcium	0-75	76-100	101-125	126-150	> 150
Copper	0-0.05	0.06-0.08	0.9-0.11	0.12-0.14	> 0.14
Zinc	0-5	6-8	9-11	12-14	> 14
Phosphorus	0-0.1	0.2-0.3	0.4-0.5	0.6-0.7	> 0.7
Manganese	0-0.1	0.2-0.3	0.4-0.5	0.6-0.7	> 0.7
Iron	0-0.3	0.4-0.6	0.7-0.9	1.0-1.2	> 1.2
Lead	0-0.05	0.06-0.08	0.09-0.11	0.12-0.14	> 0.14
Cadmium	0-0.01	0.02-0.03	0.04-0.05	0.06-0.07	> 0.07
Sodium	0-20	21-30	31-40	41-50	> 50
Potassium	0-8	9-11	12-14	15-17	> 17
Chromium	0-0.05	0.06-0.08	0.09-0.11	0.12-0.14	> 0.14
Nitrate-nitrogen	0-10	11-15	16-20	21-25	> 25
Nitrate	0-45	46-50	51-55	56-60	> 60
Magnesium	0-0.1	0.2-0.3	0.4-0.5	0.6-0.7	> 0.7
Nickel	0-0.07	0.08-0.09	0.10-0.11	0.12-0.13	> 0.13
Rating (Vr)	100	80	60	40	0

All the values are in ppm except of EC (m.mho cm^{-1})

the permissible limit (<0.1 ppm) set for it in drinking water. The higher concentration of phosphorus in groundwater is an indication of contamination by sewage and industrial pollutants (Nair *et al*., 2006). Iron and manganese (Fe/Mn) are common in groundwater and iron is the most frequent of these two contaminants, but they often occur together. The range of concentration of iron (10 to 23 ppm in monsoon and 13 to 27 ppm in summer) and manganese (0.5 ppm to 18.6 ppm in monsoon, and 0.8 ppm to 22 ppm in summer) in well waters of all the four regions were well above the permissible limits (<0.3 ppm for iron, and <0.10 ppm for manganese) set for them in drinking water. Among the four regions, severely affected region recorded the high values of these parameters in both monsoon and summer seasons and the intrusion of seawater and sediments into the land carrying these and their mixing with the groundwater was suspected for the higher values of these factors in moderately and severely affected regions. Higher levels of iron and manganese in groundwater can result in discoloured water and an unpleasant metallic taste (Jamir *et al*., 2011) which were true in the well waters of these two regions.

The permissible limit set for lead in drinking water is <0.05 ppm. In the present study, the concentrations of lead in the well waters of all the four regions during monsoon and summer seasons were far above the permissible limit and the highest value (3.0 ppm during monsoon season) was recorded in the well waters of severely affected region (Table 3b). The leaching and mixing of lead in the well waters of moderately and severely affected regions were suspected since it is reported that lead rarely occurs naturally in groundwater and it usually gets into it from the delivery system (Multani, 2010). Cadmium concentration in the well waters of severely affected region was very high (0.11 and 0.12 ppm during monsoon and summer seasons respectively) and those of least, slightly and moderately affected regions were reasonably high (range : 0.02 ppm to 0.07 ppm) in monsoon and summer seasons when compared with the permissible limit set for it in drinking water (<0.01 ppm). Cadmium is a metal found in natural deposits such as ores containing other elements and the major source of cadmium in well water are erosion of natural deposits, discharge from metal refineries and run-offs from waste materials (Thomas *et al*., 2011).

Values of sodium, potassium and chromium in the well waters of moderately and severely affected regions were above, and those of least and slightly affected regions were below the permissible limits (< 20 ppm for sodium; < 8 ppm for potassium and < 0.05 ppm for chromium) set for them in drinking water (Table 3b). Higher values of sodium and potassium occur in groundwater as a result of erosion or saltwater intrusion when saltwater from the sea seeps into underground water supplies (Mahananda *et al*., 2010), a phenomenon that occurred in the well waters of moderately and severely affected regions soon after Tsunami. Higher levels of chromium in the well waters of these regions might be due to the movements of chromium-deposited sediments

Table 3 (a) : Physio-chemical characteristics of well waters of four regions of south-west coast of Kerala

	Water parameters studied	Water temp. (°C)	pH	Salinity	EC (m.mho cm^{-1})	Hardness	Free Cl	F	Ca	Cu	Zn	P	Mn
	Standard desirable limits set for drinking water	-	$\geq$ 6.5 -8.5	<100	<1400	<300	<0.2	<1.0	<75	<0.05	<5	<0.1	<0.10
Monsoon 2009	Least affected region	28.6	6.1	52	99	41	0.1	0.4	9	0.03	0.01	**0.2**	**0.5**
	Slightly affected region	28.5	5.8	82	161	39	0.1	0.2	11	0.02	0.04	**0.3**	**1.4**
	Moderately affected region	28.6	6.8	**268**	242	137	0.1	0.2	21	0.04	0.9	**1.4**	**2.4**
	Severely affected region	28.4	7.4	**482**	552	258	0.1	0.4	37	0.03	2.4	**1.4**	**18.6**
Summer 2010	Least affected region	28.6	5.8	46	144	29	0.1	0.1	11	0.01	0.01	**0.4**	**0.8**
	Slightly affected region	31.8	5.8	98	254	62	0.1	0.2	12	0.04	0.05	**0.5**	**2.1**
	Moderately affected region	29.6	6.6	**338**	299	168	0.1	0.3	23	0.03	1.1	**1.9**	**2.4**
	Severely affected region	30.9	7.1	**414**	464	294	0.2	0.3	39	0.04	2.5	**1.0**	**22**

The values exceeding the standard desirable limits set for drinking water are shown in bold. All values excepts temp., pH and EC are in ppm

Table 3 (b) : Physio-chemical characteristics of well waters of four regions of south-west coast of Kerala

	Water parameters studied	Fe	Pb	Ca	Na	K	Cr	NO_3^--N	NO_3^-	Mg	Hg	Ni
	Standard desirable limits set for drinking water	<0.3	<0.05	<0.01	<20	<8	<0.05	<10	<45	<30	<0.001	<0.07
Monsoon 2009	Least affected region	**10**	**1.7**	**0.02**	8.5	1.1	0.01	6	26	3	0.0	0.004
	Slightly affected region	**14**	**0.6**	**0.04**	16	1.8	0.02	5	22	6	0.0	0.007
	Moderately affected region	**15**	**1.9**	**0.05**	**64**	**9.3**	**0.40**	9	40	20	0.0	0.01
	Severely affected region	**23**	**1.9**	**0.11**	**112**	**10.2**	**1.30**	**11**	**49**	**34**	0.001	0.02
Summer 2010	Least affected region	**13**	**2.0**	**0.02**	12	1.3	0.01	4	26	4	0.0	0.002
	Slightly affected region	**23**	**0.8**	**0.05**	16	2.7	0.03	4	28	7	0.0	0.004
	Moderately affected region	**16**	**1.7**	**0.07**	**80**	**11.5**	**0.55**	9	40	23	0.0	0.01
	Severely affected region	**27**	**3.0**	**0.12**	**115**	**13.7**	**1.50**	**12**	**49**	**39**	**0.003**	0.02

The values exceeding the standard desirable limits set for drinking water are shown in bold. All values are in ppm

from the sea into the land and later its leaching from the sediments and mixing with the well water. It is reported that chromium compounds are very persistent in water as sediments and there is a high potential for accumulation of chromium in aquatic life (Brindha *et al*., 2010).

Nitrate-nitrogen, nitrate and magnesium concentrations in the well waters of severely affected region in monsoon and summer seasons were moderately above the permissible limits set for them (< 10 ppm for nitrate nitrogen; < 45 ppm for nitrate and < 30 ppm for magnesium) in the drinking water (Table 3b). However, the values of these factors in least, slightly and moderately affected regions did not cause much concern. Traces of mercury were detected in the well waters of severely affected region in both seasons (0.001 ppm during monsoon and 0.003 ppm during summer) and this metal was totally absent in the well waters of other three regions. Nitrate-nitrogen and nitrate in groundwater may result from point sources such as sewage disposal system and non-point sources (Hallberg and Keeney, 1993). Complete breakdown of sewage disposal system as a result of Tsunami and the subsequent mixing of sewage with intruding sea water and seeping down and mixing with the well water might be the main reason in their elevated values in severely affected region. The increase in magnesium concentration (34 ppm during monsoon and 39 ppm during summer) in the well waters of severely affected region might be due to the mixing of intruding seawater having high magnesium concentration to land and its mixing with the well water. The source of mercury in the well waters of severely affected region is not very clear. But the Cochin Industrial belt located some 50 to 80 km from the severely affected region discharges its effluents into the sea and there was every possibility that these industrial wastes contained mercury compound also. During Tsunami, the sediments containing mercury compounds might have been

Table 4 : Water quality index of well waters of four regions of south-west coast of Kerala

Tsunami affected region	Season	WQI	Inference
Least	Monsoon 2009	75.75	Moderately polluted
	Summer 2010	71.83	Moderately polluted
Slightly	Monsoon 2009	63.00	Moderately polluted
	Summer 2010	62.06	Moderately polluted
Moderately	Monsoon 2009	49.33	Excessively polluted
	Summer 2010	39.52	Severely polluted
Severely	Monsoon 2009	19.98	Severely polluted
	Summer 2010	19.97	Severely polluted

brought to the sites through severe underwater currents and later lashed into the land and mixed with well water. Inorganic mercury compounds are the most common forms of mercury found in drinking water and this metal can seep into underground water supplies from industrial and hazardous wastes (Carr and Neary, 2006).

Based on the water quality index of well waters of four regions, the well waters of least and slightly affected regions (WQI values were 75.75 during monsoon and 71.83 during summer in least affected region, and 63.00 and 62.06 during monsoon and summer seasons respectively in slightly affected region) were moderately polluted. However, the well waters of moderately affected region were excessively polluted (WQI = 49.33) during monsoon and severely polluted (WQI = 39.52) during summer seasons. The well waters of severely affected region were severely polluted both during monsoon (WQI = 19.98) and summer (WQI = 19.97) seasons.

Moderately polluted well waters of least and slightly affected regions require suitable treatments such as filtration, chlorination, alum treatment, aeration, neutralization, softening and chemical precipitation to minimise contamination and make them fit for drinking. The well waters of moderately and severely polluted regions which were categorized as excessively or severely polluted, are not potable. The water is much degraded and is unsafe for public health. As a precautionary measure, it is suggested that people residing in these regions should not be allowed to drink water directly from the wells located here.

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References

Achari, V., C.A. Jaison, P.M. Alex, A.P. Padmakumar, P. Seralathan and E. Shaji: Groundwater Quality: A study of the Tsunami-affected Arattupuzha Coast, Kerala. Proc. Intl. Conf. on Natural Hazards and Disasters: Local and Global Perspectives, Sri Krishna Devarayar University, Ananthapur (2006).

Anputhes, M., R. Ariyaratne, N. Gamage, P. Jayakody, K. Jinapala, P.G. Somaratne, P. Weligamage, N. Weragata and D. Hambantota: Bringing Hambantota back to Normal: A Post-tsunami livelihoods need assessment of Hambantota District in Southern Sri Lanka, Colombo, Sri Lanka. *IWMI*, 55pp (2005)

BIS: Drinking Water Specification (Second Revision of IS 10500). Bureau of Indian Standards, New Delhi (2010).

Brindha, K., L. Elango and V.G. Rajesh: Occurrence of chromium and copper in groundwater around cannaries in Chromepet area of Tamilnadu. *Ind.. J. Environ. Prote.*, **30**, 818-822 (2010).

Carr, G.M. and J.P. Neary: Water Quality for Ecosystem and Human Health. UNEP (2006).

Clasen, T., and L. Smith: The drinking water response to the Indian Ocean Tsunami including the role of household water treatment. *Water, Sanitation and Health: Protection of the Human Environment: WHO, Geneva,* 5-32 (2005).

EPA: Drinking Water Contaminants. National Primary Drinking Water Regulations. United States Environmental Protection Agency Publication, p. 237 (2009).

Hallberg, G.R. and D.R. Keeney: Nitrate. *In:* Regional Groundwater Quality (Ed.: A. William). Van Nostrand Reinhold, New York pp 297-322 (1993).

IGRAC: Impact of the 24-12-04 tsunami on groundwater systems and groundwater-based water supplies. International Groundwater Resource Assessment Centre (available at http://igrac.nitg.tno.nl/tsunami2-1.html) (2005).

IUCN and IWMI: Series on Best Practice Guidelines (Sri Lanka). After the Tsunami: Water Pollution. Information paper No.11, http://www.iucnorg/places/srilanka)/images/information%20paper%20 water %20 pollution %20 paper1.pdf. (2005).

Jamir, T.T., W.B. Devi, U.I. Singh and R.K.B. Singh: Lead, iron and manganese contamination in spring pond and well water in Nagaland, one of the seven North-Eastern States of India, A future danger. *J. Chem. Pharama. Res.*, **3**, 403-411 (2011).

Kaur, H., J. Syal and S.S. Dhillon: Water quality index of the river Sutlej. *Poll. Res.*, **20,** 199-204 (2001).

KSCSTE: Environmental Impact of Tsunami in the Kerala Coast. KSCSTE Publication, p. 153 (2006).

Kurian, N.P. and T.N. Prakash: Tsunami: An analysis of its impact on the Kerala Coast. Proc. National Conference, *HYDRO*, Indian Society of Hydraulics, pp.46. (2005).

Mahananda, M.R., V.R. Mohanty and N. Behera: Physico-chemical analysis of surface and groundwater of Bargarh district, Orissa India. *Int. J. Res. Revi. App. Sci.*, **2**, 284-295 (2010).

Multani, A.: Lead contamination of drinking water in India due to PVC pipes. *Lead Action News*, **10**, 21-28 (2010).

Nair, G.A., J.A.Bohjuari, M.A.Al-Mariami, F.A.Attia and F.F.El-Toumi: Ground water quality of north-east Libya. *J. Env. Biol.,* **27,** 695-700 (2006).

Nair, G.A., A.I. Mohamed, M.M. Fadiel, M.A. Al-Mariami, J.A. Bohjuari and K. Premkumar: Physico-chemical parameters and correlation co-efficients of groundwaters of north-east Libya. *Poll. Res.*, **24,** 1-6 (2005).

Panabokke, C.R. and A.P.G.R.L. Perara***:*** Impact of Tsunami on groundwater, soils and vegetation in coastal regions of Sri Lanka. Paper presented at the NSF Workshop: Ground water Resources of Sri Lanka, Kandy (2005).

Ravisankar, N. and S. Poongothai: A study of groundwater quality in Tsunami affected areas of Sirkazhi Taluk, Nagapattinam District, Tamil Nadu, India. *Sci. Tsun. Haz.,* **27,** 47-55 (2008).

Thomas, D.R., V. Sunil and C. Latha: Assessment of seasonal variation on physico-chemical and microbiological quality at Mannuthy, Kerala. *Inter. J. Chem, Environ. Pharama. Res.,* **2**, 135-40 (2011).

UNICEF: Consequences of the Tsunami on the Coastal Aquifer in Eastern Sri Lanka Guidelines on wells rehabilitation. Trincomalee. (2005).

Villholth, K.G., H.Amerasinghe, P. Jeyakumar, C.R. Panabokke, O. Woolley, M.D. Weerasinghe, N. Amalraj, S. Pratapan, N. Burgi, D.M.D.S. Lionelrathne, N.G. Indrajit and S.R.K. Pathirana: Tsunami impacts on shallow groundwater and associated water supply on the east coast of Sri Lanka. International Water Management Institute. (http.//www.iwmi.org) 1-75 (2005).

Violette, S., G. Boulicot and S. Gorilick: Tsunami-induced groundwater salinisation in south-eastern India. *Comptes Rendus Geoscience,* **341**, 339-346 (2009).