Asian Journal of Water, Environment and Pollution, Vol. 8, No. 2 (2011), pp. 93-104.

Temporal Effects of Municipal Sewage on the Surface Water Quality (Cations and Anions) of the Buckingham Canal at Kalpakkam (India)

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Received January 28, 2009; revised and accepted December 7, 2009

Abstract: Temporal effects of treated and untreated municipal sewage on the cations – calcium (Ca), magnesium (Mg), hardness, sodium (Na) and potassium (K), and anions – chlorides (Cl^-), bicarbonates (HCO_3^-), carbonates (CO_3^{2-}) and alkalinity of surface water of the Buckingham canal were monitored across different seasons during pre-monsoon 2005 to post-monsoon – 2006 at Kalpakkam (Tamil Nadu) located on the east coast of Indian peninsula. The concentrations of each of the cations and anions were higher in the untreated sewage input zone than that of the treated sewage input zone, and at the downstream higher than that of the upstream of the outfall points of both the untreated as well as treated sewage, of the canal. These parameters except K and alkalinity were higher in concentrations during summer while all the cations and the anions were lower during monsoon. The concentrations of K and alkalinity were higher during winter. Cluster analysis based on the similarities of the cations and anions applied to the six sampling points of the canal, grouped them into two clusters, one showing higher pollution level and the other lower pollution levels of water.

Key words: Activated sludge treatment, up-stream and down-stream of canal, water quality parameters, Cluster analysis.

Introduction

Rapid expansion of human population and industrialization contributed to higher pollution load that deteriorated the surface water quality of both lotic and lentic systems particularly in developing countries (Stamou et al., 1999; Tsagarakis et al., 2001). The total wastewater generated per annum from about 200 Indian cities is about 2800 million cubic metres, of which about 65% to 70% of the wastewater does not get any treatment (Kaul et al*.,* 1989). Disposal of such municipal sewage from cities and towns is the biggest source of pollution of water bodies in India (CPCB, 2005). Therefore, Indian rivers and canals especially in urban portions are grossly polluted (Srivastava, 1992).

Among the cations the Ca, the fifth abundant element, is an important nutrient in an aquatic environment. The higher levels of Ca and Mg in aquifers are generally due to the sewage or organic pollution (Sharma et al., 2004). These are the principal cations responsible for causing hardness that is expressed in terms of calcium carbonate. The main source of Na is urine. The untreated municipal sewage contains more Na and the dumping of sewage and solid waste into the water bodies increase N concentration and sometimes, can reach more than 60 mg/l (Robert and Ebba, 1981). The other source of N in water particularly in coastal areas is derived from the sea sprays. The monovalent K is an important macro-nutrient in aquatic environment. However, little is known regarding K causing water pollution.

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Water courses receiving sewage are sinks for even anions like Cl. It may be present in high concentrations along the coastal aquifers due to sea sprays and sometimes, due to the leakage of salt water into sewerage system (Greenberg et al., 1992). An increase in Cl ion concentration in water can be used as an indicator of gross pollution. Alkalinity is more common than acidity in natural water that are not highly polluted. It is often a good indicator of the total dissolved inorganic carbon (bicarbonates and carbonates). It minimizes pH, reduces the toxicity of many metals by forming complexes, and also provides carbon as a nutrient for aquatic plants. Water with higher alkalinity generally has a high concentration of dissolved inorganic carbon that is used in photosynthesis (Weiner, 2000).

Studies on the spatio-temporal variations of the cations and anions in canals and rivers with input of municipal sewage and effluents have been carried out by various earlier investigators in India – River Hindon (Jain et al., 2002), Kathajodi (Das and Acharya, 2003), Yamuna (Ravindra et al., 2003) and Periyar and Chalakudy (Maya et al., 2007), and in other countries – Osun river in Nigeria (Olajire and Imeokparia, 2001), Llobregat River in Spain (Fernandez–Turiel et al., 2003). Subramanian (1983) reported average HCO_3^- in Indus, Ganges, Brahmaputra and Narmada rivers, Blakar and Hongve (1997) on potassium and HCO_3^- concentration in Hoylandet Stream in Norway and Stambuk (2003) on total alkalinity in Vrgorska River in Bosnia. During past three decades or so the effects of municipal untreated sewage and treated effluents, the point source pollution, on the water quality of canals and rivers though have received some attention (Kaul et al., 1989), very little has been reported comparing the effects of both untreated sewage and treated effluents on the water quality of the receiving water bodies. The present study, thus attempted to report a comparative account of the seasonal effects of untreated municipal sewage and treated effluents on the surface water quality – cations (Ca, Mg, hardness, Na and K) and anions (Cl^-, HCO_3^-, CO_3^{2-} and alkalinity) of the Buckingham canal at Kalpakkam.

Material and Methods

Description of Study Area and Sampling Sites

Kalpakkam (12°30′ N and 80°10′ E) is a small town situated 65 km south of Chennai, the capital of Tamil Nadu (India). The details of Buckingham canal running parallel to the Coromandal coast receiving the inputs of the treated sewage from Kalpakkam and the untreated sewage from the adjacent Pudhupattinam town is shown in Kumar and Reddy (2009). Every month the outfall points of the untreated sewage and treated effluents in the canal and their up-stream and down-stream points in the canal were monitored during different seasons for the cations (Ca, Mg, hardness, Na, K) and anions (Cl^-, HCO_3^-, CO_3^{2-} and total alkalinity) of the surface water during the present study. Sampling points of treated sewage – 1, 2 and 3 were chosen in the Buckingham canal, the one being the outfall point of treated sewage (TS–OP), second one is on its downstream point (TS–DS) and the third one is on its upstream point (TS–US). Three more sampling points – 4, 5 and 6 were also chosen in the Pudhupattinam portion of the canal, the fourth one being the outfall point of untreated sewage (UTS–OP), the fifth one being the downstream of the untreated sewage (UTS–DS) and the sixth one was the upstream of the untreated sewage (UTS–US) in the canal, each point being about a kilometre away from outfall points.

Sampling collection and its analysis

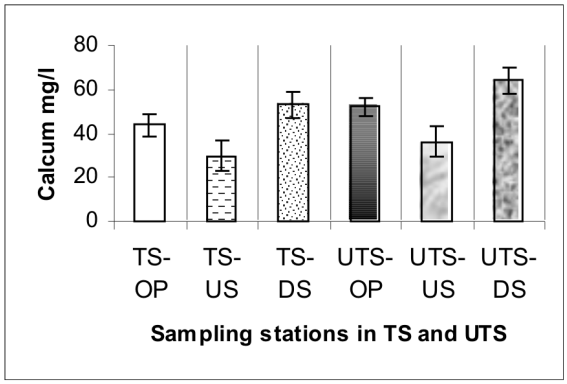
Surface water samples were collected each month from the six sampling points during different seasons of the study period – July (pre-monsoon) 2005 to December (post monsoon) 2006, located in the canal, both the Kalpakkam and Pudhupattinam sides and were transported to the laboratory for analysis. The samples were analysed for Ca and Mg by titration, Na and K by flame photometer, Cl^- by Argnometric method, HCO_3^-, CO_3^{2-} total hardness and total alkalinity by titrametric method by following the procedures given in APHA (1998). The data on these parameters of different stations in both stations in TS and UTS input zone of the canal were analyzed using two way ANOVA analyses.

Results and Discussion

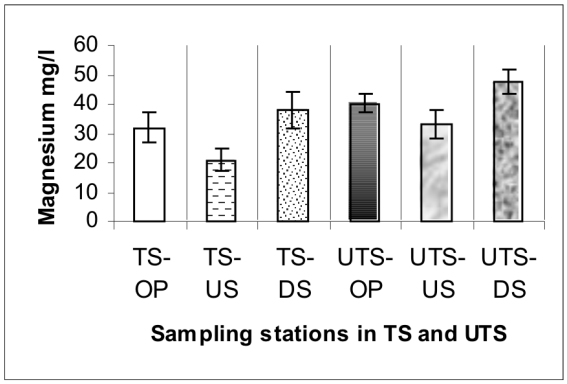
The spatio-temporal variations in cations – Ca, Mg, hardness, Na and K and anions – Cl^-, HCO_3^-, CO_3^{2-}, and total alkalinity are presented in Figures 1, 2 and 3.

Cations

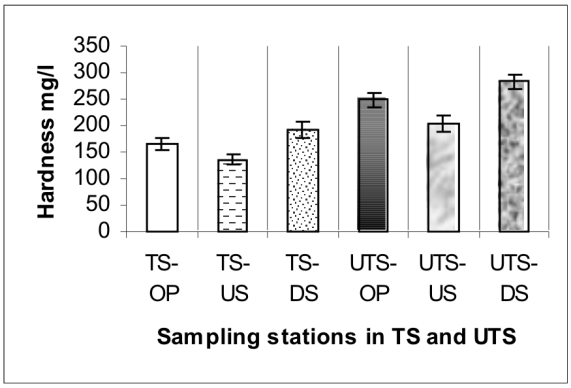
Ca: The average Ca concentration presented in Figure 1a, was low (44 ± 5 mg/l) at the TS–OP, and increased by 17% at the TS–DS than that of the TS–US point. It was higher (52 ± 4 mg/l) in the UTS–OP, and increased (19%) in the UTS–DS than that of the UTS–US. Its concentration was higher during pre-monsoon season than that of the monsoon season (2005) and decreased to 30 l ± 5 mg/l at the TS–OP, but increased (40 ± 8 mg/l) at UTS–OP in monsoon season (2005). It increased (45 ± 6 mg/l) at TS–OP and was higher (54 ± 7 mg/l) at the UTS–


Calcum mg/l
80
60
40
20
0
TS-OP
TS-US
TS-DS
UTS-OP
UTS-US
UTS-DS
Sampling stations in TS and UTS

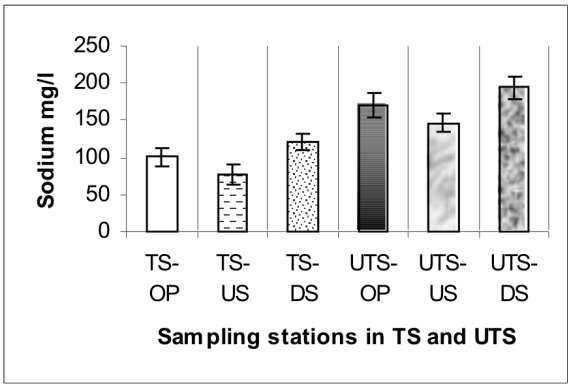
(a)


Magnesium mg/l
60
50
40
30
20
10
0
TS-OP
TS-US
TS-DS
UTS-OP
UTS-US
UTS-DS
Sampling stations in TS and UTS

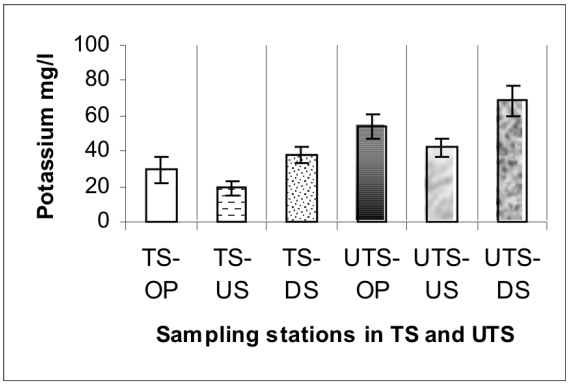
(b)


Hardness mg/l
350
300
250
200
150
100
50
0
TS-OP
TS-US
TS-DS
UTS-OP
UTS-US
UTS-DS
Sampling stations in TS and UTS

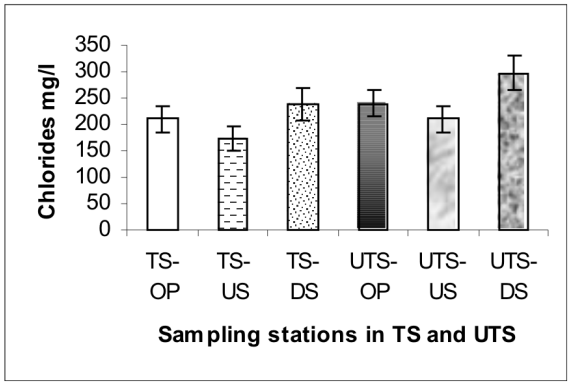
(c)


Sodium mg/l
250
200
150
100
50
0
TS-OP
TS-US
TS-DS
UTS-OP
UTS-US
UTS-DS
Sampling stations in TS and UTS

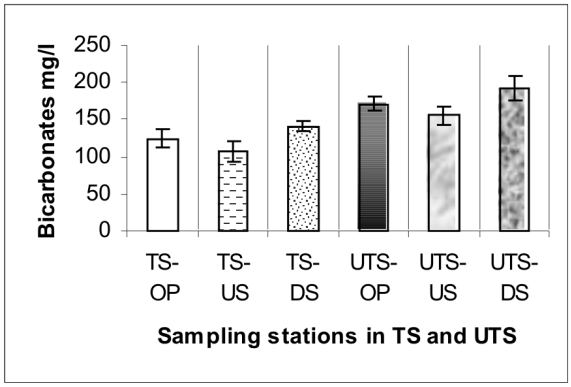
(d)


Potassium mg/l
100
80
60
40
20
0
TS-OP
TS-US
TS-DS
UTS-OP
UTS-US
UTS-DS
Sampling stations in TS and UTS

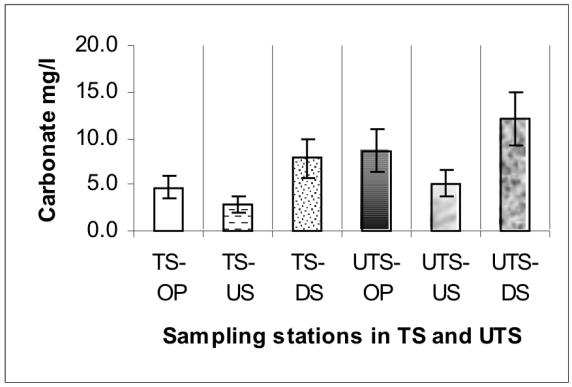
(e)


Chlorides mg/l
350
300
250
200
150
100
50
0
TS-OP
TS-US
TS-DS
UTS-OP
UTS-US
UTS-DS
Sampling stations in TS and UTS

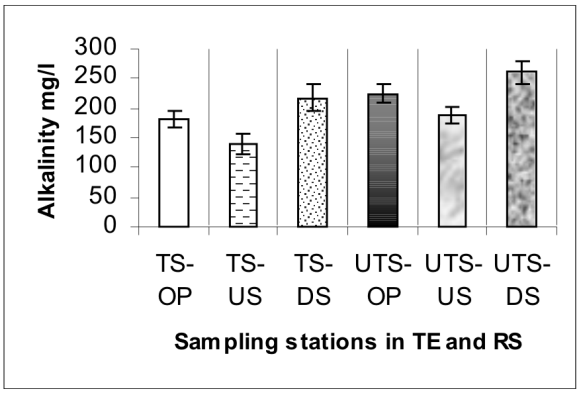
(f)


Bicarbonates mg/l
250
200
150
100
50
0
TS-OP
TS-US
TS-DS
UTS-OP
UTS-US
UTS-DS
Sampling stations in TS and UTS

(g)

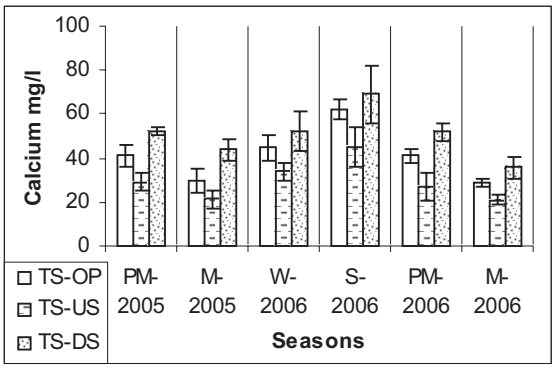

Carbonate mg/l
20.0
15.0
10.0
5.0
0.0
TS-OP
TS-US
TS-DS
UTS-OP
UTS-US
UTS-DS
Sampling stations in TS and UTS

(h)

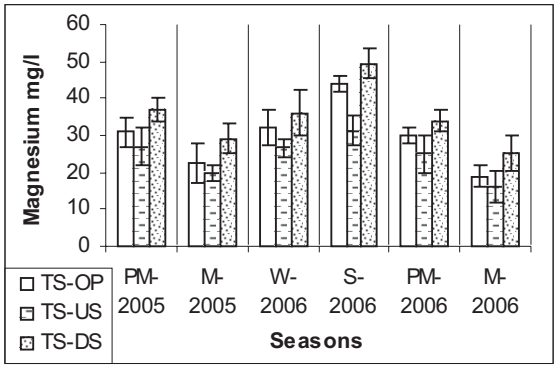


(i)

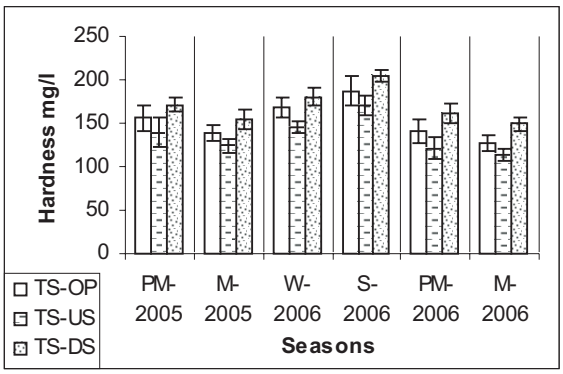
Figure 1: Average concentration in the treated and untreated sewage in the Buckingham canal – (a) Ca, (b) Mg, (c) Total hardness, (d) Na, (e) K, (f) Cl^-, (g) HCO_3^-, (h) CO_3^{2-} and (i) Total alkalinity.



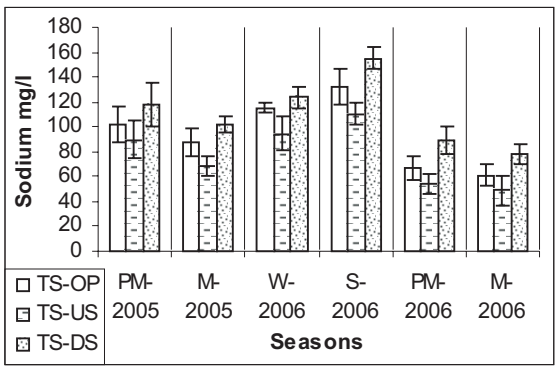
(a)



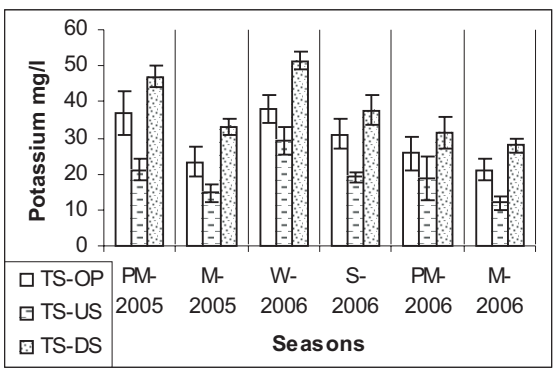
(b)



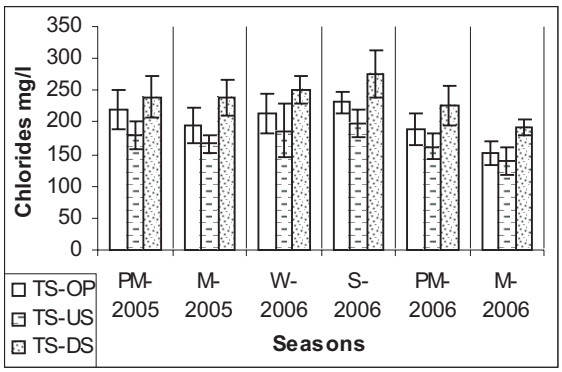
(c)



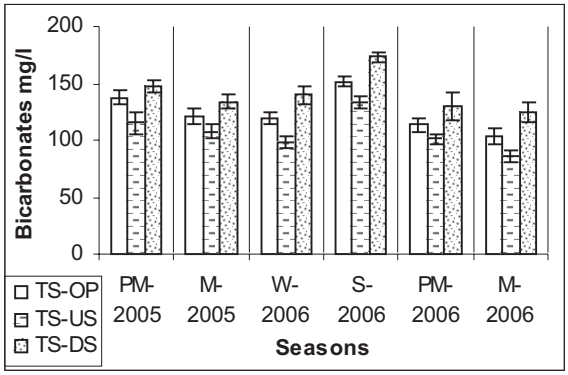
(d)



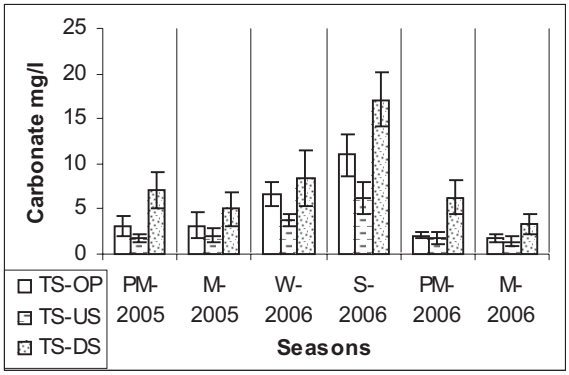
(e)



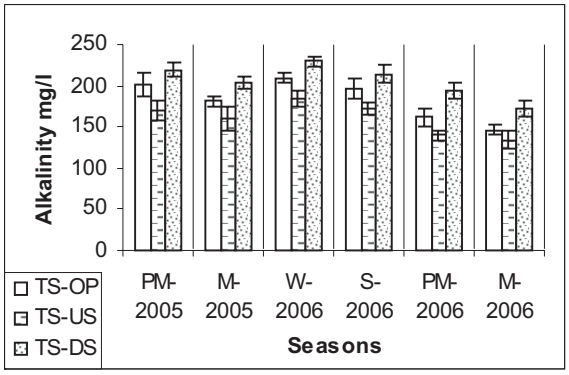
(f)



(g)

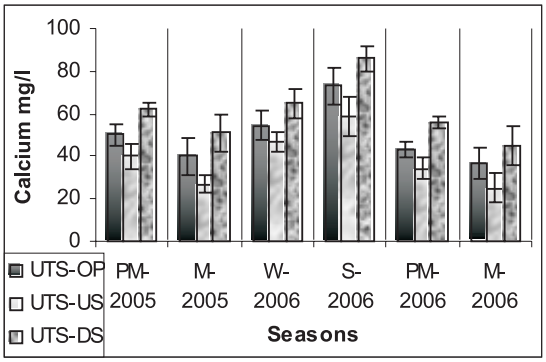


(h)

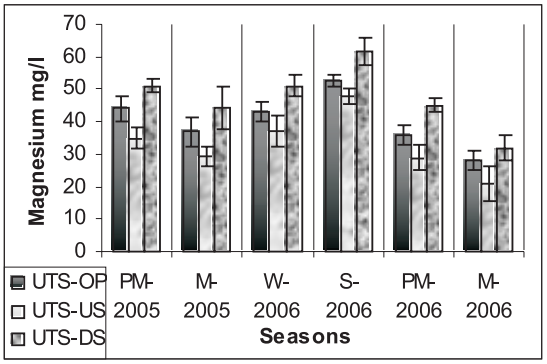


(i)

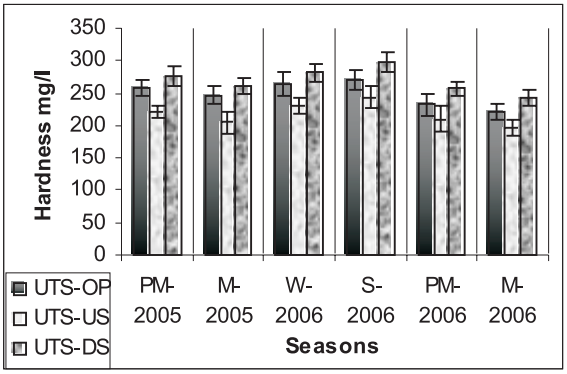
Figure 2: Spatio-temporal variation in the treated sewage falling-point zone in the Buckingham canal – (a) Ca, (b) Mg, (c) Total hardness, (d) Na, (e) K, (f) Cl^-, (g) HCO_3^-, (h) CO_3^{2-} and (i) Total alkalinity.



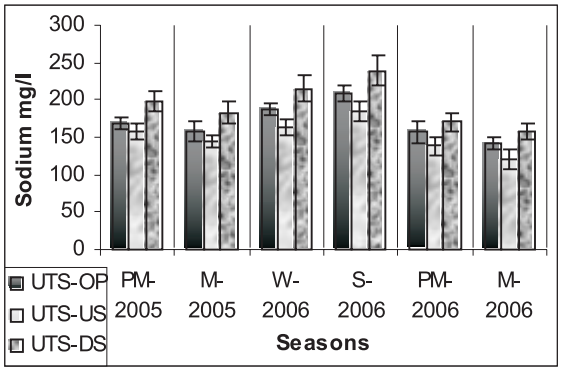
(a)



(b)



(c)



(d)

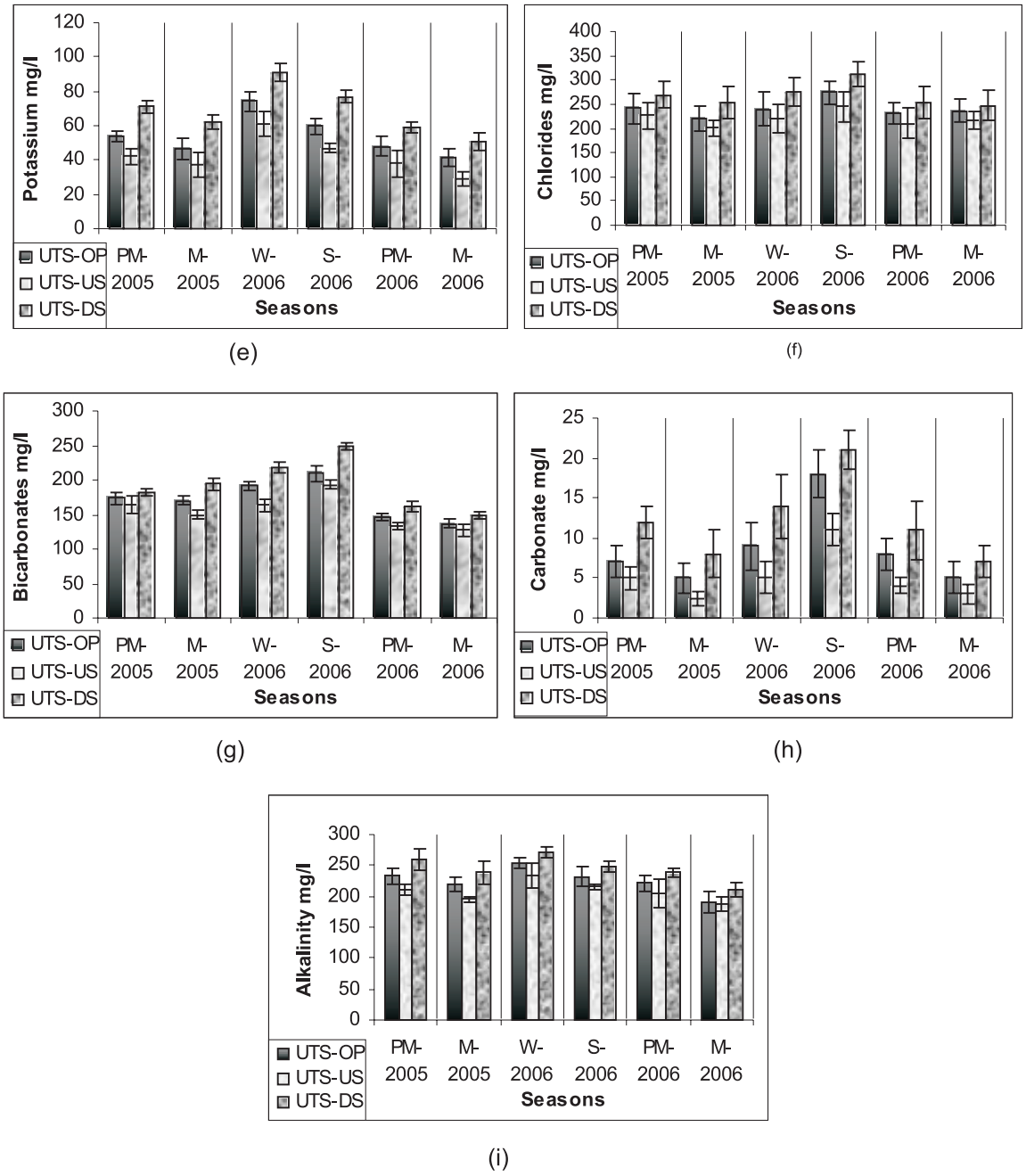


Figure 3: Spatio-temporal variation in the untreated sewage falling point-zone in the Buckingham canal – (a) Ca, (b) Mg, (c) Total hardness, (d) Na, (e) K, (f) Cl^-, (g) HCO_3^-, (h) CO_3^{2-} and (i) Total alkalinity.

OP in the winter (2006). It was higher in summer (2006) compared to that of the pre-monsoon and monsoon (2005) and winter (2006), and was 62 ± 4 mg/l in TS–OP and was further higher (73 ± 8 mg/l) at the UTS–OP. Its concentration decreased in the pre-monsoon season (2006) than that of the previous pre-monsoon (2005) and was 41 ± 3 mg/l in TS–OP and was slightly higher (43 ± 4 mg/l) at the UTS–OP. Its concentration was lower in the monsoon (2006) than that of the previous monsoon (2005) and was 29 ± 2 mg/l at the TS–OP, but increased (37 ± 8 mg/l) at UTS–OP. Its concentration increased at the TS–DS than that of the TS–US (Figure 2a) and at the UTS–DS than that of the UTS–US (Figure 3a) across all the seasons. Its concentrations showed significant temporal and spatial variations across different seasons at TS (ANOVA: $P < .05$, $F = 3.519485$, $df = 17$) as well as in UTS outfall zone ($P < .05$, $F = 2.810108$, $df = 17$), and across sampling sites – TS–OP and its upstream and

downstream in the canal ($P < .05$, $F = 10.46524$, $df = 2$). Its concentrations were higher in the UTS input zone of the canal than that of its TS input zone most probably due to release of the former containing more concentrated allocthonous substances (Olajire and Imeokparia, 2001). The present values were much less than that (211 ± 3 and 102 ±2 mg/l, respectively) of the non-polluted and polluted sewage outfall points of the Piracicaba River in Brazil (Martinell et al., 1999). The average Ca concentration was 45 mg/l in Hoylandet stream (Norway) (Blakar and Hongve, 1997), while that of the pre-monsoon, monsoon and post-monsoon were 20, 9 and 14 mg/l, respectively (Singh and Hasnain, 1999) and were 15–26 and 10–26 mg/l, respectively in Damodar river (Kumar et al., 2005). The Ca content in the sewage effluents in Indore and the Ujjain (Madhya Pradesh) were 160 and 96 mg/l in the pre-monsoon, which increased to much higher concentrations (400 and 160 mg/l) during post-monsoon (Sharma et al., 2004). Its concentrations in Periyar and Chalakudy rivers (Kerela) in non-monsoon and monsoon were 32 and 22 mg/l and 4 and 3 mg/l, respectively (Maya et al., 2007). The average Ca concentrations in the upstream were lower (28 mg/l) than that (33 mg/l) of the downstream in Osun river (Nigeria) (Olajire and Imeokparia, 2001), 91 and 106 mg/l, respectively in Llobregat river (Spain) (Fernandez–Turiel et al., 2003), and ranged from 50 to 70 and 90 to 108 mg/l, respectively in Yamuna river at Delhi (Ravindra et al., 2005), which are in consistence to the present findings.

Mg: The average Mg concentration presented in Figure 1b, was low (32 ± 5 mg/l) at the TS–OP, which increased in the TS–DS point than that of the TS–US point. It was high (40 ± 3 mg/l) in the UTS–OP and increased in the UTS–DS than that of the UTS–US. Its concentration was higher during pre-monsoon (2005) than that of the monsoon (2005). It decreased to 22 ± 5 mg/l at the TS–OP and was higher (37 ± 5 mg/l) at UTS–OP in monsoon (2005). It increased (32 ± 5 mg/l) at TS–OP and further to 43 ± 3 mg/l in the UTS–OP in winter (2006). Its concentration in summer (2006) was higher than that of the pre-monsoon, monsoon (2005) and winter (2006) and was 44 ± 2 mg/l in TS–OP and increased to 53 ± 2 mg/l at the UTS–OP Its concentration was lower in the pre-monsoon (2006) than the previous pre-monsoon (2005). It was 30 ± 2 mg/l in TS–OP, but was higher (36 ± 3 mg/l) at the UTS–OP. Its concentration was lower in the monsoon (2006) than the previous monsoon (2005) and was 19 ± 3 mg/l at the TS–OP and increased to 28 ± 3 mg/l at UTS–OP. It clearly showed that Mg concentrations increased at the TS–DS than that of the TS–US (Figure 2b) and in the UTS–DS than that of the UTS–US point across all the seasons (Figure 3b). Its concentration was found higher in the UTS input zone than that of the TS input zone of the canal, because of the former containing more concentrations of allochthonous substances. Its concentrations showed significant temporal variations across different seasons in TS–OP input zone ($P < .05$, $F = 3.724344$, $df = 17$); and spatial variation across different sampling sites and their upstream and downstream in UTS zone in the canal ($P < .05$, $F = 11.4672$, $df = 2$). In consistence, Martinell et al. (1999) reported that the Mg concentration in the sewage polluted points was higher (97 ± 2) than that of the non-polluted points (59 ±1 mg/l) in Piracicaba river. A concentration of 30 mg/l Mg is recommended for drinking water. The Ca and Mg concentrations during the present study were low in the monsoon season probably due to dilution caused by rain water, which increased during summer due to the evaporation factor. The average Mg concentration was higher in the Buckingham canal water compared to that (22 mg/l) in Hoylandet stream (Blakar and Hongve, 1997). However, it was lower in Periyar and Chalakudy rivers in non-monsoon (4 and 3 mg/l, respectively) and monsoon (1 and 0.9 mg/l, respectively) (Maya et al., 2007), that of sewage effluents in Indore and the Ujjain in the pre-monsoon (36 and 17 mg/l), which increased during post-monsoon (Sharma et al., 2004). Their average concentrations were also lowering in pre-monsoon, monsoon and post-monsoon – 11, 6 and 9 mg/l, respectively (Singh and Hasnain, 1999) and 17 and 3 mg/l, respectively in pre-monsoon and post-monsoon in Damodar River (Kumar et al., 2005). Its concentration was higher in the down-stream (28 mg/l) compared to that of up-stream (22 mg/l) in Osun River and were 35 and 10 mg/ l, respectively in Llobregat River, and ranged from 46 to 90 mg/l and 7 to 30 mg/l, respectively in the downstream and upstream in Yamuna river (Ravindra et al., 2003).

Hardness: The average total hardness presented in Figure 1c, was low (165 ± 1 mg/l) at the TS–OP, increased in the TS–DS point than that of the TS–US point. It was higher (248 ± 1 mg/l) in the UTS–OP and also increased in the UTS–DS than that of the UTS–US. It was higher in pre-monsoon than monsoon (2005) and was 156 ± 1 mg/l in TS–OP and decreased to 139 ± 9 mg/l in monsoon. It was much higher (246 ± 1 mg/l) at UTS–OP. It increased to 168 ± 1 mg/l at TS–OP in winter (2006) and further to 264 ± 2 mg/l in the UTS–OP. The hardness in summer (2006) was higher than that of the pre-monsoon and monsoon (2005) and winter (2006). The hardness was low in the pre-monsoon (2006) than the previous

pre-monsoon (2005) and was 141 ± 1 mg/l in TS–OP, and was much elevated (233 ± 17 mg/l) at the UTS–OP. It was low in the monsoon (2006) than the previous monsoon (2005) and was 128 ± 9 mg/l at the TS–OP and increased to 221 ± 1 mg/l at UTS–OP. It showed that the hardness increased at the TS–DS than that of the TS–US (Figure 2c) and at UTS–DS than that of the UTS–US point across the seasons (Figure 3c). The hardness of the water though not a pollution parameter but indicates mainly the Ca and Mg contents of water quality. The average concentration of total hardness was higher 276 mg/l in the Hindon river (Uttar Pradesh) (Jain et al., 2002) compared to that of the present values, while it ranged from 136 to 199 mg/l in Kathajodi River (Das and Acharya, 2003) and from 206 to 336 mg/l in Vrgorska river (Bosnia) during 1997–2000 (Stambuk, 2003). Several investigators reported seasonal variation in hardness in rivers and canals in consistence to the present findings – 225 ± 3 and 140 ± 9.0 mg/l in winter and rainy reason respectively, in Kathajodi river (Das and Acharya, 2003) and range from 118 to 356 mg/l in winter season and 140 to 405 mg/l in summer season in Yamuna river (Ravindra et al., 2003). It was lower during monsoon (19 and 12 mg/l) than that of the non-monsoon season (380 and 70 mg/l) in the Periyar river and Chalakudy river, respectively (Maya et al., 2007). The total hardness of the down-stream was higher (160 mg/l) than that of the up-stream (140 mg/l) in the Osun river (Olajire and Imeokparia, 2001), which corroborated to the present findings.

Na: The average Na concentration presented in Figure 1d, was low (29 ± 7 mg/l) at the TS–OP, which increased in the TS–DS point than that of the TS–US point. It was high (53 ± 7 mg/l) in the UTS–OP and likewise increased in the UTS–DS than that of the UTS–US. Its concentration was higher during pre-monsoon than monsoon– 2005 and was 102 ± 1 mg/l in TS–OP, and increased to 169 ± 7 mg/l at the UTS–OP. Its concentration in monsoon (2005) decreased (87 ± 1 mg/l) at the TS–OP, but increased (158 ± 1 mg/l) at UTS–OP. Its concentration in winter 2006 increased (115 ± 4 mg/l) at TS–OP and was further higher (187 ± 8 mg/l) in the UTS–OP. Its concentration was elevated in summer (2006) compared to that of the pre-monsoon and monsoon (2005) and winter (2006), and was 133 ± 1 mg/l in TS–OP, which increased to 209 ± 1 mg/l at the UTS–OP. Its concentration was lower in the pre-monsoon (2006) than the previous pre-monsoon (2005) and was 67 ± 9 mg/l in TS–OP; it was more than double (157 ± 1 mg/l) at the UTS–OP. Its concentration was lower in the monsoon (2006) than the previous monsoon (2005), and was 61 ± 9 mg/l at the TS–OP. It was much elevated (142 ± 9 mg/l) at UTS–OP. It clearly showed that Na concentration increased at the TS–DS than that of the TS–US (Figure 2d) and likewise in the UTS–DS than that of the UTS–US point across the seasons (Figure 3d). These Na values showed significant spatial variation across different sampling points in UTS outfall point and its upstream and downstream in the canal ($P < .05$, $F = 8.534281$, $df = 2$), and were higher in the UTS input zone than that of the TS input zone, due to the former containing more concentration of allochthonous substances. Higher concentration of Na can cause pollution (Robert and Ebba, 1981). The average concentration of Na was 117 mg/l in Hoylandet stream (Blakar and Hongve, 1997) **,** while its concentration was much higher in the sewage polluted points (1139 ± 3 mg/l) than that of the non-polluted points (227 ± 9 mg/l) in Piracicaba river (Martinell et al., 1999) and were 207 and 51 mg/l and in the pre-monsoon season and increased to 322 and 92 mg/l during post-monsoon in the sewage effluents in Indore and the Ujjain (Sharma et al., 2004). Nevertheless, the average Na concentration was relatively low during pre-monsoon, monsoon and post-monsoon being 19, 10 and 15 mg/l, respectively (Singh and Hasnain, 1999) as well as in pre-monsoon and post-monsoon (13 and 9 mg/l, respectively) in Damodar river (Kumar et al., 2005). In consistence to the present findings, higher concentration of average N was recorded in the down-stream (164 mg/l) than that of the up-stream (13 mg/l), in the Llobregat river (Fernandez–Turiel et al., 2003) and Yamuna river ranging from 88 to 148 mg/l and 7 to 11 mg/l, respectively (Ravindra et al., 2003).

K: The average concentration of monovalent K presented in Figure 1e, was low (44 ± 1 mg/l) at the TS–OP, which increased in the TS–DS point compared to that of the TS–US point. Likewise, it was high (203 ± 5 mg/l) in the UTS–OP, and increased in the UTS–DS than that of the UTS–US. Its concentration was higher in pre-monsoon (2005) than monsoon (2005) and was 37 ± 6 mg/l in TS–OP. It was higher (54 ± 3 mg/l) at the UTS–OP. Its concentration in monsoon (2005) decreased to 23 ± 4 mg/l at the TS–OP, but was higher (40 ± 5 mg/l) at UTS–OP. Its concentration in winter (2006) was higher than that of pre-monsoon and monsoon (2005) and was 38 ± 4 mg/l at TS–OP, and was higher (74 ± 6 mg/l) in the UTS–OP. Its concentration in summer decreased compared to that of winter (2006) and was 31 ± 4 mg/l in TS–OP, and was much higher (60 ± 4 mg/l) at the UTS–OP. Its concentration was lower in the pre-monsoon (2006) than the previous pre-monsoon (2005) and was 26 ± 5 mg/l in TS–OP, which was lower than that (48 ± 6

mg/l) at the UTS–OP. Its concentration was lower in the monsoon (2006) than the previous monsoon (2005) and was 21 ± 3 mg/l at the TS–OP but was higher (41 ± 5 mg/l) at UTS–OP. It showed that K concentration was elevated at the TS–DS than that of the TS–US (Figure 2e) and likewise, at the UTS–DS than that of the UTS–US point across all the seasons (Figure 3e). The K values showed significant temporal variation across different seasons in TS–OP input zone in the canal ($P < .05$, $F = 3.820922$, $df = 17$), and was significantly higher in UTS than that of the TS input zone of the canal, probably due to input of more concentrated allochthonous substances along with UTS. Its concentration was higher in polluted points (105 ± 1 mg/l) than that of the non-polluted points (72 ±1 mg/l) in Piracicaba River (Martinell et al., 1999). Its average concentration was low 7 + 9 mg/l in Hoylandet stream (Blakar and Hongve, 1997). Higher concentration of average K was recorded in the down-stream than that of the up-stream in various rivers – in Yamuna river, 39 to 51 mg/l and 18 to 22 mg/l, respectively in winter and 18 to 24 mg/l and 3 to 4 mg/l, respectively in summer (Ravindra et al., 2003), 32 and 2 mg/l, respectively in Llobregat river (Fernandez–Turiel et al., 2003), while in sewage effluents in Indore and the Ujjain were 45 and 35 mg/l in the pre-monsoon, which increased to 48 and 72 mg/l, respectively during post-monsoon (Sharma et al., 2004) and were very low, 5, 3 and 4 mg/l in pre-monsoon, monsoon and post-monsoon, respectively in Damodar river (Singh and Hasnain, 1999).

Anions

Cl^-: It is a major anion in water and wastewater, which determines the total salinity in water. Its ecological significance lies in its potential to regulate the salinity of water and exert a consequent osmotic stress on the biotic communities. The average concentration of Cl^- during the present study, presented in Figure 1f, was 210 ± 2 mg/l at the TS–OP, which increased in the TS–DS point than that of the TS–US point. It was higher 240 ± 24 mg/l in the UTS–OP and increased in the UTS–DS than that of the UTS–US. Its concentration was higher in the pre-monsoon (2005) than monsoon (2005) and was 219 ± 3 mg/l in TS–OP. It was more elevated in concentrations (241 ± 3 mg/l) at the UTS–OP. Its concentration in monsoon (2005) decreased to 195 ± 2 mg/l at the TS–OP and was higher (220 ± 2 mg/l) at UTS–OP. It increased to 214 ± 3 mg/l at TS–OP and was 240 ± 3 mg/l in the UTS–OP in winter (2006). Its concentration in summer (2006) was higher than that of the pre-monsoon and monsoon (2005) and winter (2006), and was 231 ± 1 mg/l in TS–OP and was further higher (274 ± 2 mg/l) at the UTS–OP. Its concentration was lower in the pre-monsoon (2006) than the previous pre-monsoon (2005) and was 189 ± 2 mg/l in TS–OP and further was higher (231 ± 2 mg/l) at the UTS–OP. It was lower in concentration in the monsoon (2006) than that of the previous monsoon (2005) and was 153 ± 2 mg/l at the TS–OP and was much higher (236 ± 2 mg/l) at UTS–OP. It clearly showed that Cl^- concentrations increased at the TS–DS than that of the TS–US (Figure 2f) and like-wise at the UTS–DS than that of the UTS–US point across the seasons (Figure 3f). Thus, its concentrations showed significant temporal variation across different seasons in TS ($P < .05$, $F = 2.725086$, $df = 2$) as well as in UTS input zones of the canal ($P < .05$, $F = 2.172768$, $df = 2$). The wastewater can be an important source of chloride in water bodies (Sharma et al., 2004). Cl^- concentration in contaminated surface and wastewater ranged from 30 to 100 mg/l (Greenberg, 1992). Its higher concentration in the summer could be probably due to increased temperature resulting in evaporation. However, its lower values during monsoon were probably due to dilution caused by rain water. Its concentration was higher in the down-stream than the up-stream of both outfall points of the canal, was probably due to the influence of untreated and treated sewage. Their average concentrations were much higher (418 ± 1 mg/l) in the Piracicaba river (Luiza et al., 1999) and were, however, low (108 + 9 mg/l) in Hoylandet stream (Blakar and Hongve, 1997) compared to the present values. The concentrations were 311 + 2, 294 ± 1 and 199 ± 7 mg/l in summer, winter and rainy seasons, respectively in Kathajodi river due to confluence of raw sewage released from Cuttack (Das and Acharya, 2003). Its concentration was higher during post monsoon (202–501 mg/l) than that of the pre-monsoon (83–354 mg/l) in the sewage effluents in and around Indore and Ujjain (Sharma et al., 2004). Its concentrations in monsoon season were lower (29 and 11 mg/l) than that of the non-monsoon season (140 and 50 mg/l, respectively) in the Periyar and Chalakudy river (Maya et al., 2007). In consistence to the present findings its average concentration was also higher in the down-stream (183 mg/l) than that of the up-stream (70 mg/l) in Osun river (Olajire and Imeokparia, 2001), was 269 and 21 mg/l, respectively in Llobregat river (Fernandez–Turiel et al., 2003) and 18 ± 1 and 17 ± 1 mg/l, respectively in upper Thames basin (Southern England) (Helen et al., 2005).

HCO_3^-: The average concentration of HCO_3^- presented in Figure 1g, was 124 ± 1 mg/l at the TS–OP, which increased in the TS–DS point than that of the TS–US point. It was higher (171 ± 9 mg/l) in the UTS–OP,

and likewise increased in the UTS–DS than that of the UTS–US. Its concentration was higher in pre-monsoon (2005) than monsoon (2005) and was 138 ± 6 mg/l in TS–OP; however, it was elevated, 174 ± 9 mg/l at the UTS–OP. Its concentration in monsoon (2005) decreased to 122 ± 7 mg/l at the TS–OP, but was higher (170 ± 7 mg/l) at UTS–OP. Its concentration in winter (2006) was higher (120 ± 5 mg/l) at TS–OP and was further higher (192 ± 6 mg/l) in the UTS–OP. Its concentration in summer (2006) increased compared to that of the pre-monsoon and monsoon (2005), and winter (2006) and was 152 ± 4 mg/l in TS–OP, but was much elevated (209 ± 1 mg/l) at the UTS–OP. Its concentration was lower in the pre-monsoon (2006) than the previous pre-monsoon (2005) and was 113 ± 6 mg/l in TS–OP and was higher (145 ± 5 mg/l) at the UTS–OP. Its concentration was lower in the monsoon (2006) than the previous monsoon (2005) and was 104 ± 7 mg/l at the TS–OP; however, was more elevated (137 ± 7 mg/l) at UTS–OP. It clearly showed that HCO_3^- increased at the TS–DS than that of the TS–US (Figure 2g) and also in the UTS–DS than that of the UTS–US point across the seasons (Figure 3g). Its concentration showed significant spatial variation across different sampling points in TS ($P < 0.05$, $F = 6.624817$, $df = 2$) and in UTS input zone of the canal ($P < 0.05$, $F = 11.78365$, $df = 2$). It was higher in the UTS input zone compared to that of the TS input zone in the canal, because of the former contained more allochthonous substsnces. The average bicarbonates were 64, 128, 38 and 225 mg/l in Indus, Ganges, Brahmaputra and Narmada rivers, respectively (Subramanian, 1983) while it was lower (103 mg/l) in Hoylandet stream (Blakar and Hongve, 1997); however it was higher (263 mg/l) in the Pinios River (Greece) (Fytianos et al., 2002) compared to that of the present findings. In consistence to the present findings the average HCO_3^- was higher in downs-tream (256 mg/l) than that of the up-stream (180 mg/l) in Llobregat river (Fernandez–Turiel et al., 2003). Moreover, it was lower in monsoon (17and 13 mg/l) than that of the non-monsoon season (24 and 80 mg/l, respectively) in the Periyar and Chalakudy rivers (Maya et al., 2007).

CO_3^{2-}: The average concentration of CO_3^{2-} presented in Figure 1h, was 4.7 ± 1 mg/l at the TS–OP, which increased (41 %) in the TS–DS point than that of the TS–US point. It was higher (8.7 ± 2 mg/l) in the UTS–OP, and increased in the UTS–DS than that of the UTS–US. Its concentration was higher in pre-monsoon (2005) than monsoon (2005) and was 3.1 ± 1 mg/l in TS–OP, but was higher (7 ± 2 mg/l) at the UTS–OP. Its concentration in monsoon (2005) decreased to 3.2 ± 1 mg/l at the TS–OP and was higher (5 ± 2 mg/l) at UTS–OP. However, its concentration in winter (2006) was elevated (6.7 ± 1 mg/l) at TS–OP and was higher (9 ± 3 mg/l) in the UTS–OP. Its concentration in summer (2006) increased compared to that of the pre-monsoon and monsoon (2005) and winter (2006) and was 11 ± 2 mg/l in TS–OP, which was elevated to 18 ± 3 mg/l at the UTS–OP. However, its concentration was lower in the pre-monsoon (2006) than that of the previous pre-monsoon (2005) and was 2.1 ± 0 mg/l in TS–OP, and was further higher (8 ± 2 mg/l) at the UTS–OP. However, its concentration was lower in the monsoon (2006) than that of the previous monsoon (2005) and was 1.8 ± 0.5 mg/l at the TS–OP and was higher (5 ± 2 mg/l) at UTS–OP. It increased at the TS–DS than that of the TS–US (Figure 2h) and in the UTS–DS than that of the UTS–US point across all the seasons across the seasons (Figure 3h). The CO_3^{2-} showed significant temporal variation across different seasons in TS ($P < 0.05$, $F = 3.899268$, $df = 17$); and in UTS input zone of the canal ($P < 0.05$, $F = 3.540748$, $df = 17$), and spatial variation across the sampling points in UTS input zone of the canal ($P < .05$, $F = 2.641188$, $df = 2$). It was significantly higher in the UTS input zone than that of the TS input zone, and at the down-stream than that of the up-stream of the canal, as the former contained more concentrated allochthonous substances. The average concentrations of CO_3^{2-} were elevated (8 mg/l) in the summer compared to 4 mg/l) in winter in Hindon river (Jain et al., 2002).

Total alkalinity: The average concentration of total alkalinity presented in Figure 1i, was 182 ± 1 mg/l at the TS–OP, which increased in the TS–DS than that of the TS–US. It was higher (224 ± 1 mg/l) in the UTS–OP and also increased in the UTS–DS than that of the UTS–US. Its concentration was higher in pre-monsoon than that of monsoon (2005), and was 201 + 1 mg/l in TS–OP; however, it was more elevated (232 ± 12 mg/l) at the UTS–OP. Its concentration in monsoon (2005) decreased to 181 ± 7 mg/l at the TS–OP, but was higher (219 ± 11 mg/l) at UTS–OP. Its concentration in winter (2006) increased and was 209 ± 6 mg/l at TS–OP; it was more elevated (253 ± 9 mg/l) in the UTS–OP. Its concentration in summer decreased compared to that of the winter (2006) and was 197 ± 1 mg/l in TS–OP, but was more higher (232 ± 1 mg/l) at the UTS–OP. However, its concentration was lower in the pre-monsoon and monsoon (2006) than the earlier previous pre-monsoon and monsoon (2005) and was 162 ± 11 mg/l in TS–OP, but was more elevated (221 ± 12 mg/l) at the UTS–OP in the pre-monsoon (2006) while it was 146 ± 6 mg/l at the TS–OP and was higher (191 ± 18 mg/l) at UTS–OP

in the monsoon (2006). Its concentration clearly showed increase at the TS–DS than that of the TS–US (Figure 2i) as well as in the UTS–DS than that of the UTS–US point (Figure 3i). Therefore, alkalinity showed significant temporal variation across different seasons in TS input zone ($P < 0.05$, $F = 2.332869$, $df = 17$); spatial variation across the sampling points in TS ($P < 0.05$, $F = 5.358109$, $df = 2$) as well as in UTS input zones of the canal ($P < .05$, $F = 9.339015$, $df = 2$). Its concentrations were significantly higher in the UTS input zone than that of the TS input zone, and in down-stream compared to that of the up-stream of the canal, due to the former containing more concentrated allochthonous substances. The average concentration of alkalinity was 294 mg/l in the Hindon river (Jain et al., 2002), which was higher than that of the present values. It ranged from179 to 205 mg/l during 1997–2000 in Vrgorska river (Bosnia) (Stambuk, 2003) and 150 to 600 and 80 to 250 mg/l in winter and summer, respectively in Yamuna river (Ravindra et al., 2003). The alkalinity was 324, 286 and 268 and 321, 263 and 238 mg/l, respectively during winter, summer and rainy season in the up-stream and down-stream in Vrishabhavathy river (Bangalore) (Ahipahty and Puttaiah, 2006).

Spatial similarity and site grouping

Bray-curtis cluster analysis (CA) applied to find out spatial similarity grouping the six sampling sites at the UTS and TS input zone based on the cations and anions parameters of surface water of the canal rendered a dendrogram. It depicted two statistically significant clusters (Figure 4). The clustering procedure generated two groups of sites in a very convincing manner. Interestingly, cluster 1 comprised of sites of UTS–OP, UTS–DS and TS–DS, while cluster 2 included sites of TS–OP, TS–US and UTS–US. Cluster 1 and 2 indicated relatively high and low pollution points respectively in the canal region. It implied that for rapid assessment of canal water quality, only one of the sites in each cluster may serve as good in spatial assessment as the whole monitoring network. The CA technique is useful in offering reliable classification of surface waters in the canal and may make possible to design a future spatial sampling strategy in an optimal manner (Singh et al., 2005).

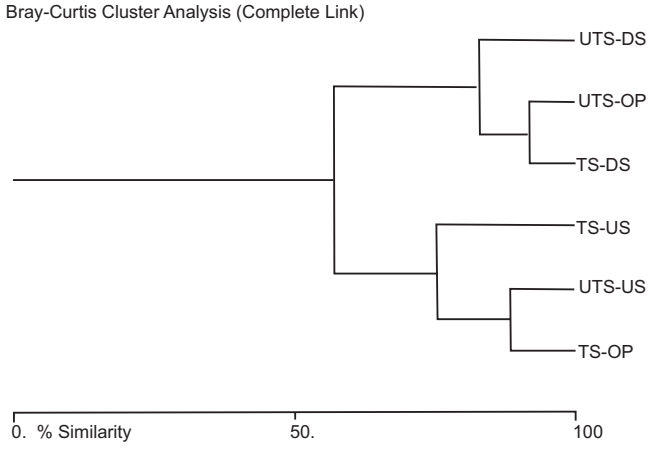


Figure 4: Dendogram showing similarity clusters based on the water quality parameters of the Buckingham canal.

Conclusion

It is concluded that the water quality in the Buckingham canal was severely modified by input of both untreated and treated municipal sewage and the deterioration was in progress and higher towards downstream. The cations and anions showed significant spatial and temporal variations, because of input of the UTS and TS. These parameters were higher in the UTS input zone than that of the TS input zone, at down-stream compared to that of the up-stream, and in the summer than during monsoon, except K and alkalinity, in both the TS and UTS input zone of the canal water. The K and alkalinity were in higher concentration during winter at both the zones. Thus, the canal was found severely polluted at both the UTS as well as TS input zones. Therefore, it is suggested that the untreated municipal sewage needs treatment through a STP – extended aeration activated sludge treatment, prior to its release into the canal; so that the burden of sewage pollution on the canal water quality can be minimal.

Acknowledgement

AYP remains grateful to Pondicherry University for providing grants covering a University Research Fellowship to him.

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