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Heavy Metal Removal from Municipal Raw Sewage by Activated Sludge Treatment Process and Effects of Sewage on the Metal Contents of Buckingham Canal Water across Different Seasons at Kalpakkam (India)

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Abstract: Removal of heavy metals (Zn, Pb, Cu, Ni and Cr) from municipal raw sewage by extended aeration activated sludge treatment process and the effects of the treated effluent in relation to the raw sewage on the heavy metal contents of water of the receiving water body, Buckingham canal at Kalpakkam was monitored seasonally during pre-monsoon, monsoon, winter and summer. It was found that the concentrations of Zn, Pb, Cu, Ni and Cr were 0.12, 0.063, 0.57, 0.63 and 0.019 ppm, respectively in the raw sewage, which were reduced considerably at each phase of the treatment, at aeration tank with a removal efficiency (RE) of 17, 13, 14, 33 and 31%, respectively, and in secondary clarifier with RE of 67, 73, 72, 87 and 47%, respectively. The concentrations of these heavy metals have increased in the downstream compared to that of its upstream of the canal in both treated as well as untreated sewage outfall zones, and were higher in the later zone. The concentrations of these heavy metals were higher during pre-monsoon and monsoon seasons followed by that of summer and winter in the canal water.

Key words: Municipal sewage, heavy metals, Zn, Pb, Cu, Ni, Cr, Buckingham canal, activated sludge treatment process.

Introduction

Municipal sewage, both treated and untreated, contains heavy metals in insoluble and soluble forms and upon interaction with organic fractions of sewage form insoluble salts of hydroxides, carbonates and phosphates (Reddy and Vijay Kumar, 2003; Stoveland et al., 1979). Presence of the heavy metals in the municipal sewage and sewage treatment systems is of concern because of their discharge into receiving water bodies as perilous effluents (Oliver and Cosgrave, 1974). These are removed from the raw sewage during the primary sedimentation and activated sludge treatment process of sewage. Their removal at the sedimentation stage is dependent upon their presence in an insoluble form or in a form that permits it to bind to the settleable solids. Most of the metals are removed at each of the stages of the sewage treatment plant (STP), resulting in the effluents containing traces of these elements. Considerable variations are seen from one circumstance to other even at the same STP; however, the factors that cause these variations are little understood (Oliver and Cosgrave, 1974; Stoveland et al., 1979).

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Depending upon the concentration of heavy metals there may be adverse effects on aquatic ecosystem and its biodiversity and more significantly the water might be polluted to such a degree that it would violate the standards for the maximum permissible limits of heavy metals in potable water (WHO, 1971). Many rivers and urban canals have high heavy metal concentrations (Vaithiyanathan et al., 1993; DWASA, 1998; Fytianos et al., 2002; Fernandez et al., 2003; Dutta et al., 2005); for example, the Yamuna river received a large amount of untreated municipal sewage containing Ni, Cr and Hg through several drains of Delhi (Rawat et al., 2003; Subramanian, 2004). These are persistent pollutants often accumulated and may gradually pass into the food chain, posing considerable health risks to human beings and animals (Weiner, 2000). Abbot (1971) reported the distribution of heavy metals in STPs in North America and their removal during primary and secondary treatment. Chekushin et al. (1993) reported the effects of municipal wastewater on metal content in Neris and Nenubas river in Lithuania. Gueguen et al. (2000) reported the effects of effluents from STP on the metal contents of Vistula river in Poland. Fernandez et al. (2003) reported the spatio-temporal variation of heavy metal contents of Llobregat river in Spain. Jardao et al. (2005) reported the influence of domestic and industrial discharges on water quality at Minas Gerairs in Brazil. Fytianos et al. (2002) reported about the temporal variation of Pb, Cr, Cu, Ni in Pinios river in Greece.

Mitra and Gupta (2000) assessed the heavy metals such as Zn, Pb, Cr in the raw and treated sewage effluents from some selected treatment plants within the Kolkata metropolitan area in India. However, information on the removal of heavy metals from the municipal raw sewage through the sewage treatment process (Kulbat et al., 2003) and temporal variation of these metals in the receiving water bodies in tropical countries particularly in Asia including India is too little. The present study reports on the removal efficiency of the concentrations of Zn, Pb, Cu, Ni and Cr from municipal raw sewage during treatment in the extended aeration activated sludge treatment process and the temporal effects of treated and untreated sewage on the heavy metal contents of the water of the receiving water body, the Buckingham canal at Kalpakkam.

Material and Methods

Description of Study Area and Sampling Sites

Kalpakkam (12º 30" N and 80º 10" E) is a small town situated 65 km south of Chennai, the capital of Tamil Nadu (India) and is the residence to more than seventy five thousand people. It has the Madras Atomic Power Station (MAPS), one of India's nuclear power plants and the Indira Gandhi Centre for Atomic Research (IGCAR). The Buckingham canal passes through the town. The details of the canal that runs parallel to the Coromandal Coast are illustrated in Kumar and Reddy (2008a). This town produces 0.6 million gallons of sewage per day, which is treated with a conventional extended aeration activated sludge treatment process (STP). The detailed description of the STP is depicted in Kumar and Reddy (2008b). The treated sewage from the STP and the untreated raw sewage from the adjacent Pudhupattinam town are released into the canal.

The outfall points of the treated and untreated sewage in the canal and their respective up and down stream points were monitored seasonally for concentrations of the heavy metals—Zn, Pb, Cu, Ni and Cr. Sampling point 1 is of the municipal raw sewage (RS) entering the STP; sampling points 2 and 3 were chosen at the STP, the former point being at its aeration tank (AT) and the later point at the secondary clarifier (SC). Another three sampling points 4, 5 and 6 were chosen in the canal, the 4th one being the outfall point of Treated Effluent (TE-OP), 5th one is its downstream point (TE-DS) and the 6th one is its upstream point (TE-US). Three more sampling points 7, 8 and 9 were chosen at the portion of the canal at the Pudhupattinam area, the 7th one being the outfall point of untreated raw sewage (RS-OP), the 8th one being the downstream of the untreated raw sewage (RS-DS) and the 9th one was the upstream of the untreated sewage (RS-US) in the canal, each point being about half a kilometre away from outfall points.

Sample Collection and Its Analysis

The samples were collected from all the nine points seasonally—pre-monsoon (July), monsoon (October), winter (January) and summer (April) during July 2005 to November 2006 in the pre-cleaned tarson polypropylene bottles and soon stored in a cold room at 4ºC to avoid any chemical interaction taking place in the bottles. Suspended materials were filtered out from the RS as well as canal water samples using 0.45 mm filter paper. The concentrations of heavy metals were analyzed using Atomic Absorption Spectrometry (AAS) of GBC 902 make.

Results and Discussion

Heavy Metal Removal from Municipal Raw Sewage by Treatment Process

During the present study it was found that the concentrations of Zn, Pb, Cu, Ni and Cr in RS ranked in

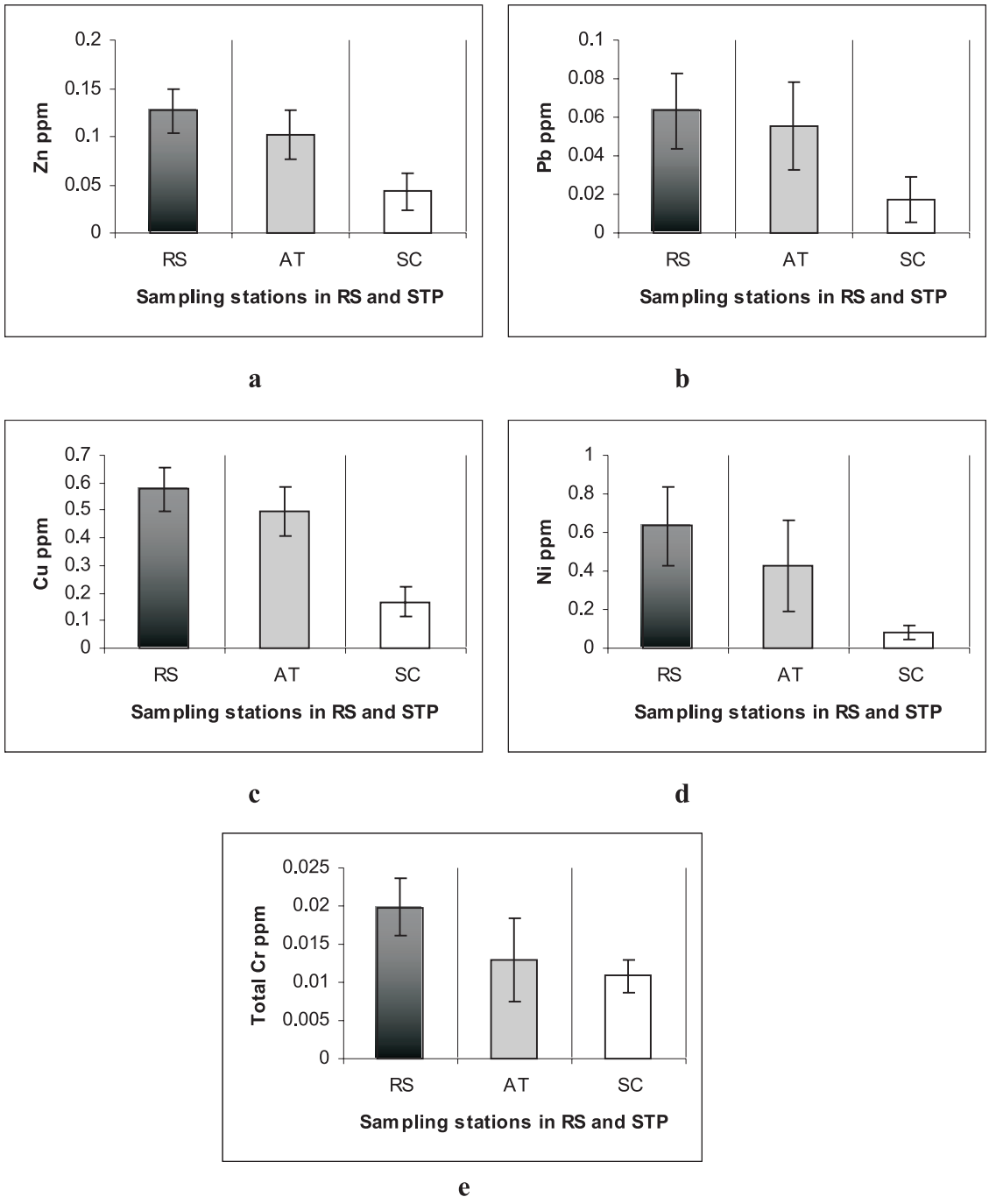

Figure 1: Average removal of heavy metals of municipal raw sewage in the aeration tank (AT) and secondary clarifier (SC) of the STP: (a) Zn, (b) Pb, (c) Cu, (d) Ni and (e) Total Cr.

the order Ni>Cu>Zn>Pb>Cr; and that in the treated effluents released from the secondary clarifier of STP ranked in the order Cu>Ni>Zn>Cr >Pb (Figure 1). There was a considerable decrease in average concentration of these metals in each stage of STP; at AT the Zn, Pb, Cu, Ni and Cr were removed by Removal Efficiency (RE) of 17, 13, 14, 33 and 31%, respectively and at SC with a RE of 67, 73, 72, 87 and 47% respectively. ANOVA of the concentrations of heavy metals across the three sampling points and the seasons showed significant spatio-temporal variations (Zn: $P<0.0001$; Pb and Ni: $P<0.07$; Cu and Cr: $P<0.05$). It clearly showed the significance of SC of the STP in the removal of heavy metal from raw sewage.

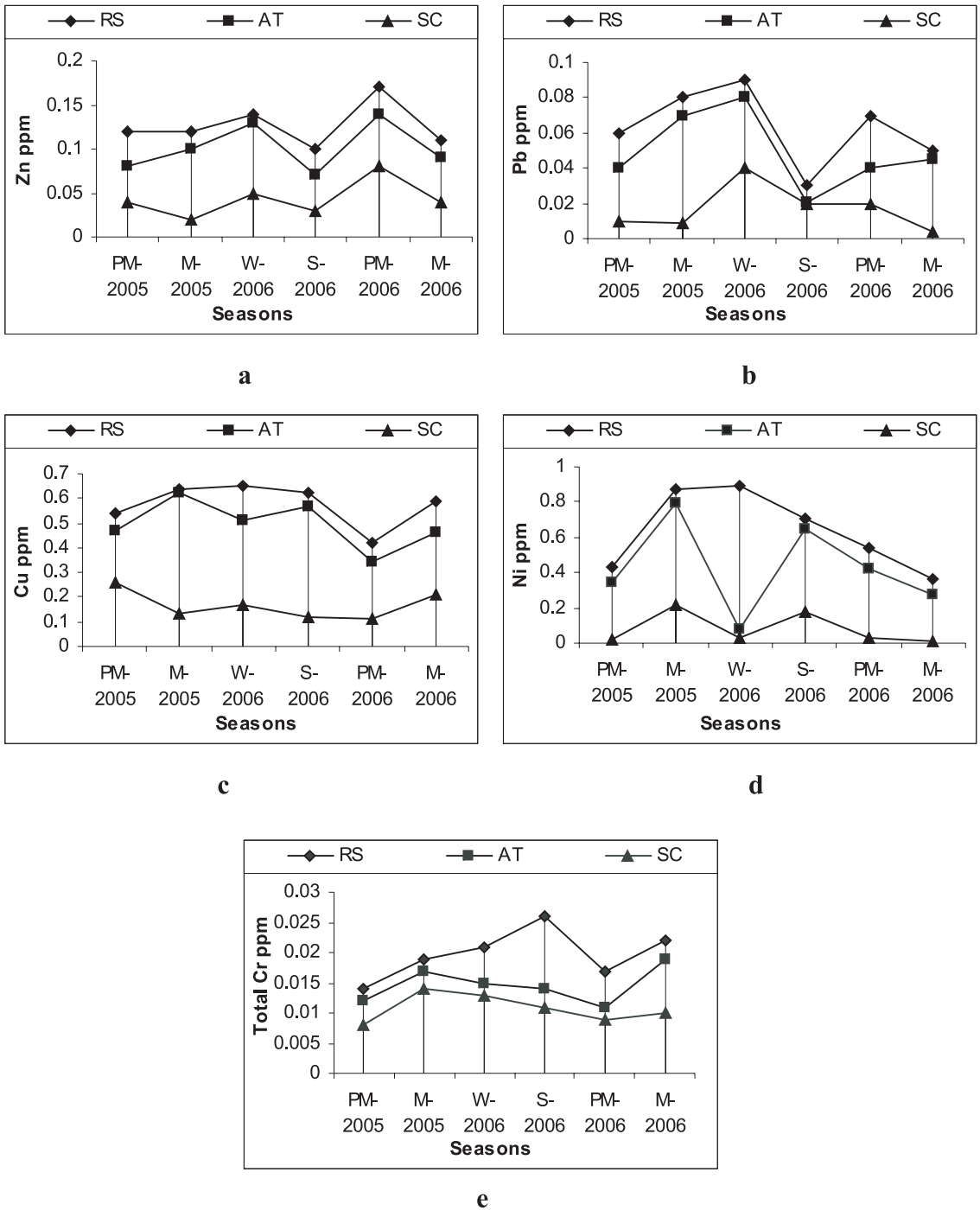

Figure 2: Temporal variation in removal of heavy metals from the municipal raw sewage in the aeration tank (AT) and secondary clarifier (SC) of the STP - (a) Zn, (b) Pb, (c) Cu, (d) Ni and (e) Total Cr.

Zinc: Its average concentration in the influent RS was reduced by a RE of 17% in AT and 67% in SC in the STP (Figure 1a). In the pre-monsoon season of 2005 its concentration in municipal RS decreased by a RE of 33% in AT and 66% in SC. In the monsoon season of 2005 its concentration in RS decreased by a RE of 16% in AT and 83% in SC. In the winter season 2006, its concentration in RS decreased by a RE of 7% in AT and 64% in SC. In the summer season 2006, its concentration in RS decreased by a RE of 30% in AT and 70% in SC. In the following pre-monsoon season 2006 its concentration in RS decreased by a RE of 18% in AT and 53% in SC and in following monsoon season 2006 its concentration in RS decreased by a RE of 18% in AT

and 64% in SC (Figure 2a). In consistence with the present findings, Stoveland et al. (1979) reported decrease in Zn by 60% at the Day Hulme STP in Manchester (UK). Gueguen et al. (2000) reported that Zn, Cu and Pb reduced by 80–100% in the effluent from the Plaszow STP.

Lead: Its average concentration in the influent RS decreased by a RE of 13% in AT and 73% in SC (Figure 1b). In the pre-monsoon season of 2005 its concentration decreased by a RE of 33% in AT and 83% in SC. In the monsoon season - 2005 its concentration in RS decreased by a RE of 13% in AT and 88% in SC. In the winter season 2006 its concentration in RS decreased by a RE of 11% in AT and 56% in SC. In the summer season 2006 its concentration in RS decreased by a RE of 30% in AT and 33% in SC. In the following pre-monsoon season of 2006 its concentration in RS decreased by a RE of 43% in AT and to 72% in SC and in following monsoon season 2006 its concentration in RS decreased by a RE of 10% in AT and to 92% in SC (Figure 2b).

Copper: Its average concentration in the influent RS decreased by a RE of 14% in AT and to 72% in SC (Figure 1c). In the pre-monsoon season of 2005 its concentration in RS decreased by a RE of 12% in AT and to 52% in SC. In the monsoon season 2005 its concentration in RS decreased by a RE of 3% in AT and 79% in SC. In the winter season 2006 its concentration in RS decreased by a RE of 22% in AT and 74% in SC. In the summer season of 2006 its concentration in RS decreased by a RE of 8% in AT and 80% in SC. In the following pre-monsoon season 2006 its concentration in RS decreased by a RE of 19% in AT and 74% in SC and in the following monsoon season - 2006 its concentration in RS decreased by a RE of 22% in AT and 64% in SC (Figure 2c).

Nickel: Its average concentration in the influent RS decreased by a RE of 33% in AT and 87% in SC (Figure 1d). In the pre-monsoon season of 2005 its concentration in RS decreased by a RE of 21% in AT and 51% in SC. In the monsoon season of 2005 its concentration in RS decreased by a RE of 9% in AT and 75% in SC. In the winter season 2006 its concentration in RS decreased by a RE of 28% in AT and 70% in SC. In the summer season 2006 its concentration in RS decreased by a RE of 10% in AT and 75% in SC. In the following pre-monsoon season of 2006 its concentration in RS decreased by a RE of 22% in AT and 95% in SC and in the following monsoon season 2006 its concentration in RS decreased by a RE of 25% in AT and 97% in SC (Figure 2d). In consistence with the present findings, Stoveland et al. (1979) reported that the RE for Ni during primary sedimentation varied from 0 to 40% and during activated sludge treatment from 0 to 100%. The heavy metals like Ni can form volatile metal-organic complexes in the natural environment by microbial mediation (Reddy and Vijay Kumar, 2003; Weiner, 2000) volatilization being an important removal mechanism.

Total chromium: Its average concentration in the influent RS decreased by a RE of 31% in AT and 47% in SC (Figure 1e). In the pre-monsoon season of 2005 its concentration in RS decreased by a RE of 14% in AT and 42% in SC. In the monsoon season of 2005 its concentration in RS decreased by a RE of 11% in AT and 26% in SC. In the winter season 2006 its concentration in RS decreased by a RE of 29% in AT and 61% in SC. In the summer season 2006 its concentration in RS decreased by a RE of 17% in AT and 35% in SC. In the following pre-monsoon season of 2006 its concentration in municipal RS decreased by a RE of 35% in AT and 47% in SC and in the subsequent monsoon season 2006 its concentration in RS decreased by a RE of 14% in AT and 55% in SC (Figure 2e).

Oliver and Crosgrove (1974), in consistence with the present findings, reported the removal of 50% of Zn, 70% Pb, 60% Cu and 1% of Ni by wastewater treatment plant. Stoveland et al. (1979) showed primary sedimentation removing 41% of Zn, 21% of Ni and 28% of Cr at Shalford Sewage Treatment Works; while the activated sludge treatment process removed 60% of Zn, 27% of Ni, 70% of Cr at Daughalmt Sewage Treatment Works at Manchester (UK). Mitra and Gupta (2000) reported 0.07, 0.17 and 0.012 ppm of Cu, Pb and Cr, respectively in the raw sewage at Kolkata, and with a RE of 49, 60 and 67% of Pb, Cu and Cr, respectively in the secondary treated sewage. Kulbat et al. (2003) reported the average reduction rates was 86.2 and 80.7% for Zn, 83 and 48% for Pb, 93.2 and 78.1% for Cu and 66.7 and 45.3% for Cr in 2000 and 2001, respectively during the wastewater treatment process. The SC is found to be of greater significance for removal of heavy metals from sewage in the STP. The removal of metals was probably through adsorption of dissolved metals and fine particulate matter to the sludge flock (Oliver and Crosgrove, 1974). Our findings showed that the removal efficiency of Zn, Pb, Cu and Ni in the sewage treatment plant at Kalpakkam, is relatively better than that at Kolkata metropolitan area.

Effects of Sewage on the Heavy Metal Contents of Canal Water

The average heavy metal contents in the TE and RS at their respective out-fall points as well as at their downstream points in the canal were of similar ranking order i.e., Cu>Ni>Zn>Pb>Cr, while that of the upstream was in the ranking order of Ni>Cu>Zn>Pb>Cr. It was

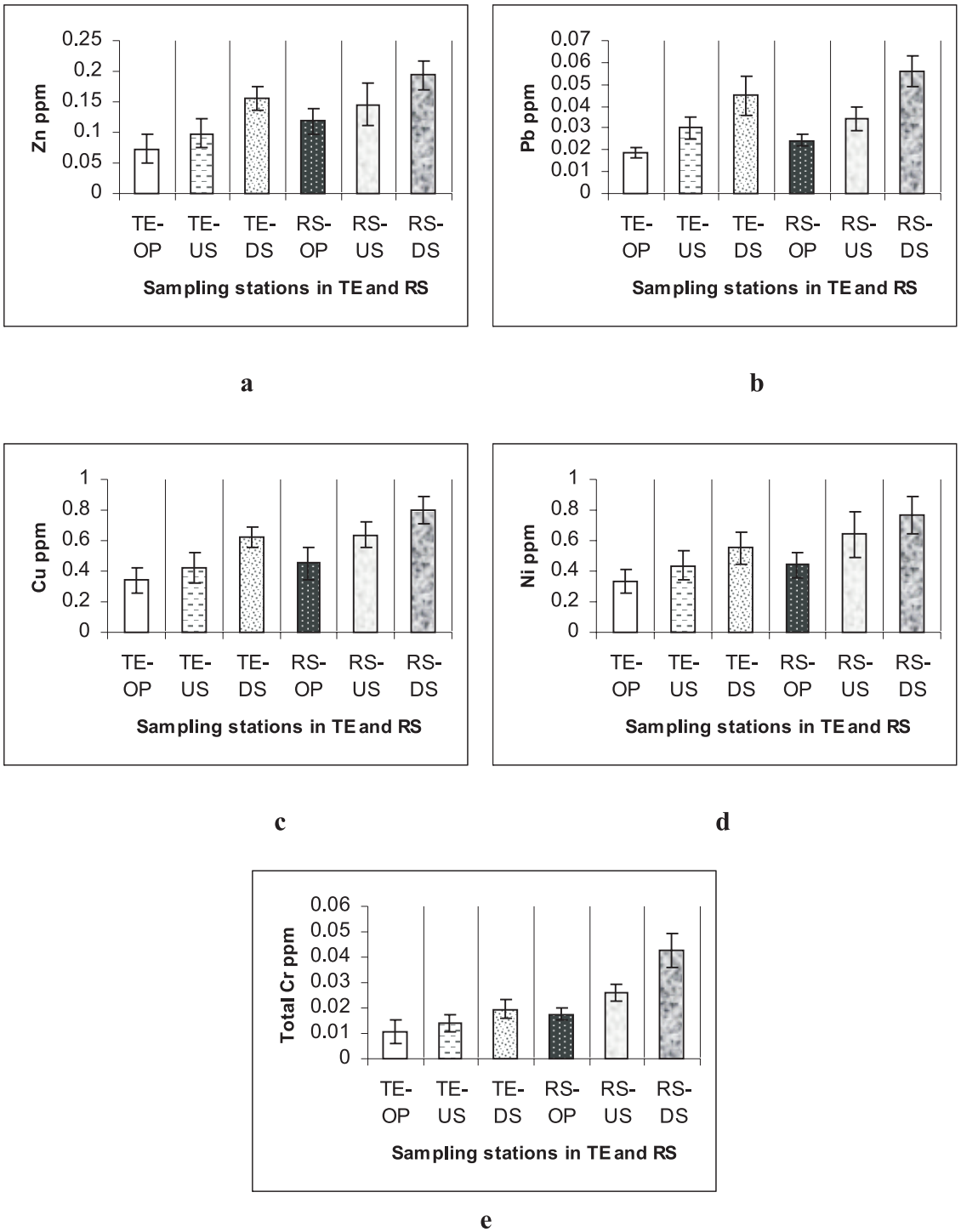

Figure 3: Average concentration of heavy metals in the treated effluent and raw sewage in the Buckingham canal: (a) Zn, (b) Pb, (c) Cu, (d) Ni and (e) Total Cr.

found that the heavy metals, Zn, Pb, Cu, Ni and Cr, increased by 1.6, 1.5, 1.48, 1.3 and 1.46 folds and by 1.36, 1.64, 1.3, 1.2 and 1.4 folds, respectively in the downstream compared to that of the upstream of the outfall points of the treated and untreated sewage, respectively in the canal (Figure 3). The phenomenal increase in the downstream points are most probably because of the flow of the treated and untreated sewage along with the water in the canal; and also probably due to the discharge of storm water, untreated domestic

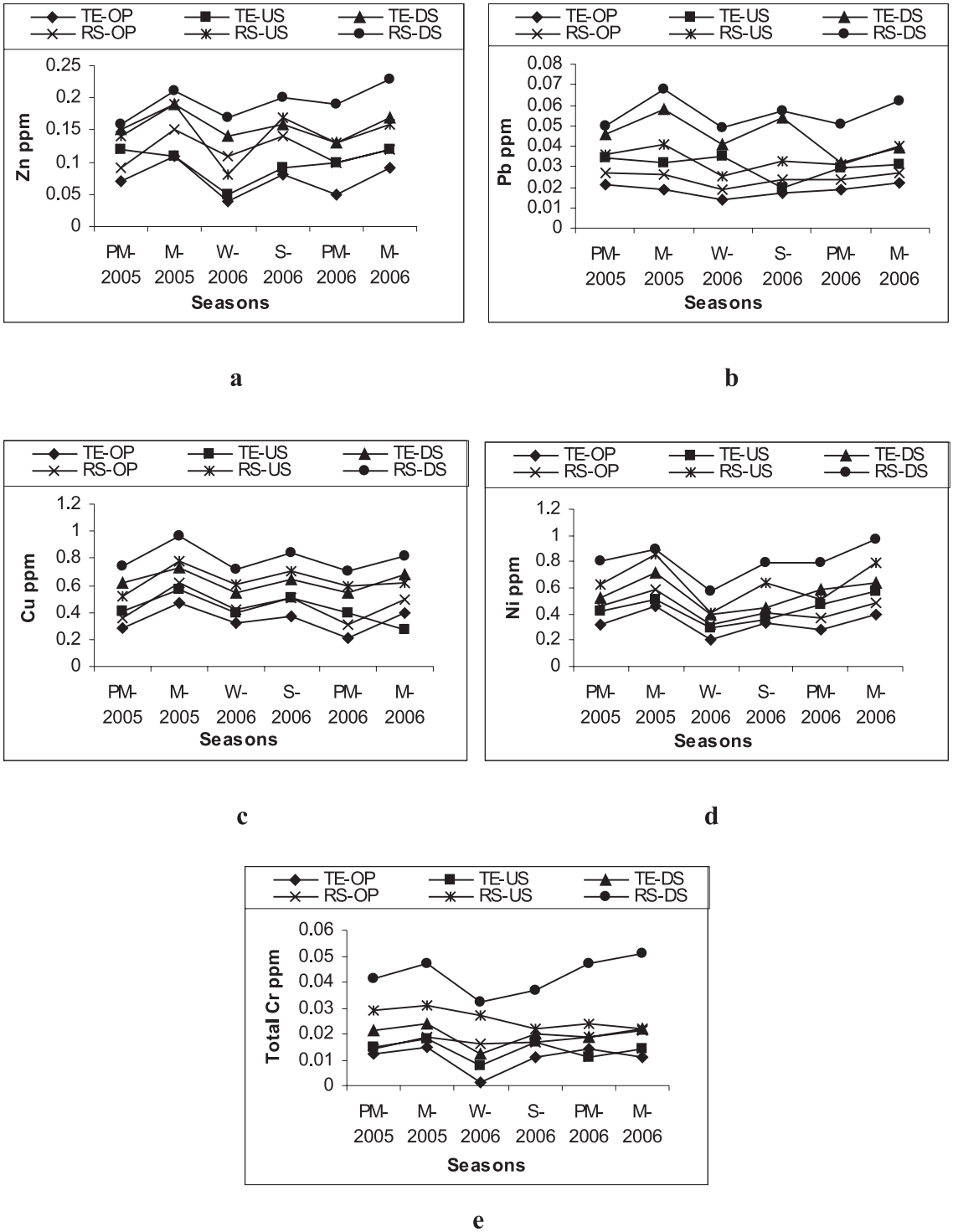

Figure 4: Spatio-temporal variation in heavy metal content of the treated effluent and municipal raw sewage at the outfall point and that at upstream and downstream of the Buckingham canal: (a) Zn, (b) Pb, (c) Cu, (d) Ni and (e) Total Cr.

sewage and fecal matter into the canal directly by the human population inhabiting slum areas along its banks. Chekushin et al. (1993), in consistence with the present findings, reported higher concentrations of metals in the Neris and Nenubas rivers in Lithuania due to release of municipal wastewater. Similarly, Gueguen et al. (2000) reported increase in total metal concentrations at the downstream than that of the upstream station, and were

of 5.1, 1.6 and 1.4 times for Pb, Zn and Cu, respectively in Vistula river at Cracow (Poland). They further reported that the particulate metal fraction increased from upstream to downstream which formed metallic complexes with Cu, Zn and Pb, and have also reported increased concentration of Zn and Cu in the downstream compared to its upstream station of Lambro river.

Dutta et al. (2005) reported higher concentration of Zn in downstream than that of the upstream in river Ganga attributing to heavy rainfall and addition of storm water from the region. They further reported higher mean concentration of Pb in water on the downstream of the river Ganga and attributed the increase in concentration due to the higher density of human population along the Hooghly estuary towards Kolkata releasing increased volume of domestic sewage into the river, which may be the reason of higher Pb content in water in the downstream compared to its upstream. Fernandez et al. (2003), in corroboration to the present findings, also reported increased Pb, Cr, Ni, Cu and Zn in downstream in Llobregat river in Spain and attributed to increasing human activities.

The concentrations of Zn, Pb, Cu, Ni and Cr in canal water were higher during pre-monsoon and monsoon followed by summer and winter (Figure 4). ANOVAS of these concentrations at TE-OP and that of TE-DS and TE-US showed significant seasonal variation (Zn and Cu: $P<0.05$; Ni and Cr: $P<0.0001$), and at RS-OP and the RS-US and RS-DS (Zn and Ni: $P<0.0001$; Pb: $P<0.007$). Gaur et al. (2005), in corroboration to the present findings, recorded seasonal variations in concentration of heavy metals in the water of Gomuti river in India.

Zinc: Its average concentration increased by 53% at TE-DS point and was higher than that of TE-OP and that of the TE-US point. It increased by 42% in RS-DS than that of the RS-OP, and was higher than the RS-US (Figure 3a). In pre-monsoon season of 2005 its concentration was lower than monsoon season of 2005 and increased by 50% in the TE-DS than that of the TE-OP, and was higher than the TE-US (Figure 4a). It also increased by 44% in the RS-DS and was higher than that of the RS-OP and RS-US. Its concentration was higher in monsoon season 2005 and increase by 42% at the TE-DS than that of the RS-OP, and was higher than the TE-US. It also increased by 28% in the RS-DS than that of the RS-OP and was higher than the RS-US point. Its concentration in winter season 2006 decreased at TE-OP, which increased by 71% in the TE-DS compared to that of the TE-OP and was higher than the TE-US.

It also increased by 35% at the RS-DS compared to that of the RS-OP, and was higher than the RS-US. Its concentrations in summer season of 2006 was higher than that of the winter of 2005 and increased by 50% in the TE-DS compared to that of the TE-OP, and was higher than the TE-US. It also increased by 30% in the RS-DS than that of the RS-OP, and was higher than the RS-US. Its concentration was lower in the pre-monsoon season 2006 than the previous pre-monsoon 2005 and increased by 61% in the TE-DS compared to that of the TE-OP, and was higher than the TE-US, and by 47% in the RS-DS compared to that of the RS-OP and was higher than the RS-US. Its concentration was lower in the monsoon season of 2006 than the previous monsoon of 2005; it increased by 47% at the TS-DS than that of the TE-OP and was higher than the TE-US; and by 48% in the RS-DS than that of the RS-OP and was higher than the RS-US point (Figure 4a).

Lead: Its average concentration increased by 60% in the TE-DS point compared to that of the TE-OP and was higher than that of the TE-US point. It also increased by 57% in the RS-DS than that of the RS-OP, and was higher than the RS-US (Figure 3b). In pre-monsoon season of 2005 its concentration was lower than monsoon season of 2005; but increased by 54% in the TE-DS compared to that of the TE-OP, and was higher than the TE-US and by 46% in the RS-DS than that of the RS-OP being higher than the RS-US (Figure 4b). Its concentration was higher in monsoon season 2005 and increased by 67% at the TE-DS than that of the TE-OP and was higher than the TE-US. It also increased by 40% in the RS-DS than that of the RS-OP and was higher than the RS-US. Its concentration in winter season 2006 decreased at TE-OP, but increased by 65% in the TE-DS and was higher than that of TE-US and by 48% at the RS-DS compared to that of the RS-OP and was higher than the RS-US.

Its concentrations in summer season of 2006 increased compared to that of the winter of 2005. It increased by 69% in the TE-DS than that of the TE-OP and was higher than the TE-US and by 58% in the RS-DS than that of the RS-OP and was higher than the RS-US. Its concentration was lower in the pre-monsoon season of 2006 than the previous pre-monsoon of 2005, but increased by 41% in the TE-DS than that of the TE-OP and was higher than the TE-US. It also increased by 53% in the RS-DS compared to that of the RS-OP, and was higher than the RS-US. Its concentration was lower in the monsoon season of 2006 than the previous monsoon of 2005; but increased by 44% at the TE-DS than that of the TE-OP and was higher than the TE-US. It also increased by 56% in the RS-DS than that of the RS-OP

and was higher than the RS-US point (Figure 4b). Dutta et al. (2005), in consistence with the present findings, reported higher concentration of Pb in the monsoon season followed by that in summer and winter.

Copper: Its average concentration increased by 45% in the TE-DS point compared to that of the TE-OP and was higher than that of the TE-US point. It also increased by 44% in the RS-DS than the RS-OP and was higher than that of the RS-US (Figure 3c). In pre-monsoon season of 2005 its concentration was lower than monsoon season of 2005, but increased by 55% in the TE-DS than that of TE-OP and higher than the TE-US. Similarly, it increased by 51% in the RS-DS than that of the RS-OP and was higher than RS-US (Figure 4c). Its concentration was higher in monsoon season 2005 and increased by 49% at the TE-DS than that of the TE-OP and also higher than the TE-US. It also increased by 38% in the RS-DS than that of the RS-OP and was higher than RS-US. Its concentration in winter season 2006 decreased at TE-OP, which increased by 41% in the TE-DS and higher than that of the TE-US. It increased by 42% at the RS-DS than that of the RS-OP and was higher than RS-US.

Its concentration in summer season of 2006 was higher than that of the winter of 2005 and increased by 26% in the TE-DS than that of the TE-OP, and was also higher than TE-US. It also increased by 39% in the RS-DS compared to that of the RS-OP and was also higher than the RS-US. Its concentration was lower in the pre-monsoon season of 2006 than the previous pre-monsoon of 2005 and increased by 61% in the TE-DS compared to that of the TE-OP and also higher than the TE-US. Similarly, it increased by 56% in the TE-DS compared to that of the RS-OP and was higher than the RS-US. Its concentration was lower in the monsoon season of 2006 than the previous monsoon of 2005, but increased by 42% at the TE-DS compared to that of the TE-OP and was higher than the TE-US. It increased by 40% in the RS-DS compared to that of the RS-OP and was higher than the RS-US point (Figure 4c).

Nickel: Its average concentration at the TE-DS point increased by 40% compared to that of TE-OP and was higher compared to that of the TE-US point. It also increased by 43% in the RS-DS compared to RS-OP and was higher than that of the RS-US (Figure 3d). In pre-monsoon season of 2005 its concentration was lower than monsoon season same year but increased by 38% in the TE-DS compared to that of TE-OP and was higher than the TE-US. It also increased by 43% in the RS-DS compared to that of RS-OP and was higher than the RS-US (Figure 4d). Its concentration increased in monsoon season 2005 by 35% at the TE-DS than the TE-OP and was higher compared to that of the TE-US. Its concentration increased by 40% in the RS-DS compared to that of the RS-OP, and was higher than the RS-US. Its concentration in winter season 2006 decreased at TE-OP, but increased by 46% in the TE-DS and was higher compared to that of the TE-US. It also increased by 44% at the RS-DS compared to that of the RS-OP and was higher than the RS-US.

Its concentration in summer season of 2006 increased compared to that of the winter of 2005. It was higher by 20% in the TE-DS compared to that of the TE-OP and the TE-US point. It also increased by 48% in the RS-DS compared to that of the RS-OP and was higher than the RS-US. Its concentration was lower in the pre-monsoon season of 2006 than the previous pre-monsoon of 2005 but increased by 53% in the TE-DS compared to that of the TE-OP and was higher than the TE-US. It also increased by 53% in the RS-DS compared to that of the RS-OP and was higher than the RS-US. Its concentration was lower in the monsoon season of 2006 than the previous monsoon of 2005 but increased by 39% at the TE-DS compared to that of the TE-OP and higher than the TE-US. It also increased by 50% in the RS-DS compared to that of the RS-OP and higher than the RS-US point (Figure 4d).

Total Chromium: Its average concentration increased by 47% in the TE-DS point compared to that of the TE-OP and was higher than the TE-US point. It also increased by 60% in the RS-DS compared to that of the RS-OP and higher than the RS-US (Figure 3e). In pre-monsoon season of 2005 its concentration was lower than monsoon season of 2005 but increased by 43% in the TE-DS compared to that of the TE-OP and was higher than the TE-US. It also increased by 66% in the RS-DS compared to that of the RS-OP and was higher than the RS-US (Figure 4e). Its concentration was higher in monsoon season 2005 and increased by 38% in the TE-DS compared to that of the TE-OP and was higher than the TE-US. It also increased by 60% in the RS-DS compared to that of the RS-OP and was higher than the RS-US. Its concentration in winter season 2006 decreased at TE-OP but increased by 91% in the TE-DS and was higher than that of the TE-US point. It increased by 50% at the RS-DS compared to that of the RS-OP and was higher than the RS-US.

Its concentrations in summer season of 2006 increased compared to that of the winter of 2005 and increased by 47% in the TE-DS compared to that of the TE-OP and was higher than the TE-US. It also increased by 54% in the RS-DS compared to that of the RS-OP and was higher than the RS-US. Its concentration was lower in the pre-

monsoon season of 2006 than the previous pre-monsoon of 2005 but it increased by 26% in the TE-DS compared to that of the TE-OP and was higher than the TE-US. It also increased by 60% in the RS-DS compared to that of the RS-OP and was higher than the RS-US. Its concentration was lower in the monsoon season of 2006 than the previous monsoon of 2005 but increased by 50% at the TE-DS compared to that of the TE-OP and was higher than the TE-US. It also increased by 59% in the RS-DS compared to that of the RS-OP and was higher than the RS-US point (Figure 4e).

It was reported that Dholai and Norai Khal regions discharged municipal sewage into Buriganga and Balu rivers respectively, in Dhaka (Bangladesh) where the Cr content in the storm water drains were 0.092 and 0.025 ppm, respectively (DWASA, 1998); these are higher compared to the present findings. Gaur et al. (2005), in consistence with the present findings, reported increased concentration of heavy metals in water in the river Gomti in its urban portion in the monsoon season compared to summer and winter, which could be due to the release of water from the catchment areas i.e., runoff coming from areas like open dumping waste sites, city drains and industrial drainage. Moreover, the soil dust input may have increased the metal concentration in the river system (Chekushin, 1993). They attributed the higher concentrations of these metals in the water of river Gomti in summer compared to winter to high amount of untreated sewage coming from the urban portion of the river. Similar variations in heavy contents across the seasons were also reported in river Ganga; the monsoon exhibiting the highest concentration followed by summer and winter (Dutta et al., 2005). However, Sinha et al. (2007) did not find any such variation in mercury in Ganga water. The major point source of the heavy metals entering the systems could be untreated wastes from the domestic, industrial or other anthropogenic sources (Rawat et al., 2003). The high concentration of the heavy metals in rainy season could be due to the input of soil carrying the metals through runoff of storm water along with municipal sewage into the canal. The higher concentration of the heavy metals in the summer compared to winter in the present study was probably due to more dry-fall of dust particles resulting from heavy vehicular movement on the adjacent east coast roads.

Conclusion

In the present study, it is concluded that:

- The content of heavy metals in the municipal RS was high and showed temporal variation and the concentrations of metals ranked in the order Ni>Cu>Zn>Pb>Cr in the RS whereas that in the TE ranked in the order Cu>Ni>Zn>Cr>Pb. There was minor decrease in heavy metals in AT, but the decrease was considerable in the SC of the STP indicating its importance in heavy metal removal from RS.
- The heavy metals were found in higher concentrations in the monsoon season in the TE and RS, which were lower in the winter season.
- The heavy metals of RS that was let into the canal directly contaminated the canal water more than that of the TE, which is the cause of concern. Therefore, we suggest that the RS should be treated properly by the conventional STP prior to its release; so that the burden of heavy metal pollution can be minimal in the canal.

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Calendar of Events

World Ecological Forum
1 to 2 July 2010
Visby, Gotland, Sweden
Website: http://www.worldecologicalforum.com
Contact name: Ms Sari Arho Havrén

International Workshop on Geomorphological Hazards
21 to 23 July 2010
Kanyakumari, Tamil Nadu, India
Website: http://www.geohazardsmsu.co.nr/
Contact name: Prof. N. Chandrasekhar
Organized by: IAGAIG Working Group on Geomorphological Hazard and M.S. University, Tirunelveli India

Auroville Green Practices Seminar
26 to 28 August 2010
Auroville, Tamil Nadu, India
Website: http://www.auroco.in/greenpractices
Contact name: Raghu Kolli
Organized by: Auroville Consulting

World Water Week in Stockholm
5 to 11 September 2010
Stockholm, Sweden
Website: http://www.worldwaterweek.org
Contact name: Lovisa Selander
Organized by: Stockholm International Water Institute (SIWI)

2010 International Conference on Environmental Science and Applications
10 to 12 September 2010
Singapore
Website: http://www.iceea.org/
Contact name: CBEES Editor

2010 PEACE/CREAM-AP (EAST II) International Ocean Workshop
11 September 2010
Gangneung, Republic of Korea, Gangwondo, Korea (South)
Website: http://atmos.kangnung.ac.kr/ch/peace2010
Contact name: Dr. Hyo Choi
Organized by: Gangneung-Wonju National University

25th Annual WateReuse Symposium
12 to 15 September 2010
Washington, DC, United States
Website: http://www.watereuse.org/conferences/symposium/25
Contact name: Courtney Tharpe
Organized by: WateReuse Association

Water Pricing Conference 2010
20 to 21 September 2010
Melbourne, VIC, Australia
Website: http://www.iir.com.au/waterpricing
Contact name: Rose Stibbard
Organized by: IIR Conferences

Coastal, Marine Structures and Breakwaters WA
28 to 29 September 2010
Perth, WA, Australia
Website: http://www.marinestructures.com.au
Contact name: Judy Hizon
Organized by: IQPC