# EVALUATION OF WATER QUALITY
# AND POLLUTION SOURCES OF GULSHAN LAKE

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**DEPARTMENT OF CIVIL ENGINEERING**
**BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY**
**DHAKA, BANGLADESH**

**JULY, 2011**

# EVALUATION OF WATER QUALITY AND POLLUTION SOURCES OF GULSHAN LAKE

A THESIS SUBMITTED BY

MD. IBRAHIM SABIT

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

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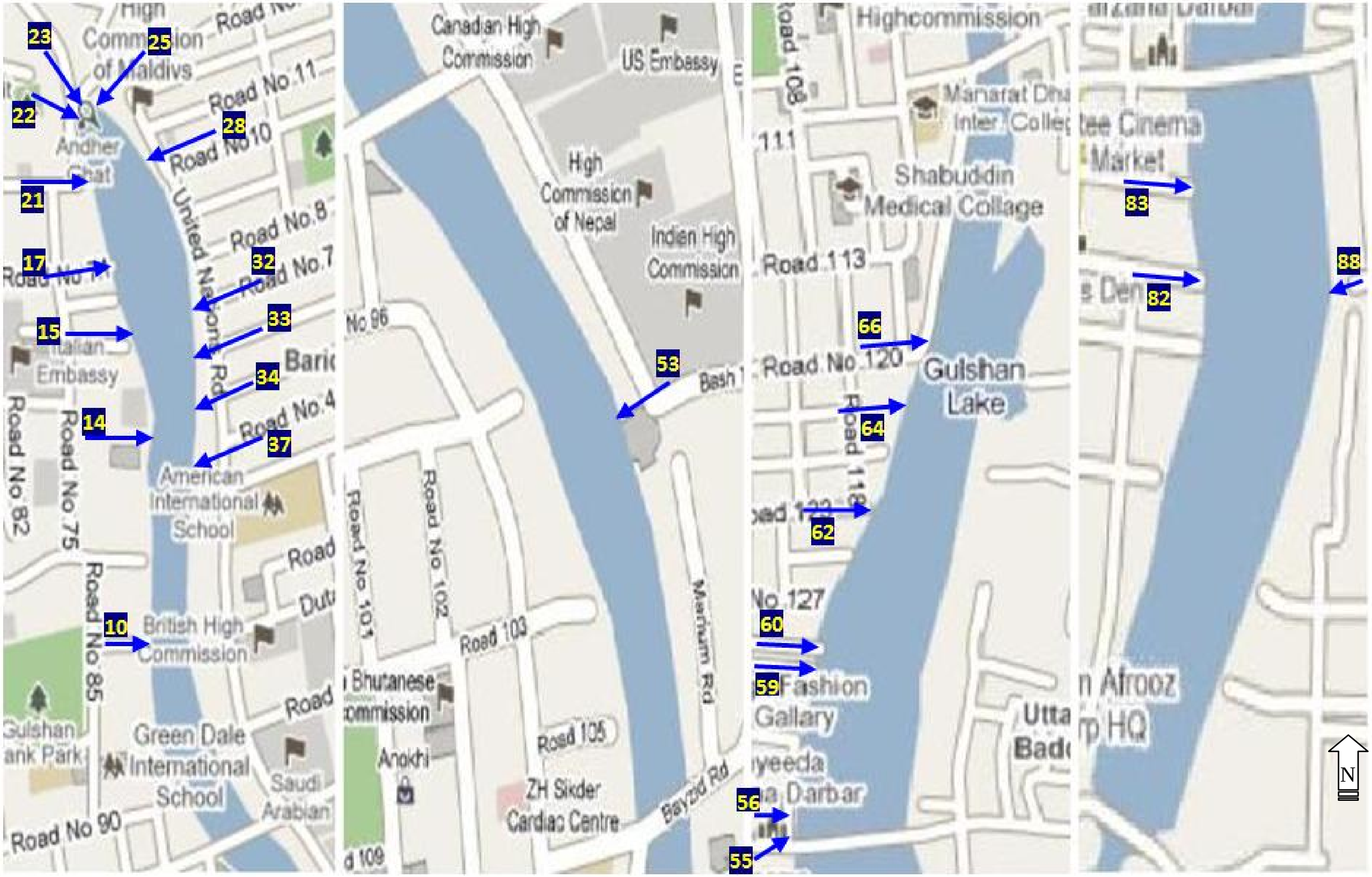
# Appendix B

Major outfalls along Gulshan Lake


23
25
22
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10
High Commission of Maldivs
Andher Ghat
Road No 11
Road No 10
Road No 8
Road No 7
Road No 4
United Nations Rd
Italian Embassy
American International School
British High Commission
Green Dale International School
Saudi Arabian
Gulshan Park
Road No 82
Road No 75
Road No 85
Road No 90
Canadian High Commission
US Embassy
High Commission of Nepal
Indian High Commission
53
Road No 101
Road No 102
Road 103
Road 105
Bhutanese Commission
Anokhi
ZH Sikder Cardiac Centre
Bayzid Rd
Marium Rd
Highcommission
Manarat Dhaka Inter. College
Shabuddin Medical Collage
Road 113
Road No 120
Gulshan Lake
66
64
62
60
59
56
55
No 127
Fashion Gallary
Road 108
Road 118
Market
83
82
88
N

# Appendix C

Table C1: Analytical methods used for determination of water quality parameter

| Elements | Method Used | Equipment | MDL |
|---|---|---|---|
| pH | USEPA 150.1;<br>SM 4500-$H^+$ B | WTW Glass Probes,<br>HACH HQ10 pH Meter | <1 |
| Conductivity | USEPA 120.1; SM 2510 B | WTW EC Probes,<br>HACH EC Probes | 0.1 S/cm |
| Turbidity | USEPA 180.1 Rev 2;<br>SM 2130 B | HACH Portable Turbidimeter,<br>DR Lange Turbidimeter | 0.01 NTU |
| Color | USEPA 110.2; SM 2120 C | DR 4000 UV Spectrophotometer | 0.01 Pt-Co units |
| TDS | USEPA 160.2;<br>SM 2540 B-D | Oven | 5 mg/L |
| TSS | USEPA 160.2; SM 2540 D | Oven | 5 mg/L |
| DO | SM 4500-O B & G;<br>USEPA 360.3 & 360.2 | WTW DO Meter<br>HACH LDO Meter | 0.1 mg/L |
| $SO_4^{2-}$ | USEPA 375.4;<br>SM 4500-$SO_4$ | DR 4000 UV Spectrophotometer | 7 mg/L |
| $S^{2-}$ | USEPA 376.2 | DR 4000 UV Spectrophotometer | 0.002 mg/L |
| $PO_4^{3-}$ | USEPA 365.1;<br>SM 4500-$PO_4$ | DR 4000 UV Spectrophotometer | 0.04 mg/L |
| $NO_3$-N | USEPA 353.2;<br>SM 4500-$NO_3$-N-F | DR 4000 UV Spectrophotometer | 0.1 mg/L |
| $NO_2$-N | USEPA 353.2;<br>SM 4500-$NO_2$-N-F | DR 4000 UV Spectrophotometer | 0.008 mg/L |
| $NH_3$-N | USEPA 350.1;<br>SM 4500-$NH_3$-B | DR 4000 UV Spectrophotometer | 0.017 mg/L |
| $BOD_5$ | USEPA 405.1; SM 5210 B;<br>SM 5210 D | DR 4000 UV Spectrophotometer | 0.2 mg/L |
| COD | USEPA 410.4; SM 5220 D | DR 4000 UV Spectrophotometer | 2 mg/L |
| FC | SM 9222 G | Filtration System with Vacuum<br>Pump; incubator | 0 per 100 mL |
| Cd | USEPA 213.2; SM 3113 B | Shimadzu AA-6800 HVG FLAAS | 0.1 mg/L |
| Cr | USEPA 200.9 Rev 2.2;<br>SM 3111 B | Shimadzu AA-6800 GFAAS | 0.001 mg/L |
| Pb | USEPA 200.9 Rev 2.2;<br>SM 3111 B | Shimadzu AA-6800 GFAAS;<br>Shimadzu AA-6800 FLAAS | 0.01 mg/L |

*(Source: Environmental Engineering Laboratory, Department of Civil Engineering, BUET)*

# Appendix D

Test Results of Chemical Analysis of Water and Sediment Samples collected from Gulshan Lake

Table D1: Test Results of water samples collected on Nov’09

| Sl. | Parameter | Unit | W-1 | W-2 | W-3 | W-4 | W-5 | W-6 | W-7 | W-8 | W-9 | W-10 | W-11 | W-12 | W-13 | W-14 | W-15 | W-16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | pH | ---- | 7.46 | 7.46 | 7.57 | 7.49 | 7.42 | 7.51 | 7.41 | 7.47 | 7.57 | 7.55 | 7.7 | 7.69 | 7.64 | 7.67 | 7.65 | 7.7 |
| 2 | EC | µS/cm | 450 | 451 | 441 | 442 | 421 | 444 | 456 | 467 | 464 | 470 | 470 | 471 | 466 | 462 | 464 | 464 |
| 3 | Color | Pt-Co | 144 | 134 | 179 | 140 | 136 | 109 | 200 | 128 | 115 | 151 | 120 | 103 | 114 | 86 | 102 | 85 |
| 4 | TSS | mg/L | 33 | 30 | 27 | 11 | 3 | 4 | 10 | 4 | 2 | 46 | 7 | 0 | 110 | 14 | 3 | 48 |
| 5 | TDS | mg/L | 226 | 275 | 248 | 225 | 231 | 216 | 243 | 242 | 255 | 230 | 254 | 250 | 235 | 233 | 241 | 219 |
| 6 | DO | mg/L | 0.03 | 0.04 | 0.05 | 0.04 | 0.07 | 0.1 | 0.04 | 0.07 | 0.06 | 0.03 | 0.55 | 0.84 | 0.1 | 0.26 | 0.53 | 1.56 |
| 7 | BOD$_5$ | mg/L | 18 | 17.6 | 5.6 | 17.6 | 9.6 | 7.6 | 13.6 | 20 | 2.8 | 11.6 | 2.8 | 1.6 | 0.5 | 0.57 | 1 | 1.6 |
| 8 | COD | mg/L | 80 | 72 | 71 | 67 | 60 | 34 | 73 | 95 | 34 | 80 | 57 | 60 | 23 | 22 | 36 | 50 |
| 9 | NH$_3$-N | mg/L | 14.73 | 9.2 | 11.28 | 12.63 | 9.68 | 8.3 | 9.85 | 12.7 | 15.03 | 14.3 | 15.68 | 15.95 | 14.93 | 13.93 | 13.55 | 13.35 |
| 10 | NO$_3$-N | mg/L | 0.2 | -- | 0.2 | -- | 0.2 | -- | 0.2 | -- | 0.2 | -- | 0.2 | -- | 0.2 | -- | 0.2 | -- |
| 11 | NO$_2$-N | mg/L | -- | -- | 0.0086 | -- | -- | -- | 0.011 | -- | -- | -- | 0.0132 | -- | -- | -- | 0.0176 | -- |
| 12 | PO$_4$ | mg/L | 0.599 | 1.206 | 1.014 | 1.436 | 1.737 | 2.076 | 1.722 | 1.695 | 1.956 | 1.728 | 4.09 | 3.266 | 4.934 | 4.824 | 4.982 | 5.094 |
| 13 | S$^{2-}$ | µg/L | -- | -- | 0.024 | -- | -- | -- | 0.023 | -- | -- | -- | 0.02 | -- | -- | -- | 0.018 | -- |
| 14 | Pb | mg/L | -- | -- | 0.018 | -- | -- | -- | 0.014 | -- | -- | -- | 0.011 | -- | -- | -- | 0.012 | -- |
| 15 | FC | /100 ml | -- | -- | 12100 | -- | -- | -- | TNTC | -- | -- | -- | 14400 | -- | -- | -- | TNTC | -- |

Table D2: Test Results of water samples collected on Dec’09

| Sl. | Parameter | Unit | W-1 | W-2 | W-3 | W-4 | W-5 | W-6 | W-7 | W-8 | W-9 | W-10 | W-11 | W-12 | W-13 | W-14 | W-15 | W-16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | pH | ---- | 7.68 | 7.79 | 7.86 | 7.75 | 7.59 | 8.04 | 7.75 | 7.81 | 7.65 | 7.66 | 7.76 | 7.74 | 7.83 | 7.84 | 7.85 | 7.83 |
| 2 | EC | µS/cm | 483 | 475 | 474 | 477 | 467 | 475 | 497 | 507 | 497 | 496 | 505 | 515 | 507 | 505 | 508 | 508 |
| 3 | Color | Pt-Co | 108 | 160 | 134 | 156 | 108 | 174 | 146 | 194 | 122 | 142 | 136 | 96 | 94 | 86 | 82 | 86 |
| 4 | TSS | mg/L | 86 | 57 | 66 | 112 | 63 | 95 | 141 | 127 | 60 | 3 | 9 | 9 | 66 | 53 | 26 | 12 |
| 5 | TDS | mg/L | 236 | 258 | 264 | 269 | 265 | 254 | 222 | 273 | 239 | 287 | 266 | 281 | 248 | 244 | 255 | 262 |
| 6 | DO | mg/L | 1.31 | 1.64 | 2.36 | 0.51 | 0.07 | 3.74 | 0.14 | 0.47 | 0.3 | 0.1 | 0.48 | 0.28 | 2.92 | 2.11 | 2.38 | 2.24 |
| 7 | $BOD_5$ | mg/L | 15.6 | 18 | 9.6 | 7.6 | 11.6 | 10 | 18 | 24 | 14 | 14 | 17.6 | 19.2 | 9.8 | 11.3 | 11.8 | 14.8 |
| 8 | COD | mg/L | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 9 | $NH_3$-N | mg/L | 16.25 | 16.975 | 16.3 | 15 | 14.575 | 15.625 | 12.4 | 15.4 | 14.925 | 15.85 | 16.525 | 17.125 | 9.65 | 17.275 | 19.075 | 15.35 |
| 10 | $NO_3$-N | mg/L | 0.2 | -- | 0.2 | -- | 0.3 | -- | 0.2 | -- | 0.2 | -- | 0.1 | -- | 0.2 | -- | 0.2 | -- |
| 11 | $NO_2$-N | mg/L | -- | -- | 0.0148 | -- | -- | -- | 0.012 | -- | -- | -- | 0.0146 | -- | -- | -- | 0.0328 | -- |
| 12 | $PO_4$ | mg/L | 0.337 | 0.294 | 0.318 | 0.441 | 0.27 | 0.294 | 0.325 | 0.215 | 2.178 | 2.158 | 1.714 | 3.398 | 4.632 | 4.814 | 4.552 | 5.048 |
| 13 | $S^{2-}$ | µg/L | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 14 | Pb | mg/L | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 15 | FC | /100 ml | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |

Table D3: Test Results of water samples collected on Jan’10

| Sl. | Parameter | Unit | W-1 | W-2 | W-3 | W-4 | W-5 | W-6 | W-7 | W-8 | W-9 | W-10 | W-11 | W-12 | W-13 | W-14 | W-15 | W-16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | pH | ---- | 7.63 | 7.64 | 7.65 | 7.7 | 7.77 | 7.74 | 7.69 | 7.77 | 7.74 | 7.73 | 7.83 | 7.8 | 7.82 | 7.83 | 7.81 | 7.83 |
| 2 | EC | µS/cm | 430 | 431 | 427 | 425 | 431 | 430 | 439 | 433 | 441 | 438 | 464 | 457 | 482 | 479 | 487 | 487 |
| 3 | Color | Pt-Co | 172 | 184 | 96 | 175 | 135 | 150 | 164 | 177 | 104 | 170 | 135 | 156 | 113 | 135 | 121 | 118 |
| 4 | TSS | mg/L | 82 | 51 | 32 | 43 | 33 | 63 | 59 | 47 | 32 | 37 | 8 | 13 | 22 | 17 | 19 | 3 |
| 5 | TDS | mg/L | 269 | 304 | 293 | 279 | 295 | 269 | 279 | 280 | 286 | 274 | 282 | 270 | 277 | 295 | 305 | 293 |
| 6 | DO | mg/L | 0.19 | 0.1 | 0.09 | 0.33 | 1.45 | 0.62 | 0.09 | 1.18 | 0.4 | 0.54 | 0.69 | 0.57 | 0.81 | 0.48 | 0.6 | 0.66 |
| 7 | BOD$_5$ | mg/L | 30 | 17.1 | 18.3 | 14.6 | 16.4 | 12.4 | 19.6 | 20 | 11.7 | 9.2 | 11.7 | 9.2 | 4.8 | 7.2 | 6 | 7.2 |
| 8 | COD | mg/L | 120 | 111 | 115 | 122 | 137 | 118 | 118 | 121 | 108 | 126 | 105 | 107 | 78 | 87 | 86 | 87 |
| 9 | $NH_3$-N | mg/L | 12.78 | 13.45 | 14.73 | 13.78 | 12.78 | 18 | 16.15 | 14.4 | 12.5 | 14.25 | 14 | 13.75 | 15 | 15.75 | 16 | 14 |
| 10 | $NO_3$-N | mg/L | 0.1 | -- | 0.1 | -- | 0 | -- | 0 | -- | 0 | -- | 0 | -- | 0.2 | -- | 0.1 | -- |
| 11 | $NO_2$-N | mg/L | -- | -- | 0.0002 | -- | -- | -- | 0 | -- | -- | -- | 0 | -- | -- | -- | 0 | -- |
| 12 | $PO_4$ | mg/L | 0.383 | 0.29 | 0.25 | 0.21 | 0.321 | 0.29 | 0.36 | 0.34 | 0.806 | 0.597 | 1.18 | 1.639 | 3.898 | 3.436 | 4.222 | 3.842 |
| 13 | $S^{2-}$ | µg/L | -- | -- | 0.022 | -- | -- | -- | 0.036 | -- | -- | -- | 0.042 | -- | -- | -- | 0.025 | -- |
| 14 | Pb | mg/L | -- | -- | 0.032 | -- | -- | -- | 0.036 | -- | -- | -- | 0.04 | -- | -- | -- | 0.039 | -- |
| 15 | FC | /100 ml | -- | -- | 62000 | -- | -- | -- | 338000 | -- | -- | -- | 390000 | -- | -- | -- | 90000 | -- |

Table D4: Test Results of water samples collected on Mar’10

| Sl. | Parameter | Unit | W-1 | W-2 | W-3 | W-4 | W-5 | W-6 | W-7 | W-8 | W-9 | W-10 | W-11 | W-12 | W-13 | W-14 | W-15 | W-16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | pH | ---- | 7.32 | 7.35 | 7.37 | 7.34 | 7.34 | 7.33 | 7.33 | 7.32 | 7.43 | 7.4 | 7.37 | 7.36 | 7.44 | 7.43 | 7.62 | 7.63 |
| 2 | EC | µS/cm | 515 | 515 | 511 | 514 | 528 | 526 | 543 | 536 | 591 | 585 | 614 | 616 | 642 | 643 | 643 | 640 |
| 3 | Color | Pt-Co | 198 | 189 | 164 | 186 | 92 | 109 | 106 | 151 | 160 | 128 | 88 | 96 | 106 | 146 | 130 | 124 |
| 4 | TSS | mg/L | 44 | 39 | 51 | 75 | 44 | 40 | 8 | 33 | 10 | 42 | 46 | 31 | 27 | 29 | 92 | 25 |
| 5 | TDS | mg/L | 309 | 326 | 314 | 289 | 290 | 294 | 315 | 310 | 351 | 337 | 317 | 333 | 333 | 337 | 300 | 354 |
| 6 | DO | mg/L | 0.05 | 0.06 | 0.04 | 0.04 | 0.06 | 0.08 | 0.06 | 0.09 | 0.13 | 0.08 | 0.08 | 0.06 | 0.1 | 0.57 | 0.07 | 0.47 |
| 7 | BOD$_5$ | mg/L | 38 | 12 | 18 | 20 | 16 | 20 | 22 | 20 | 26 | 20 | 20 | 24 | 22 | 18 | 28 | 20 |
| 8 | COD | mg/L | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 9 | NH$_3$-N | mg/L | 12 | 12.25 | 13.25 | 12.75 | 12.75 | 14 | 15.75 | 14.5 | 19 | 14.25 | 18.25 | 18 | 21 | 21.75 | 18.75 | 19.75 |
| 10 | NO$_3$-N | mg/L | 0 | -- | 0 | -- | 0 | -- | 0 | -- | 0 | -- | 0 | -- | 0 | -- | 0 | -- |
| 11 | NO$_2$-N | mg/L | -- | -- | 0.008 | -- | -- | -- | 0 | -- | -- | -- | 0 | -- | -- | -- | 0.006 | -- |
| 12 | PO$_4$ | mg/L | 1.76 | 2.14 | 0.95 | 1.18 | 1.93 | 2.15 | 3.14 | 2.14 | 7 | 5.65 | 6.85 | 6.45 | 7.4 | 8.55 | 8.55 | 8.35 |
| 13 | S$^{2-}$ | µg/L | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 14 | Pb | mg/L | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 15 | FC | /100 ml | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |

Table D5: Test Results of water samples collected on May'10

| Sl. | Parameter | Unit | W-1 | W-2 | W-3 | W-4 | W-5 | W-6 | W-7 | W-8 | W-9 | W-10 | W-11 | W-12 | W-13 | W-14 | W-15 | W-16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | pH | ---- | 7.13 | 7.28 | 7.35 | 7.38 | 7.33 | 7.43 | 7.32 | 7.45 | 7.34 | 7.38 | 7.39 | 7.42 | 7.51 | 7.52 | 7.44 | 7.52 |
| 2 | EC | µS/cm | 482 | 479 | 476 | 478 | 499 | 500 | 507 | 504 | 513 | 513 | 524 | 521 | 511 | 511 | 512 | 511 |
| 3 | Color | Pt-Co | 148 | 188 | 119 | 177 | 121 | 126 | 146 | 145 | 137 | 117 | 131 | 130 | 76 | 82 | 86 | 80 |
| 4 | TSS | mg/L | 30 | 6 | 49 | 3 | 15 | 6 | 5 | 39 | 3 | 5 | 8 | 4 | 34 | 5 | 10 | 15 |
| 5 | TDS | mg/L | 299 | 297 | 283 | 297 | 309 | 291 | 306 | 295 | 338 | 328 | 346 | 328 | 338 | 348 | 355 | 335 |
| 6 | DO | mg/L | 0.27 | 0.1 | 0.88 | 1.08 | 0.36 | 1.42 | 0.1 | 1.48 | 0.24 | 1.33 | 1.67 | 1.69 | 1.76 | 1.86 | 1.9 | 1.62 |
| 7 | $BOD_5$ | mg/L | 7 | 27.2 | 46.4 | 17.6 | 32 | 17.6 | 36.8 | 15 | 6.8 | 22 | 12.8 | 24 | 14 | 14.4 | 18 | 5.5 |
| 8 | COD | mg/L | 60.8 | 59 | 26 | 49 | 38 | 48 | 31 | 62.4 | 57 | 63 | 67 | 63 | 64 | 56 | 58 | 57 |
| 9 | $NH_3$-N | mg/L | 11.75 | 12.5 | 12 | 14 | 13.25 | 11.75 | 14 | 13.25 | 10.75 | 12 | 12.5 | 10 | 4.75 | 5.25 | 4.25 | 6 |
| 10 | $NO_3$-N | mg/L | 0 | -- | 0 | -- | 0 | -- | 0 | -- | 0 | -- | 0 | -- | 0 | -- | 0 | -- |
| 11 | $NO_2$-N | mg/L | -- | -- | 0 | -- | -- | -- | 0 | -- | -- | -- | 0 | -- | -- | -- | 0 | -- |
| 12 | $PO_4$ | mg/L | 2.3 | 2.65 | 2.2 | 2.2 | 2.9 | 2.3 | 2.5 | 2.15 | 4.88 | 4.58 | 5.12 | 5.02 | 5.82 | 6.21 | 6.96 | 6.85 |
| 13 | $S^{2-}$ | µg/L | -- | -- | 0.024 | -- | -- | -- | 0.023 | -- | -- | -- | 0.02 | -- | -- | -- | 0.01 | -- |
| 14 | Pb | mg/L | -- | -- | 0.041 | -- | -- | -- | 0.038 | -- | -- | -- | 0.04 | -- | -- | -- | 0.042 | -- |
| 15 | FC | /100 ml | -- | -- | TNTC | -- | -- | -- | TNTC | -- | -- | -- | TNTC | -- | -- | -- | TNTC | -- |

Table D6: Test Results of water samples collected on Aug'10

| Sl. | Parameter | Unit | W-1 | W-2 | W-3 | W-4 | W-5 | W-6 | W-7 | W-8 | W-9 | W-10 | W-11 | W-12 | W-13 | W-14 | W-15 | W-16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | pH | ---- | 6.41 | 6.46 | 6.61 | 6.78 | 6.79 | 6.74 | 6.94 | 7 | 7.14 | 7.07 | 7.09 | 7.08 | 7.24 | 7.23 | 7.23 | 7.15 |
| 2 | EC | µS/cm | 418 | 422 | 429 | 428 | 423 | 425 | 428 | 435 | 446 | 441 | 457 | 458 | 459 | 461 | 456 | 456 |
| 3 | Color (Test) | Pt-Co | 138 | 121 | 80 | 118 | 99 | 85 | 109 | 101 | 103 | 113 | 92 | 103 | 76 | 87 | 82 | 99 |
| 4 | TSS | mg/L | 112 | 56 | 119 | 63 | 95 | 66 | 75 | 139 | 129 | 102 | 115 | 110 | 123 | 116 | 119 | 123 |
| 5 | TDS | mg/L | 185 | 172 | 164 | 189 | 201 | 178 | 199 | 165 | 175 | 195 | 181 | 150 | 147 | 158 | 137 | 171 |
| 6 | DO | mg/L | 0.38 | 0.24 | 0.36 | 0.09 | 0.13 | 0.07 | 0.1 | 0.14 | 0.1 | 0.11 | 0.11 | 0.06 | 0.93 | 0.42 | 1.78 | 0.05 |
| 7 | $BOD_5$ | mg/L | 16.8 | 19.2 | 17.6 | 12.8 | 14.4 | 9.2 | 12.2 | 10.6 | 12.4 | 8.6 | 11.2 | 13.2 | 9.8 | 12 | 11.4 | 8.8 |
| 8 | COD | mg/L | 62 | 53 | 52 | 34 | 32 | 42 | 48 | 41 | 50 | 60 | 37 | 44 | 50 | 58 | 54 | 50 |
| 9 | $NH_3$-N | mg/L | 2.75 | 2 | 3 | 3 | 2.25 | 1.5 | 3 | 2.25 | 1.75 | 1.25 | 2 | 0.75 | 1.75 | 1.5 | 1.25 | 1.25 |
| 10 | $NO_3$-N | mg/L | 0.4 | -- | 0.4 | -- | 0.4 | -- | 0.4 | -- | 0.4 | -- | 0.4 | -- | 0.4 | -- | 0.4 | -- |
| 11 | $NO_2$-N | mg/L | -- | -- | 0.008 | -- | -- | -- | 0.006 | -- | -- | -- | 0.004 | -- | -- | -- | 0.005 | -- |
| 12 | $PO_4$ | mg/L | 3.1 | 3.5 | 4.15 | 4.6 | 4.5 | 4.1 | 3.9 | 4.55 | 3.95 | 4.4 | 4.7 | 5.4 | 5.5 | 4.5 | 4.15 | 5.35 |
| 13 | $S^{2-}$ | µg/L | -- | -- | 0.015 | -- | -- | -- | 0.015 | -- | -- | -- | 0.005 | -- | -- | -- | 0.003 | -- |
| 14 | Pb | mg/L | -- | -- | 0.017 | -- | -- | -- | 0.029 | -- | -- | -- | 0.01 | -- | -- | -- | 0.014 | -- |
| 15 | FC | /100 ml | -- | -- | TNTC | -- | -- | -- | TNTC | -- | -- | -- | TNTC | -- | -- | -- | TNTC | -- |

Table D7: Moisture content and organic matter content for sediment samples collected on 30 May 2010

| Sediment Sample | Weight (g) | | | | Moisture Content (%) | Org. matter Content (%) |
|---|---|---|---|---|---|---|
| | Crucible | Crucible with raw sediment | Heating after 24 h in oven (100ºC) | Heating after 1 hr in heater (500ºC) | | |
| S-1 | 37.9194 | 83.3971 | 49.5088 | 48.3124 | 40.7 | 2.5 |
| S-2 | 36.6577 | 73.7604 | 43.1966 | 42.196 | 41.5 | 2.4 |
| S-3 | 38.7797 | 83.0276 | 47.141 | 45.9613 | 43.3 | 2.6 |
| S-4 | 34.7772 | 66.7302 | 39.804 | 39.1098 | 40.4 | 1.8 |

Table D8: Data from experiments for determination of ex-situ SOD of sediment samples

(a) Sample S1

| Time, min | DO, mg/L | Time, min | DO, mg/L |
|---|---|---|---|
| 1 | 5.59 | 114 | 5.10 |
| 2 | 5.58 | 126 | 5.08 |
| 4 | 5.58 | 135 | 5.05 |
| 6 | 5.58 | 153 | 5.00 |
| 8 | 5.56 | 163 | 4.93 |
| 10 | 5.55 | 178 | 4.90 |
| 12 | 5.54 | 195 | 4.83 |
| 14 | 5.53 | 202 | 4.72 |
| 16 | 5.53 | 209 | 4.69 |
| 23 | 5.5 | 282 | 3.32 |
| 25 | 5.49 | 300 | 3.20 |
| 32 | 5.46 | 315 | 2.93 |
| 38 | 5.43 | 330 | 2.27 |
| 45 | 5.40 | 360 | 1.15 |
| 57 | 5.37 | 365 | 0.62 |
| 64 | 5.33 | 375 | 0.35 |
| 77 | 5.27 | 380 | 0.12 |
| 86 | 5.22 | 382 | 0.05 |
| 98 | 5.17 | 383 | 0.02 |
| 110 | 5.11 | 384 | 0.02 |

Table D8: Data from experiments for determination of ex-situ SOD of sediment samples

(b) Sample S2

| Time, min | DO, mg/L | Time, min | DO, mg/L |
|---|---|---|---|
| 1 | 4.88 | 36 | 4.29 |
| 2 | 4.81 | 37 | 4.28 |
| 3 | 4.74 | 38 | 4.27 |
| 4 | 4.74 | 39 | 4.26 |
| 5 | 4.72 | 40 | 4.25 |
| 6 | 4.70 | 41 | 4.24 |
| 7 | 4.69 | 42 | 4.23 |
| 8 | 4.68 | 43 | 4.21 |
| 9 | 4.66 | 44 | 4.20 |
| 10 | 4.65 | 45 | 4.19 |
| 11 | 4.64 | 50 | 4.04 |
| 12 | 4.64 | 55 | 3.98 |
| 13 | 4.63 | 60 | 3.96 |
| 14 | 4.61 | 65 | 3.92 |
| 15 | 4.61 | 70 | 3.91 |
| 16 | 4.57 | 80 | 3.91 |
| 17 | 4.57 | 90 | 3.89 |
| 18 | 4.57 | 100 | 3.72 |
| 19 | 4.55 | 110 | 3.64 |
| 20 | 4.55 | 120 | 3.57 |
| 21 | 4.54 | 130 | 3.54 |
| 22 | 4.53 | 145 | 3.52 |
| 23 | 4.52 | 160 | 3.50 |
| 24 | 4.51 | 175 | 3.48 |
| 25 | 4.50 | 190 | 3.45 |
| 26 | 4.49 | 205 | 3.42 |
| 27 | 4.47 | 220 | 3.39 |
| 28 | 4.44 | 235 | 3.35 |
| 29 | 4.42 | 360 | 2.17 |
| 30 | 4.40 | 390 | 1.95 |
| 31 | 4.35 | 420 | 1.62 |
| 32 | 4.34 | 440 | 1.14 |
| 33 | 4.33 | 460 | 0.76 |
| 34 | 4.32 | 480 | 0.38 |
| 35 | 4.31 | | |

Table D8: Data from experiments for determination of ex-situ SOD of sediment samples
(c) Sample S3

| Time, min | DO, mg/L | Time, min | DO, mg/L |
|---|---|---|---|
| 1 | 5.00 | 115 | 4.62 |
| 3 | 5.17 | 128 | 4.53 |
| 5 | 5.29 | 154 | 4.32 |
| 7 | 5.37 | 169 | 4.20 |
| 9 | 5.46 | 186 | 4.09 |
| 11 | 5.56 | 252 | 3.15 |
| 13 | 5.57 | 274 | 1.73 |
| 15 | 5.56 | 295 | 0.90 |
| 17 | 5.56 | 297 | 0.75 |
| 19 | 5.55 | 298 | 0.69 |
| 22 | 5.54 | 301 | 0.45 |
| 27 | 5.52 | 303 | 0.29 |
| 29 | 5.47 | 305 | 0.18 |
| 33 | 5.44 | 306 | 0.08 |
| 41 | 5.36 | 307 | 0.06 |
| 52 | 5.34 | 308 | 0.03 |
| 61 | 5.26 | 309 | 0.02 |
| 85 | 5.15 | 310 | 0.02 |

Table D8: Data from experiments for determination of ex-situ SOD of sediment samples
(d) Sample S4

| Time, min | DO, mg/L | Time, min | DO, mg/L |
|---|---|---|---|
| 1 | 5.56 | 143 | 4.41 |
| 3 | 5.49 | 158 | 4.26 |
| 4 | 5.48 | 164 | 4.17 |
| 18 | 5.42 | 230 | 3.01 |
| 30 | 5.33 | 320 | 0.64 |
| 35 | 5.29 | 321 | 0.35 |
| 41 | 5.24 | 322 | 0.22 |
| 46 | 5.21 | 323 | 0.15 |
| 51 | 5.13 | 324 | 0.09 |
| 84 | 4.92 | 325 | 0.05 |
| 100 | 4.78 | 326 | 0.02 |
| 119 | 4.62 | 327 | 0.01 |

(e) Table D9: Calculation for SOD measurement of sediment samples collected on May’10

| Serial | Sample ID | Initial DO, mg | Final DO, mg | Variation in DO, mg | Sediment sample, gm | Specific gravity (assumed) | SOD, mg $O_2$/g sediment | SOD, g $O_2$/$m^3$ sediment |
|---|---|---|---|---|---|---|---|---|
| 1 | S-1 | 5.59 | 0.02 | 5.57 | 5 | 2.65 | 1.114 | 3019 |
| 2 | S-2 | 4.95 | 0.38 | 4.57 | 5 | 2.65 | 0.914 | 2477 |
| 3 | S-3 | 5.57 | 0.02 | 5.55 | 5 | 2.65 | 1.11 | 3009 |
| 4 | S-4 | 5.59 | 0.02 | 5.57 | 5 | 2.65 | 1.114 | 3019 |

# Appendix E

Seasonal Variation of Water Quality at Different Sampling Points, and
Minimum, Maximum and Average Values of Measured Water Quality Parameters

Table E1: Seasonal variation of water quality parameters at sampling point W-1

| Sl. | Parameter | Unit | Nov-09 | Dec-09 | Jan-10 | Mar-10 | May-10 | Aug-10 |
|---|---|---|---|---|---|---|---|---|
| 1 | pH | -- | 7.46 | 7.68 | 7.63 | 7.32 | 7.13 | 6.41 |
| 2 | EC | µS/cm | 450 | 483 | 430 | 515 | 482 | 418 |
| 3 | Color | Pt-Co | 144 | 108 | 172 | 198 | 148 | 138 |
| 4 | TSS | mg/L | 33 | 86 | 82 | 44 | 30 | 112 |
| 5 | TDS | mg/L | 226 | 236 | 269 | 309 | 299 | 185 |
| 6 | DO | mg/L | 0.03 | 1.31 | 0.19 | 0.05 | 0.27 | 0.38 |
| 7 | $BOD_5$ | mg/L | 18 | 15.6 | 30 | 38 | 7 | 16.8 |
| 8 | COD | mg/L | 80 | -- | 120 | -- | 60.8 | 62 |
| 9 | $NH_3$-N | mg/L | 14.73 | 16.25 | 12.78 | 12 | 11.75 | 2.75 |
| 10 | $NO_3$-N | mg/L | 0.2 | 0.2 | 0.1 | 0 | 0 | 0.4 |
| 11 | $NO_2$-N | mg/L | -- | -- | -- | -- | -- | -- |
| 12 | $PO_4$ | mg/L | 0.599 | 0.337 | 0.383 | 1.76 | 2.3 | 3.1 |
| 13 | $S^{2-}$ | µg/L | -- | -- | -- | -- | -- | -- |
| 14 | Pb | mg/L | -- | -- | -- | -- | -- | -- |
| 15 | FC | /100 ml | -- | -- | -- | -- | -- | -- |

Table E2: Seasonal variation of water quality parameters at sampling point W-2

| Sl. | Parameter | Unit | Nov-09 | Dec-09 | Jan-10 | Mar-10 | May-10 | Aug-10 |
|---|---|---|---|---|---|---|---|---|
| 1 | pH | -- | 7.46 | 7.79 | 7.64 | 7.35 | 7.28 | 6.46 |
| 2 | EC | µS/cm | 451 | 475 | 431 | 515 | 479 | 422 |
| 3 | Color | Pt-Co | 134 | 160 | 184 | 189 | 188 | 121 |
| 4 | TSS | mg/L | 30 | 57 | 51 | 39 | 6 | 56 |
| 5 | TDS | mg/L | 275 | 258 | 304 | 326 | 297 | 172 |
| 6 | DO | mg/L | 0.04 | 1.64 | 0.1 | 0.06 | 0.1 | 0.24 |
| 7 | $BOD_5$ | mg/L | 17.6 | 18 | 17.1 | 12 | 27.2 | 19.2 |
| 8 | COD | mg/L | 72 | -- | 111 | -- | 59 | 53 |
| 9 | $NH_3$-N | mg/L | 9.2 | 16.975 | 13.45 | 12.25 | 12.5 | 2 |
| 10 | $NO_3$-N | mg/L | -- | -- | -- | -- | -- | -- |
| 11 | $NO_2$-N | mg/L | -- | -- | -- | -- | -- | -- |
| 12 | $PO_4$ | mg/L | 1.206 | 0.294 | 0.29 | 2.14 | 2.65 | 3.5 |
| 13 | $S^{2-}$ | µg/L | -- | -- | -- | -- | -- | -- |
| 14 | Pb | mg/L | -- | -- | -- | -- | -- | -- |
| 15 | FC | /100 ml | -- | -- | -- | -- | -- | -- |

Table E3: Seasonal variation of water quality parameters at sampling point W-3

| Sl. | Parameter | Unit | Nov-09 | Dec-09 | Jan-10 | Mar-10 | May-10 | Aug-10 |
|---|---|---|---|---|---|---|---|---|
| 1 | pH | -- | 7.57 | 7.86 | 7.65 | 7.37 | 7.35 | 6.61 |
| 2 | EC | µS/cm | 441 | 474 | 427 | 511 | 476 | 429 |
| 3 | Color | Pt-Co | 179 | 134 | 96 | 164 | 119 | 80 |
| 4 | TSS | mg/L | 27 | 66 | 32 | 51 | 49 | 119 |
| 5 | TDS | mg/L | 248 | 264 | 293 | 314 | 283 | 164 |
| 6 | DO | mg/L | 0.05 | 2.36 | 0.09 | 0.04 | 0.88 | 0.36 |
| 7 | $BOD_5$ | mg/L | 5.6 | 9.6 | 18.3 | 18 | 46.4 | 17.6 |
| 8 | COD | mg/L | 71 | -- | 115 | -- | 26 | 52 |
| 9 | $NH_3$-N | mg/L | 11.28 | 16.3 | 14.73 | 13.25 | 12 | 3 |
| 10 | $NO_3$-N | mg/L | 0.2 | 0.2 | 0.1 | 0 | 0 | 0.4 |
| 11 | $NO_2$-N | mg/L | 0.0086 | 0.0148 | 0.0002 | 0.008 | 0 | 0.008 |
| 12 | $PO_4$ | mg/L | 1.014 | 0.318 | 0.25 | 0.95 | 2.2 | 4.15 |
| 13 | $S^{2-}$ | µg/L | 0.024 | -- | 0.022 | -- | 0.024 | 0.015 |
| 14 | Pb | mg/L | 0.018 | -- | 0.032 | -- | 0.041 | 0.017 |
| 15 | FC | /100 ml | 12100 | -- | 62000 | -- | TNTC | TNTC |

Table E4: Seasonal variation of water quality parameters at sampling point W-4

| Sl. | Parameter | Unit | Nov-09 | Dec-09 | Jan-10 | Mar-10 | May-10 | Aug-10 |
|---|---|---|---|---|---|---|---|---|
| 1 | pH | -- | 7.49 | 7.75 | 7.7 | 7.34 | 7.38 | 6.78 |
| 2 | EC | µS/cm | 442 | 477 | 425 | 514 | 478 | 428 |
| 3 | Color | Pt-Co | 140 | 156 | 175 | 186 | 177 | 118 |
| 4 | TSS | mg/L | 11 | 112 | 43 | 75 | 3 | 63 |
| 5 | TDS | mg/L | 225 | 269 | 279 | 289 | 297 | 189 |
| 6 | DO | mg/L | 0.04 | 0.51 | 0.33 | 0.04 | 1.08 | 0.09 |
| 7 | $BOD_5$ | mg/L | 17.6 | 7.6 | 14.6 | 20 | 17.6 | 12.8 |
| 8 | COD | mg/L | 67 | -- | 122 | -- | 49 | 34 |
| 9 | $NH_3$-N | mg/L | 12.63 | 15 | 13.78 | 12.75 | 14 | 3 |
| 10 | $NO_3$-N | mg/L | -- | -- | -- | -- | -- | -- |
| 11 | $NO_2$-N | mg/L | -- | -- | -- | -- | -- | -- |
| 12 | $PO_4$ | mg/L | 1.436 | 0.441 | 0.21 | 1.18 | 2.2 | 4.6 |
| 13 | $S^{2-}$ | µg/L | -- | -- | -- | -- | -- | -- |
| 14 | Pb | mg/L | -- | -- | -- | -- | -- | -- |
| 15 | FC | /100 ml | -- | -- | -- | -- | -- | -- |

Table E5: Seasonal variation of water quality parameters at sampling point W-5

| Sl. | Parameter | Unit | Nov-09 | Dec-09 | Jan-10 | Mar-10 | May-10 | Aug-10 |
|---|---|---|---|---|---|---|---|---|
| 1 | pH | -- | 7.42 | 7.59 | 7.77 | 7.34 | 7.33 | 6.79 |
| 2 | EC | µS/cm | 421 | 467 | 431 | 528 | 499 | 423 |
| 3 | Color | Pt-Co | 136 | 108 | 135 | 92 | 121 | 99 |
| 4 | TSS | mg/L | 3 | 63 | 33 | 44 | 15 | 95 |
| 5 | TDS | mg/L | 231 | 265 | 295 | 290 | 309 | 201 |
| 6 | DO | mg/L | 0.07 | 0.07 | 1.45 | 0.06 | 0.36 | 0.13 |
| 7 | $BOD_5$ | mg/L | 9.6 | 11.6 | 16.4 | 16 | 32 | 14.4 |
| 8 | COD | mg/L | 60 | -- | 137 | -- | 38 | 32 |
| 9 | $NH_3$-N | mg/L | 9.68 | 14.575 | 12.78 | 12.75 | 13.25 | 2.25 |
| 10 | $NO_3$-N | mg/L | 0.2 | 0.3 | 0 | 0 | 0 | 0.4 |
| 11 | $NO_2$-N | mg/L | -- | -- | -- | -- | -- | -- |
| 12 | $PO_4$ | mg/L | 1.737 | 0.27 | 0.321 | 1.93 | 2.9 | 4.5 |
| 13 | $S^{2-}$ | µg/L | -- | -- | -- | -- | -- | -- |
| 14 | Pb | mg/L | -- | -- | -- | -- | -- | -- |
| 15 | FC | /100 ml | -- | -- | -- | -- | -- | -- |

Table E6: Seasonal variation of water quality parameters at sampling point W-6

| Sl. | Parameter | Unit | Nov-09 | Dec-09 | Jan-10 | Mar-10 | May-10 | Aug-10 |
|---|---|---|---|---|---|---|---|---|
| 1 | pH | -- | 7.51 | 8.04 | 7.74 | 7.33 | 7.43 | 6.74 |
| 2 | EC | µS/cm | 444 | 475 | 430 | 526 | 500 | 425 |
| 3 | Color | Pt-Co | 109 | 174 | 150 | 109 | 126 | 85 |
| 4 | TSS | mg/L | 4 | 95 | 63 | 40 | 6 | 66 |
| 5 | TDS | mg/L | 216 | 254 | 269 | 294 | 291 | 178 |
| 6 | DO | mg/L | 0.1 | 3.74 | 0.62 | 0.08 | 1.42 | 0.07 |
| 7 | $BOD_5$ | mg/L | 7.6 | 10 | 12.4 | 20 | 17.6 | 9.2 |
| 8 | COD | mg/L | 34 | -- | 118 | -- | 48 | 42 |
| 9 | $NH_3$-N | mg/L | 8.3 | 15.625 | 18 | 14 | 11.75 | 1.5 |
| 10 | $NO_3$-N | mg/L | -- | -- | -- | -- | -- | -- |
| 11 | $NO_2$-N | mg/L | -- | -- | -- | -- | -- | -- |
| 12 | $PO_4$ | mg/L | 2.076 | 0.294 | 0.29 | 2.15 | 2.3 | 4.1 |
| 13 | $S^{2-}$ | µg/L | -- | -- | -- | -- | -- | -- |
| 14 | Pb | mg/L | -- | -- | -- | -- | -- | -- |
| 15 | FC | /100 ml | -- | -- | -- | -- | -- | -- |

Table E7: Seasonal variation of water quality parameters at sampling point W-7

| Sl. | Parameter | Unit | Nov-09 | Dec-09 | Jan-10 | Mar-10 | May-10 | Aug-10 |
|---|---|---|---|---|---|---|---|---|
| 1 | pH | -- | 7.41 | 7.75 | 7.69 | 7.33 | 7.32 | 6.94 |
| 2 | EC | µS/cm | 456 | 497 | 439 | 543 | 507 | 428 |
| 3 | Color | Pt-Co | 200 | 146 | 164 | 106 | 146 | 109 |
| 4 | TSS | mg/L | 10 | 141 | 59 | 8 | 5 | 75 |
| 5 | TDS | mg/L | 243 | 222 | 279 | 315 | 306 | 199 |
| 6 | DO | mg/L | 0.04 | 0.14 | 0.09 | 0.06 | 0.1 | 0.1 |
| 7 | $BOD_5$ | mg/L | 13.6 | 18 | 19.6 | 22 | 36.8 | 12.2 |
| 8 | COD | mg/L | 73 | -- | 118 | -- | 31 | 48 |
| 9 | $NH_3$-N | mg/L | 9.85 | 12.4 | 16.15 | 15.75 | 14 | 3 |
| 10 | $NO_3$-N | mg/L | 0.2 | 0.2 | 0 | 0 | 0 | 0.4 |
| 11 | $NO_2$-N | mg/L | 0.011 | 0.012 | 0 | 0 | 0 | 0.006 |
| 12 | $PO_4$ | mg/L | 1.722 | 0.325 | 0.36 | 3.14 | 2.5 | 3.9 |
| 13 | $S^{2-}$ | µg/L | 0.023 | -- | 0.036 | -- | 0.023 | 0.015 |
| 14 | Pb | mg/L | 0.014 | -- | 0.036 | -- | 0.038 | 0.029 |
| 15 | FC | /100 ml | TNTC | -- | 338000 | -- | TNTC | TNTC |

Table E8: Seasonal variation of water quality parameters at sampling point W-8

| Sl. | Parameter | Unit | Nov-09 | Dec-09 | Jan-10 | Mar-10 | May-10 | Aug-10 |
|---|---|---|---|---|---|---|---|---|
| 1 | pH | -- | 7.47 | 7.81 | 7.77 | 7.32 | 7.45 | 7 |
| 2 | EC | µS/cm | 467 | 507 | 433 | 536 | 504 | 435 |
| 3 | Color | Pt-Co | 128 | 194 | 177 | 151 | 145 | 101 |
| 4 | TSS | mg/L | 4 | 127 | 47 | 33 | 39 | 139 |
| 5 | TDS | mg/L | 242 | 273 | 280 | 310 | 295 | 165 |
| 6 | DO | mg/L | 0.07 | 0.47 | 1.18 | 0.09 | 1.48 | 0.14 |
| 7 | $BOD_5$ | mg/L | 20 | 24 | 20 | 20 | 15 | 10.6 |
| 8 | COD | mg/L | 95 | -- | 121 | -- | 62.4 | 41 |
| 9 | $NH_3$-N | mg/L | 12.7 | 15.4 | 14.4 | 14.5 | 13.25 | 2.25 |
| 10 | $NO_3$-N | mg/L | -- | -- | -- | -- | -- | -- |
| 11 | $NO_2$-N | mg/L | -- | -- | -- | -- | -- | -- |
| 12 | $PO_4$ | mg/L | 1.695 | 0.215 | 0.34 | 2.14 | 2.15 | 4.55 |
| 13 | $S^{2-}$ | µg/L | -- | -- | -- | -- | -- | -- |
| 14 | Pb | mg/L | -- | -- | -- | -- | -- | -- |
| 15 | FC | /100 ml | -- | -- | -- | -- | -- | -- |

Table E9: Seasonal variation of water quality parameters at sampling point W-9

| Sl. | Parameter | Unit | Nov-09 | Dec-09 | Jan-10 | Mar-10 | May-10 | Aug-10 |
|---|---|---|---|---|---|---|---|---|
| 1 | pH | -- | 7.57 | 7.65 | 7.74 | 7.43 | 7.34 | 7.14 |
| 2 | EC | µS/cm | 464 | 497 | 441 | 591 | 513 | 446 |
| 3 | Color | Pt-Co | 115 | 122 | 104 | 160 | 137 | 103 |
| 4 | TSS | mg/L | 2 | 60 | 32 | 10 | 3 | 129 |
| 5 | TDS | mg/L | 255 | 239 | 286 | 351 | 338 | 175 |
| 6 | DO | mg/L | 0.06 | 0.3 | 0.4 | 0.13 | 0.24 | 0.1 |
| 7 | $BOD_5$ | mg/L | 2.8 | 14 | 11.7 | 26 | 6.8 | 12.4 |
| 8 | COD | mg/L | 34 | -- | 108 | -- | 57 | 50 |
| 9 | $NH_3$-N | mg/L | 15.03 | 14.925 | 12.5 | 19 | 10.75 | 1.75 |
| 10 | $NO_3$-N | mg/L | 0.2 | 0.2 | 0 | 0 | 0 | 0.4 |
| 11 | $NO_2$-N | mg/L | -- | -- | -- | -- | -- | -- |
| 12 | $PO_4$ | mg/L | 1.956 | 2.178 | 0.806 | 7 | 4.88 | 5.4 |
| 13 | $S^{2-}$ | µg/L | -- | -- | -- | -- | -- | -- |
| 14 | Pb | mg/L | -- | -- | -- | -- | -- | -- |
| 15 | FC | /100 ml | -- | -- | -- | -- | -- | -- |

Table E10: Seasonal variation of water quality parameters at sampling point W-10

| Sl. | Parameter | Unit | Nov-09 | Dec-09 | Jan-10 | Mar-10 | May-10 | Aug-10 |
|---|---|---|---|---|---|---|---|---|
| 1 | pH | -- | 7.55 | 7.66 | 7.73 | 7.4 | 7.38 | 7.07 |
| 2 | EC | µS/cm | 470 | 496 | 438 | 585 | 513 | 441 |
| 3 | Color | Pt-Co | 151 | 142 | 170 | 128 | 117 | 113 |
| 4 | TSS | mg/L | 46 | 3 | 37 | 42 | 5 | 102 |
| 5 | TDS | mg/L | 230 | 287 | 274 | 337 | 328 | 195 |
| 6 | DO | mg/L | 0.03 | 0.1 | 0.54 | 0.08 | 1.33 | 0.11 |
| 7 | $BOD_5$ | mg/L | 11.6 | 14 | 9.2 | 20 | 22 | 8.6 |
| 8 | COD | mg/L | 80 | -- | 126 | -- | 63 | 60 |
| 9 | $NH_3$-N | mg/L | 14.3 | 15.85 | 14.25 | 14.25 | 12 | 1.25 |
| 10 | $NO_3$-N | mg/L | -- | -- | -- | -- | -- | -- |
| 11 | $NO_2$-N | mg/L | -- | -- | -- | -- | -- | -- |
| 12 | $PO_4$ | mg/L | 1.728 | 2.158 | 0.597 | 5.65 | 4.58 | 4.4 |
| 13 | $S^{2-}$ | µg/L | -- | -- | -- | -- | -- | -- |
| 14 | Pb | mg/L | -- | -- | -- | -- | -- | -- |
| 15 | FC | /100 ml | -- | -- | -- | -- | -- | -- |

Table E11: Seasonal variation of water quality parameters at sampling point W-11

| Sl. | Parameter | Unit | Nov-09 | Dec-09 | Jan-10 | Mar-10 | May-10 | Aug-10 |
|---|---|---|---|---|---|---|---|---|
| 1 | pH | -- | 7.7 | 7.76 | 7.83 | 7.37 | 7.39 | 7.09 |
| 2 | EC | µS/cm | 470 | 505 | 464 | 614 | 524 | 457 |
| 3 | Color | Pt-Co | 120 | 136 | 135 | 88 | 131 | 92 |
| 4 | TSS | mg/L | 7 | 9 | 8 | 46 | 8 | 115 |
| 5 | TDS | mg/L | 254 | 266 | 282 | 317 | 346 | 181 |
| 6 | DO | mg/L | 0.55 | 0.48 | 0.69 | 0.08 | 1.67 | 0.11 |
| 7 | $BOD_5$ | mg/L | 2.8 | 17.6 | 11.7 | 20 | 12.8 | 11.2 |
| 8 | COD | mg/L | 57 | -- | 105 | -- | 67 | 37 |
| 9 | $NH_3$-N | mg/L | 15.68 | 16.525 | 14 | 18.25 | 12.5 | 2 |
| 10 | $NO_3$-N | mg/L | 0.2 | 0.1 | 0 | 0 | 0 | 0.4 |
| 11 | $NO_2$-N | mg/L | 0.0132 | 0.0146 | 0 | 0 | 0 | 0.004 |
| 12 | $PO_4$ | mg/L | 4.09 | 1.714 | 1.18 | 6.85 | 5.12 | 4.7 |
| 13 | $S^{2-}$ | µg/L | 0.02 | -- | 0.042 | -- | 0.02 | 0.005 |
| 14 | Pb | mg/L | 0.011 | -- | 0.04 | -- | 0.04 | 0.01 |
| 15 | FC | /100 ml | 14400 | -- | 390000 | -- | TNTC | TNTC |

Table E12: Seasonal variation of water quality parameters at sampling point W-12

| Sl. | Parameter | Unit | Nov-09 | Dec-09 | Jan-10 | Mar-10 | May-10 | Aug-10 |
|---|---|---|---|---|---|---|---|---|
| 1 | pH | -- | 7.69 | 7.74 | 7.8 | 7.36 | 7.42 | 7.08 |
| 2 | EC | µS/cm | 471 | 515 | 457 | 616 | 521 | 458 |
| 3 | Color | Pt-Co | 103 | 96 | 156 | 96 | 130 | 103 |
| 4 | TSS | mg/L | 0 | 9 | 13 | 31 | 4 | 110 |
| 5 | TDS | mg/L | 250 | 281 | 270 | 333 | 328 | 150 |
| 6 | DO | mg/L | 0.84 | 0.28 | 0.57 | 0.06 | 1.69 | 0.06 |
| 7 | $BOD_5$ | mg/L | 1.6 | 19.2 | 9.2 | 24 | 24 | 13.2 |
| 8 | COD | mg/L | 60 | -- | 107 | -- | 63 | 44 |
| 9 | $NH_3$-N | mg/L | 15.95 | 17.125 | 13.75 | 18 | 10 | 0.75 |
| 10 | $NO_3$-N | mg/L | -- | -- | -- | -- | -- | -- |
| 11 | $NO_2$-N | mg/L | -- | -- | -- | -- | -- | -- |
| 12 | $PO_4$ | mg/L | 3.266 | 3.398 | 1.639 | 6.45 | 5.02 | 5.4 |
| 13 | $S^{2-}$ | µg/L | -- | -- | -- | -- | -- | -- |
| 14 | Pb | mg/L | -- | -- | -- | -- | -- | -- |
| 15 | FC | /100 ml | -- | -- | -- | -- | -- | -- |

Table E13: Seasonal variation of water quality parameters at sampling point W-13

| Sl. | Parameter | Unit | Nov-09 | Dec-09 | Jan-10 | Mar-10 | May-10 | Aug-10 |
|---|---|---|---|---|---|---|---|---|
| 1 | pH | -- | 7.64 | 7.83 | 7.82 | 7.44 | 7.51 | 7.24 |
| 2 | EC | µS/cm | 466 | 507 | 482 | 642 | 511 | 459 |
| 3 | Color | Pt-Co | 114 | 94 | 113 | 106 | 76 | 76 |
| 4 | TSS | mg/L | 110 | 66 | 22 | 27 | 34 | 123 |
| 5 | TDS | mg/L | 235 | 248 | 277 | 333 | 338 | 147 |
| 6 | DO | mg/L | 0.1 | 2.92 | 0.81 | 0.1 | 1.76 | 0.93 |
| 7 | $BOD_5$ | mg/L | 0.5 | 9.8 | 4.8 | 22 | 14 | 9.8 |
| 8 | COD | mg/L | 23 | -- | 78 | -- | 64 | 50 |
| 9 | $NH_3$-N | mg/L | 14.93 | 9.65 | 15 | 21 | 4.75 | 1.75 |
| 10 | $NO_3$-N | mg/L | 0.2 | 0.2 | 0.2 | 0 | 0 | 0.4 |
| 11 | $NO_2$-N | mg/L | -- | -- | -- | -- | -- | -- |
| 12 | $PO_4$ | mg/L | 4.934 | 4.632 | 3.898 | 7.4 | 5.82 | 5.5 |
| 13 | $S^{2-}$ | µg/L | -- | -- | -- | -- | -- | -- |
| 14 | Pb | mg/L | -- | -- | -- | -- | -- | -- |
| 15 | FC | /100 ml | -- | -- | -- | -- | -- | -- |

Table E14: Seasonal variation of water quality parameters at sampling point W-14

| Sl. | Parameter | Unit | Nov-09 | Dec-09 | Jan-10 | Mar-10 | May-10 | Aug-10 |
|---|---|---|---|---|---|---|---|---|
| 1 | pH | -- | 7.67 | 7.84 | 7.83 | 7.43 | 7.52 | 7.23 |
| 2 | EC | µS/cm | 462 | 505 | 479 | 643 | 511 | 461 |
| 3 | Color | Pt-Co | 86 | 86 | 135 | 146 | 82 | 87 |
| 4 | TSS | mg/L | 14 | 53 | 17 | 29 | 5 | 116 |
| 5 | TDS | mg/L | 233 | 244 | 295 | 337 | 348 | 158 |
| 6 | DO | mg/L | 0.26 | 2.11 | 0.48 | 0.57 | 1.86 | 0.42 |
| 7 | $BOD_5$ | mg/L | 0.57 | 11.3 | 7.2 | 18 | 14.4 | 12 |
| 8 | COD | mg/L | 22 | -- | 87 | -- | 56 | 58 |
| 9 | $NH_3$-N | mg/L | 13.93 | 17.275 | 15.75 | 21.75 | 5.25 | 1.5 |
| 10 | $NO_3$-N | mg/L | -- | -- | -- | -- | -- | -- |
| 11 | $NO_2$-N | mg/L | -- | -- | -- | -- | -- | -- |
| 12 | $PO_4$ | mg/L | 4.824 | 4.814 | 3.436 | 8.55 | 6.21 | 4.5 |
| 13 | $S^{2-}$ | µg/L | -- | -- | -- | -- | -- | -- |
| 14 | Pb | mg/L | -- | -- | -- | -- | -- | -- |
| 15 | FC | /100 ml | -- | -- | -- | -- | -- | -- |

Table E15: Seasonal variation of water quality parameters at sampling point W-15

| Sl. | Parameter | Unit | Nov-09 | Dec-09 | Jan-10 | Mar-10 | May-10 | Aug-10 |
|---|---|---|---|---|---|---|---|---|
| 1 | pH | -- | 7.65 | 7.85 | 7.81 | 7.62 | 7.44 | 7.23 |
| 2 | EC | µS/cm | 464 | 508 | 487 | 643 | 512 | 456 |
| 3 | Color | Pt-Co | 102 | 82 | 121 | 130 | 86 | 82 |
| 4 | TSS | mg/L | 3 | 26 | 19 | 92 | 10 | 119 |
| 5 | TDS | mg/L | 241 | 255 | 305 | 300 | 355 | 137 |
| 6 | DO | mg/L | 0.53 | 2.38 | 0.6 | 0.07 | 1.9 | 1.78 |
| 7 | $BOD_5$ | mg/L | 1 | 11.8 | 6 | 28 | 18 | 11.4 |
| 8 | COD | mg/L | 36 | -- | 86 | -- | 58 | 54 |
| 9 | $NH_3$-N | mg/L | 13.55 | 19.075 | 16 | 18.75 | 4.25 | 1.25 |
| 10 | $NO_3$-N | mg/L | 0.2 | 0.2 | 0.1 | 0 | 0 | 0.4 |
| 11 | $NO_2$-N | mg/L | 0.0176 | 0.0328 | 0 | 0.006 | 0 | 0.005 |
| 12 | $PO_4$ | mg/L | 4.982 | 4.552 | 4.222 | 8.55 | 6.96 | 4.15 |
| 13 | $S^{2-}$ | µg/L | 0.018 | -- | 0.025 | -- | 0.01 | 0.003 |
| 14 | Pb | mg/L | 0.012 | -- | 0.039 | -- | 0.042 | 0.014 |
| 15 | FC | /100 ml | TNTC | -- | 90000 | -- | TNTC | TNTC |

Table E16: Seasonal variation of water quality parameters at sampling point W-16

| Sl. | Parameter | Unit | Nov-09 | Dec-09 | Jan-10 | Mar-10 | May-10 | Aug-10 |
|---|---|---|---|---|---|---|---|---|
| 1 | pH | -- | 7.7 | 7.83 | 7.83 | 7.63 | 7.52 | 7.15 |
| 2 | EC | µS/cm | 464 | 508 | 487 | 640 | 511 | 456 |
| 3 | Color | Pt-Co | 85 | 86 | 118 | 124 | 80 | 99 |
| 4 | TSS | mg/L | 48 | 12 | 3 | 25 | 15 | 123 |
| 5 | TDS | mg/L | 219 | 262 | 293 | 354 | 335 | 171 |
| 6 | DO | mg/L | 1.56 | 2.24 | 0.66 | 0.47 | 1.62 | 0.05 |
| 7 | $BOD_5$ | mg/L | 1.6 | 14.8 | 7.2 | 20 | 5.5 | 8.8 |
| 8 | COD | mg/L | 50 | -- | 87 | -- | 57 | 50 |
| 9 | $NH_3$-N | mg/L | 13.35 | 15.35 | 14 | 19.75 | 6 | 1.25 |
| 10 | $NO_3$-N | mg/L | -- | -- | -- | -- | -- | -- |
| 11 | $NO_2$-N | mg/L | -- | -- | -- | -- | -- | -- |
| 12 | $PO_4$ | mg/L | 5.094 | 5.048 | 3.842 | 8.35 | 6.85 | 5.35 |
| 13 | $S^{2-}$ | µg/L | -- | -- | -- | -- | -- | -- |
| 14 | Pb | mg/L | -- | -- | -- | -- | -- | -- |
| 15 | FC | /100 ml | -- | -- | -- | -- | -- | -- |

Table E17: Minimum measured values of water quality parameters at different sampling campaigns

| Sl. | Element | Unit | 1st Min. | 2nd Min. | 3rd Min. | 4th Min. | 5th Min. | 6th Min. | All Min. |
|---|---|---|---|---|---|---|---|---|---|
| 1 | pH | -- | 7.41 | 7.59 | 7.63 | 7.32 | 7.13 | 6.41 | 6.41 |
| 2 | EC | µS/cm | 421 | 467 | 425 | 511 | 476 | 418 | 418 |
| 3 | Color | Pt-Co | 85 | 82 | 96 | 88 | 76 | 76 | 76 |
| 4 | TSS | mg/L | 0 | 3 | 3 | 8 | 3 | 56 | 0 |
| 5 | TDS | mg/L | 216 | 222 | 269 | 289 | 283 | 137 | 137 |
| 6 | DO | mg/L | 0.03 | 0.07 | 0.09 | 0.04 | 0.1 | 0.05 | 0.03 |
| 7 | $BOD_5$ | mg/L | 0.5 | 7.6 | 4.8 | 12 | 5.5 | 8.6 | 0.5 |
| 8 | COD | mg/L | 22 | 0 | 78 | 0 | 26 | 32 | 0 |
| 9 | $NH_3$-N | mg/L | 8.3 | 9.65 | 12.5 | 12 | 4.25 | 0.75 | 0.75 |
| 10 | $NO_3$-N | mg/L | 0.2 | 0.1 | 0 | 0 | 0 | 0.4 | 0 |
| 11 | $NO_2$-N | mg/L | 0.0086 | 0.012 | 0 | 0 | 0 | 0.004 | 0 |
| 12 | $PO_4$ | mg/L | 0.599 | 0.215 | 0.21 | 0.95 | 2.15 | 3.1 | 0.21 |
| 13 | $S^{2-}$ | µg/L | 0.018 | — | 0.022 | — | 0.01 | 0.003 | 0.003 |
| 14 | Pb | mg/L | 0.011 | — | 0.032 | — | 0.038 | 0.01 | 0.01 |

"—" means that particular parameter was not tested in that campaign

Table E18: Maximum measured values of water quality parameters at different sampling campaigns

| Sl. | Element | Unit | 1st Max. | 2nd Max. | 3rd Max. | 4th Max. | 5th Max. | 6th Max. | All Max. |
|---|---|---|---|---|---|---|---|---|---|
| 1 | pH | -- | 7.7 | 8.04 | 7.83 | 7.63 | 7.52 | 7.24 | 8.04 |
| 2 | EC | µS/cm | 471 | 515 | 487 | 643 | 524 | 461 | 643 |
| 3 | Color | Pt-Co | 200 | 194 | 184 | 198 | 188 | 138 | 200 |
| 4 | TSS | mg/L | 110 | 141 | 82 | 92 | 49 | 139 | 141 |
| 5 | TDS | mg/L | 275 | 287 | 305 | 354 | 355 | 201 | 355 |
| 6 | DO | mg/L | 1.56 | 3.74 | 1.45 | 0.57 | 1.9 | 1.78 | 3.74 |
| 7 | $BOD_5$ | mg/L | 20 | 24 | 30 | 38 | 46.4 | 19.2 | 46.4 |
| 8 | COD | mg/L | 95 | 0 | 137 | 0 | 67 | 62 | 137 |
| 9 | $NH_3$-N | mg/L | 15.95 | 19.08 | 18 | 21.75 | 14 | 3 | 21.75 |
| 10 | $NO_3$-N | mg/L | 0.2 | 0.3 | 0.2 | 0 | 0 | 0.4 | 0.4 |
| 11 | $NO_2$-N | mg/L | 0.0176 | 0.0328 | 0.0002 | 0.008 | 0 | 0.008 | 0.0328 |
| 12 | $PO_4$ | mg/L | 5.094 | 5.048 | 4.222 | 8.55 | 6.96 | 5.5 | 8.55 |
| 13 | $S^{2-}$ | µg/L | 0.024 | — | 0.042 | — | 0.024 | 0.015 | 0.042 |
| 14 | Pb | mg/L | 0.018 | — | 0.04 | — | 0.042 | 0.029 | 0.042 |

Table E19: Average measured values of water quality parameters at different sampling campaigns

| Sl. | Element | Unit | 1st Avg. | 2nd Avg. | 3rd Avg. | 4th Avg. | 5th Avg. | 6th Avg. | Overall Average |
|---|---|---|---|---|---|---|---|---|---|
| 1 | pH | -- | 7.56 | 7.78 | 7.75 | 7.4 | 7.39 | 6.94 | 7.49 |
| 2 | EC | µS/cm | 456.44 | 493.5 | 448.82 | 572.63 | 502.57 | 440.13 | 487 |
| 3 | Color | Pt-Co | 127.88 | 126.5 | 144.07 | 135.82 | 125.57 | 100.38 | 127 |
| 4 | TSS | mg/L | 22 | 61.57 | 35.07 | 39.75 | 14.82 | 103.88 | 44.5 |
| 5 | TDS | mg/L | 238.94 | 257.69 | 284.38 | 319.32 | 318.32 | 172.94 | 268 |
| 6 | DO | mg/L | 0.28 | 1.32 | 0.55 | 0.13 | 1.11 | 0.32 | 0.63 |
| 7 | $BOD_5$ | mg/L | 8.26 | 14.19 | 13.47 | 21.5 | 19.82 | 12.52 | 15 |
| 8 | COD | mg/L | 57.13 | -- | 109.13 | -- | 53.7 | 47.94 | 68.3 |
| 9 | $NH_3$-N | mg/L | 12.82 | 15.52 | 14.46 | 16.13 | 10.5 | 1.96 | 12.2 |
| 10 | $NO_3$-N | mg/L | 0.2 | 0.2 | 0.07 | 0 | 0 | 0.4 | 0.14 |
| 11 | $NO_2$-N | mg/L | 0.02 | 0.02 | 0.01 | 0.01 | 0 | 0.01 | 0.02 |
| 12 | $PO_4$ | mg/L | 2.65 | 1.94 | 1.38 | 4.64 | 4.04 | 4.4 | 3.14 |
| 13 | $S^{2-}$ | µg/L | 0.03 | -- | 0.04 | -- | 0.02 | 0.01 | 0.03 |
| 14 | Pb | mg/L | 0.02 | -- | 0.04 | -- | 0.05 | 0.02 | 0.03 |

The thesis titled **"EVALUATION OF WATER QUALITY AND POLLUTION SOURCES OF GULSHAN LAKE"** submitted by MD. IBRAHIM SABIT, Roll No. 040804108F, and Session: April 2008 has been accepted as satisfactory in partial fulfillment for the requirement of the degree of Master of Science in Civil and Environmental Engineering on 27 July 2011.

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# Declaration

Declared that, except for the contents where specific reference has been made to the work of others, the studies embodied in this thesis is the result of research work, carried by the author.

Neither the thesis nor any part thereof has been submitted or is being concurrently submitted to any other university or other educational institute for the award of any degree or diploma, except for publication.

July, 2011

Author

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# Abstract

Gulshan Lake is the northernmost lake in a chain of water bodies in Dhaka (Gulshan Lake, Hatirjheel, Begunbari Khal, Balu River and Shitalakhya River), all suffering from serious pollution. Gulshan Lake is about 3800m long having an average depth of about 2.5m. Encroachment, disposal of untreated domestic and commercial wastewater and dumping of solid wastes have degraded the overall quality of the Lake. Gulshan Lake is one of the last remaining water bodies of Dhaka city; not only is its presence important for the sustenance of the eco-system, it is also considered as major source of groundwater recharge. This study focuses on the assessment of water and sediment qualities of Gulshan Lake, identification of sources of pollution and characterization of selected major outfalls of the Lake.

The major types of wastewater/ storm water outfalls contributing to the pollution of Gulshan Lake include (i) Storm sewer pipes, (ii) Open channels, (iii) Box culverts, and (iv) Small private outfalls. A detailed inventory of outfalls of Gulshan Lake has been prepared. A total of 102 outfalls have been identified, which included 24 major (diameter/ size 24 inch and above) outfalls. Measured dry weather flow rate through 4 major outfalls varied from about 2 to 2.8 L/sec. Outfall discharges are characterized by high concentrations of $BOD_5$ (56-160 mg/l), COD (129-188 mg/l), Ammonia (16-28 mg/l), Phosphate (3.55-13.4 mg/l), TDS (277-413 mg/l) and Color (164-321 Pt-Co unit). These are comparable to the characteristics of raw sewage.

Water quality of Gulshan Lake has been monitored during November 2009 to August 2010, covering both dry season and wet season through six sampling campaigns (five in dry season and one in wet season). Water samples were collected from sixteen locations along eight cross sections along Gulshan Lake during the study. The water samples were tested for a range of parameters including pH, Color, EC, TDS, TSS, DO, $BOD_5$, COD, Fecal Coliform, $NH_3$-N, $NO_3$-N, $NO_2$-N, $PO_4$, $SO_4$, and $S^{2-}$. Results showed fluctuations in chemical composition of Lake water, both spatially and temporally. The Lake water has been characterized by very low DO (mostly below 2 mg/l) and very high fecal coliform (FC) throughout the year, indicating severe organic/fecal pollution of the water body. The high $BOD_5$ (up to 46.0 mg/l) and COD (up to 130 mg/l) values also indicated significant organic pollution. Many dead fishes have been found afloat in the Lake during the study. A trend of decreasing DO and increasing BOD with the advancement of dry season was observed; the situation improved during the wet season, but only marginally. The Lake water has been found to contain high concentration of nutrients [mainly ammonia (10 to 20 mg/l), and phosphate (up to 8.55 mg/l)], especially during the dry season. Among the parameters tested, Color, TDS and Ammonia showed the most significant seasonal variation due to the influence of rain and storm runoff; decreasing concentration of Color, TDS and Ammonia and increasing concentration of TSS was observed during the wet season (i.e., August). EC and phosphate showed significant spatial variation, with increasing concentration towards downstream. Along a particular cross-section, quality of Lake water, collected from both banks, did not vary significantly (except for few locations), irrespective of the location of outfalls; possibly indicating that the Lake is reasonably well-mixed.

Relatively high concentrations of Cadmium and Lead have been found in the Lake sediments. The Lake sediments also have very high oxygen demand (pSOD), which may be responsible for persistent low DO of Lake water throughout the year.

The poor water quality of Gulshan Lake is also contributing to the pollution of Hatirjheel, where a restoration project is currently being implemented, and the water bodies downstream. It is very important to take immediate steps to restore the water and sediment qualities of Gulshan Lake. Development of domestic sewer network in the Gulshan Lake watershed areas for diverting domestic sewage (and also industrial effluent, if any) flows away from the Lake is the most important and urgent task in this regard. It is also important to develop a comprehensive management plan for revival of all lakes, khals, and wetlands within Dhaka city.

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# ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| AAS | Atomic Absorption Spectrophotometer |
| APHA | American Public Health Association |
| BBS | Bangladesh Bureau of Statistics |
| BIWTA | Bangladesh Inland Water Transport Authority |
| BWDB | Bangladesh Water Development Board |
| BGMEA | Bangladesh Garment Manufacturers and Exporters Association |
| BMD | Bangladesh Meteorological Department |
| BOD | Biochemical Oxygen Demand |
| BRTC | Bureau of Research, Testing and Consultation |
| BUET | Bangladesh University of Engineering and Technology |
| BWDB | Bangladesh Water Development Board |
| COD | Chemical Oxygen Demand |
| CPCB | Central Pollution Control Board |
| DCC | Dhaka City Corporation |
| DMA | Dhaka Metropolitan Area |
| DMDP | Dhaka Metropolitan Development Plan |
| DO | Dissolved oxygen |
| DoE | Department of Environment |
| DWASA | Dhaka Water Supply and Sewerage Authority |
| EC | Electrical Conductivity |
| EPA | Environmental Protection Agency |
| GIS | Geographic Information System |
| GL | Gulshan Lake |
| GoB | Government of Bangladesh |
| GPS | Global Positioning System |
| IWFM | Institute of Water and Flood Management |
| IWM | Institute of Water Modeling |
| JICA | Japan International Cooperation Agency |
| LGED | Local Government Engineering Department |
| msl | Mean Sea Level |
| MSW | Municipal Solid Waste |
| NBOD | Nitrogenous Biochemical Oxygen Demand |
| NGO | Non Government Organization |
| RAJUK | Rajdhani Unnayan Kartripakkhya |
| SDS | Sewage Diversion Structures |
| SOB | Survey of Bangladesh |
| STP | Sewage Treatment Plant |
| SWO | Special Works Organization |
| SWTP | Saidabad Water Treatment Plant |
| TDS | Total Dissolved Solids |
| ThOD | Theoretical Oxygen Demand |
| TSS | Total Suspended Solids |
| USEPA | United States Environmental Protection Agency |
| USGS | United States Geological Survey |

# CHAPTER 1

# INTRODUCTION

## 1.1 Background

Gulshan Lake with an area of about 100 ha is one of the major lakes in Dhaka city. Its northern end is located just to the south of Baridhara DOHS. From here it stretches along the eastern side of the Gulshan Avenue and Tejgaon Gulshan Link Road up to the Hatirjheel near Gulshan Shooting Complex; Badda area and Pragati Sharani are located on the eastern side of the lake. It serves the very important hydrological functions of draining and detaining storm sewer from exclusive VIP zone of Dhaka city. Once upon a time, Dhaka's lakes were interconnected through canals. Though the links have been severed, the lakes are still an integral part of the eco-system. They act as water retention basins during the Monsoon and besides, being the sources of biodiversity of the area, they are an important part of the scenic beauty. Gulshan Lake is one of the last remaining water bodies of the city. Not only is its presence important for the sustenance of the eco-system, as the largest remaining water body, it is a major source of recharge of the ground water.

The area in and around Gulshan, Banani and Baridhara has always been Dhaka's most exclusive residential haven mainly because of the pristine lake that used to encircle these neighborhoods. But the curse of encroachment has led to the disappearance of large portions of the lake. Whatever is left is also being threatened by land-grabbing and rampant pollution, killing the aquatic life in the lake and endangering its ecological balance. It has been reported that vested quarters are to trying to grab parts of the Gulshan Lake to build new residential plots inside the lake by illegally filling it with soil. The lake is being filled at the sides of Road No 21, 22, 23, 24, 28, 55, 105, 118 and 136. Large portions of the lake at the Gulshan, Banani and Baridhara residential areas have been grabbed by some influential people over the years defacing the panoramic view of the area and degrading the environment. It may be noted that Gulshan Lake has been declared an ecologically critical area and the Department of Environment (DoE) was given the charge of monitoring the cleanliness of the lake. Rajdhani Unnayan Kortripokhho (Rajuk) owns the lake and leased it out to Bangladesh Fisheries Development Corporation (BFDC) for five years. BFDC was in charge of introducing land and aquatic organisms as well as fish through appropriate and sustainable technology.

Domestic waste is being dumped into the lake on a regular basis. Sewers of many houses at Badda and Baridhara areas are connected directly to the lake as the Dhaka Water Supply and Sewerage Authority (DWASA) has no sewer network in these areas. One of the main causes of the pollution is that almost all the domestic sewers from the adjacent Badda area unload into the lake. According to press reports, more than 12,000 cubic meters of untreated toxic chemical and human wastes from Tejgaon, Badda, and Pragati Sarani are dumped every day into the lake. Besides, sedimentation has reduced the water retention capacity of the lake drastically. Storm water runoff discharging into the lake also contains significant waste load (Chowdhury et al., 1998). The pollution caused by factors such as sedimentation and toxic contamination has damaged the essential features of the lake.

At present, Gulshan Lake is mainly used for pisciculture. It has been reported in press that the Department of Environment has found the water of the Gulshan Lake to be heavily contaminated and unfit for the survival of aquatic species. Incidences of fish kill are quite common in different stretches of Gulshan Lake. At many points, fishes, cultured in the lake by some private enterprises, died and were seen afloat creating an alarm in the minds of residents of the metropolis. At that time, tests of water samples showed that the dissolved oxygen (DO) content of water was 0.5 mg/l or near zero as against the 5 mg/l required for survival of fishes. The fish kill incidences have been attributed to the severe contamination of the lake, especially during the dry season.

Hatirjheel, a major storm water detention basin of Dhaka city, where a restoration project is currently being implemented, receives the discharges from Gulshan Lake.

During dry season, when there is virtually no rainfall, the discharge from Gulshan Lake to Hatirjheel was estimated to be 14 cfs, which essentially represents the domestic sewage and industrial wastewater that is discharged into this Lake. According to a recent study (Samad, 2009), the quality of Gulshan Lake water during dry season at a point close to its confluence with Hatirjheel resembled that of domestic sewage, with very high BOD (120 mg/l), COD (197 mg/l), ammonia (22.85 mg/l), and very low Dissolved Oxygen (0.14 mg/l). Thus, the success of the planned Hatirjheel restoration project will be compromised if Gulshan Lake remains at its present state. However, systematic study is yet to be conducted on identifying the sources of pollution and assessing the quality of water and sediment of Gulshan Lake. These data and information are vital for planning and designing the restoration of Gulshan Lake.

## 1.2 Objectives

The major objectives of the present thesis are as follows:

(a) Identification of major outfalls and point sources discharging into Gulshan Lake;

(b) Assessment of the characteristics of discharge from selected major outfalls during dry season.

(c) Assessment of water quality of Gulshan Lake through periodic monitoring at selected locations, especially during dry season; and

(d) Assessment of sediment characteristics of Gulshan Lake.

## 1.3 Outline of Methodologies

The major outfalls into Gulshan Lake have been identified through analysis of available maps (on drainage and storm sewer network of Dhaka), discussions with DWASA officials and actual field surveys. The point sources have been identified through actual field survey and information from local people.

Characteristics of water quality of Gulshan Lake have been assessed by collecting and analyzing surface water sampled from 16 (sixteen) locations within the Lake over a period of 8 months from November 2009 to August 2010. For this purpose, Gulshan Lake has been divided into four segments: (i) from just south to Baridhara DOHS area to Madani Avenue (Gulshan 1-Badda Police station link road), (ii) from Madani Avenue to Bayjid road (near Manarat Dhaka International College), (iii) from Bayjid Road to South Avenue (Gulshan-Badda Link road), (iv) from South Avenue to Gulshan Shooting Complex. From every segment, 4 sampling locations have been selected along 2 cross-sections. Details of the sampling locations are presented in Chapter 3.

Water quality monitoring has been carried out through collection and analysis of water samples at 6 different times (covering both dry and wet seasons) during the period from November 2009 to August 2010. The collected lake water samples have been analyzed for a total of 15 water quality parameters, including Dissolved Oxygen (DO), pH, Electrical Conductivity (EC), Color, Biochemical Oxygen Demand ($BOD_5$), Ammonia ($NH_3$-N), Phosphate ($PO_4$), Total Dissolved solids (TDS) and Total Suspended Solids (TSS) for all samples and Chemical Oxygen Demand (COD), Faecal Coliform (FC), Nitrate ($NO_3$-N), Nitrite ($NO_2$-N), Sulfides ($S^{2-}$) and Lead (Pb) for selected campaigns. Wastewater coming out the selected major outfalls has been characterized through collection and analysis of water/ wastewater samples during dry season. The water/ wastewater samples have been tested in the Laboratory for a wide range of parameters including DO, pH, Color, TDS, TSS, EC, $NH_3$-N, $NO_3$-N, $NO_2$-N, $PO_4$, $BOD_5$, COD, $S^{2-}$ and Pb. Among these tests, $NH_3$-N, $NO_3$-N, $NO_2$-N, $PO_4$, COD and $S^{2-}$ concentrations have been measured with a Spectrophotometer (HACH, DR400U or 2010U). FC has been determined by the membrane filtration technique. Other parameters have been measured following Standard Methods.

A total of 102 outfalls have been identified, which included 24 major (i.e. diameter/ size and flow is significant) outfalls. A total of four sediment samples were collected for characterization of sediment of Gulshan Lake. The samples have been analyzed for moisture content, organic matter content, selected metal concentration (Cd, Cr and Pb) using an AAS (Shimadzu, AA6800). Sediment Oxygen Demand (SOD) has been estimated using the ex-situ method outlined by Matlock et al. (2003).

## 1.4 Organization of the Thesis

This thesis comprises of five Chapters. Apart from this introductory chapters, the others are:

Chapter 2: This Chapter presents literature review covering background information on the Gulshan Lake area and its environmental significance. Environmental significance of selected water and sediment quality parameters has also been inscribed.

Chapter 3: This Chapter identifies the outfalls discharging into Gulshan Lake. The flow rate and characteristics of wastewater through selected outfalls have also been presented.

Chapter 4: This Chapter presents water and sediment quality data of Gulshan Lake; also presents subsequent effect of outfall discharge on water quality. Based on the analysis of the test results, this Chapter describes the current state of water quality and sediment quality of different stretches of Gulshan Lake during both dry and wet seasons.

Chapter 5: This final Chapter summarizes the major conclusions from the present study. It also presents recommendations for future study relating Gulshan Lake.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 General

Wetlands are vital water bodies, crucial as in a natural ecosystem as a kidney in a human body. Their role is complex and varied. Apart from being highly productive as the habitat of birds, fishes and a variety of other aquatic life forms, including microorganisms, wetlands provide other ecosystem services, from maintaining the natural balance to sustaining human livelihoods. Unfortunately, there has been much neglect of wetlands in recent times through lack of appreciation of their role and the pressures of growing human needs (agriculture, urbanization) and sheer mismanagement of land resources. Unplanned and uncontrolled developments of Dhaka city are destroying the entire natural drainage system, causing severe water logging and sometimes flooding. There is also a misconception that wetlands are only wastelands. As a result, many precious wetlands have sacrificed and converted to other uses throughout Dhaka city. Once upon a time, lakes in Dhaka interconnected through canals. Though the links have disconnected, the lakes are still an integral part of the eco-system. They act as water retention basins during the rainy season and are an important part of the scenic beauty. Dhaka city is endowed with rich wetland resources (e.g. Gulshan lake, Dhanmondi Lake, Uttara Lake, Banani Lake, etc) that are also facing degradation by the aforementioned threats. The degradation in the water quality affects the floral and faunal population along with the people dependent on these ecosystems. This trend has to be checked and reversed for the greater interest. Gulshan Lake is one of the last remaining water bodies of the city. Not only is its presence important for the sustenance of the eco-system, as the largest remaining lake, it is a major source of the recharge of the groundwater. However, pollution and encroachment have become major threats to the existence of the Lake. Hence, the conservation of wetlands/lakes deserves the utmost attention. Therefore, evaluation of water and sediment quality in Gulshan

Lake and identification of outfalls are very important. The present study focuses on assessing present status and variation of water quality of Gulshan Lake, also for identifying the outfalls into the lake. The purpose of this Chapter of is to provide a brief background of Gulshan Lake, its corresponding watershed and water quality.

## 2.2 Description of Watershed around Gulshan Lake

When the other contemporary sophisticated areas like Wari, Ramna and Purana Paltan were spoiled by excessive development of houses, small business enterprises, educational institutions, coaching centers, health care centers etc., the city authority, Dhaka Improvement Trust (DIT), established Dhanmondi, Gulshan, Banani, Baridhara and Uttara residential areas. DIT developed the Gulshan Model Town in 1961. Unfortunately, these residential areas are gradually facing the same fate, with rapid development of different types of residential, commercial and even industrial establishments in these areas, with the extension of Mohakhali, Tejgaon, Badda and other adjoining areas. According to a press report, the first Master Plan of Dhaka suggested that at least 480 hectors of open space would be kept in the city for better condition of the city environment. According to the then DIT, the open space decreased to 318 hectors in 1978 and in recent years, open space is estimated at less than 60 hectors. DIT transformed into the Rajdhani Unnayan Kartripakkha (Rajuk) in 1987.

Dhaka has been experiencing huge migration and natural growth of population every year due to many push and pull factors. Population consensus data shows approximately 370,000 people lived in Gulshan, Banani, Baridhara and Badda areas (i.e. major part of Gulshan Lake watershed area) in 2006. This huge population growth has increased the basic demand for settlements and utility services. These demands turn into establishment of both formal and informal settlements (slums and squatters) rapidly all around the city. However, at some places the existing residential land uses have converted to commercial uses. Most of the designated residential areas including Dhanmondi, Gulshan, Baridhara, Uttara and Banani are also more or less occupied by excess number of schools, colleges, universities, coaching centers, industries and factories particularly garments, health care centers (hospitals, clinics, diagnostic centers), mushrooming shopping malls and small-scale business enterprises. A mixed-use zone is considered as a zone that cover residential plus commercial land uses. It has been observed from existing land use pattern that mixed land uses like diplomatic missions, offices of different companies, rest houses, shops and display centers, banks, recreation parks etc. are found common in residential areas of Gulshan and Baridhara. These non-residential uses are destroying the residential sanctity of this area. They are scattered throughout the residential areas of Gulshan, Badda and Shahjadpur. In addition, the area is having major commercial developments along major roads. Therefore, Gulshan Lake watershed area will experience additional pressure on utility services and transport needs due to changes in their land use character. Overall, mixed-use areas surrounding Gulshan Lake have been categorized as follows:

1. West side of Pragati Sarani from Rampura Bridge to Shajadpur, except diplomatic zone;
2. Both sides of Gulshan Avenue from Shooting Club up to the northern end including the Gulshan Circle-1 and Circle-2.

Most of the lakes/ water bodies of Dhaka city have been encroached for construction of both formal and informal settlements. Local influential people have also been occupying land reclaimed from lakes, canals and rivers. In fact, the wetland encroachment in Dhaka city has become a regular practice, which is threatening the wetland ecosystem and biodiversity. According to press reports, there were around 50 khals in Dhaka city and their length was 256 km during 1960s. But, due to the encroachment, presently there are only 26 khals and their length is 125 km. According to DWASA, only 26 khals out of the former 43 are recognizable now in Dhaka city and the rest have been encroached.

The watershed of Gulshan Lake accommodates expatriates; there is also an exclusive diplomatic zone in this area. Nevertheless, the Gulshan Lake watershed area also houses significant habitations of poor and lower income people. Land grabbers have been running a very lucrative business erecting makeshift structures across a vast swath in Shahjadpur side of Gulshan Lake and renting them out to poor people. These slum settlements not only contribute to pollution of the low lying area, but also harbor criminals. An unscrupulous section of officials makes money providing illegal connections of utility services to these makeshift structures. In addition, infrastructural development specially the real estate is a lucrative business and people are building houses, offices, and other infrastructure in legal and illegal way over the Lake. Indiscriminate filling of Gulshan-Banani-Baridhara Lake, RAJUK's bid to build commercial structures on public parks and open spaces and unplanned commercialization of residential plots are fast changing Gulshan Residential Model Town into an urban ghetto. The ever-shrinking silhouette of Gulshan Lake snaking through the posh residential areas tells a grim story of indiscriminate land filling, resulting in possible extinction of the waterbody. At the nearby Gulshan Avenue, a playground has disappeared. According to press reports, at least three public parks have disappeared or are in the process of disappearance at Gulshan-2 roundabout. There are few open spaces/ parks in Gulshan and Baridhara area apart from two lakes - Gulshan Lake and Banani Lake. There is a playground adjacent to Wonderland in Gulshan.

## 2.3 Existing Environmental Condition of Gulshan Lake

Gulshan Lake is the northernmost lake in a chain of water bodies (Gulshan Lake, Hatirjheel, Begunbari Khal, Balu River and Sitalakhya River) of increasing pollution from north to south. Gulshan Lake has crossed three roads - Madani Avenue (near Gulshan-1), Bayzid road (near Shahjadpur) and Gulshan-Badda link road. There is a gate at the interface of the Lake with Hatirjheel near Shooting Club, which restricts the regular flow of water towards downstream. Flow from Gulshan Lake then meets the combined flows of Banani Lake and Mohakhali drainage channel at Hatirjheel. The combined flow moves eastward through Begunbari Khal/ Hatirjheel, which is one of the main drainage channels of Dhaka city. The Begunbari Khal-Hatirjheel system, stretching from behind the Sonargaon Hotel to Rampura bridge, drains about 30 km$^2$ of Dhaka city. Along the way, it drains the crowded parts of the city, including Tejgaon, Mohakhali, Karwan Bazar, Panthapath, Banani-Gulshan, Green Road, and Farmgate area. Beyond Rampura Bridge, the Begunbari Khal flows eastward, eventually meeting Norai Khal-Balu river system, which finally discharges into Sitalakhya River (Samad, 2009).

In pursuance of Section 5 of The Bangladesh Environment Conservation Act 1995, the Government has declared some wetlands of the country as ecologically critical Areas (ECA) for the protection of natural environment and sustainable environmental management. Gulshan Lake is one of the eight ECA's declared by Department of Environment (Islam, 2005; Kothari et. al., 2000). An "Ecologically Critical Area (ECA)" is ecologically defined areas or ecosystem, affected adversely by the changes brought through human activities.

Gulshan Lake is one of the two wonderful lakes (another one being Dhanmondi Lake) serving as an ornament not only to the locality but also to the entire city. It serves as a breathing space and keeps the local environment cool and soothing. The Lake is composed of four segments (i.e. from north to south, see Appendix A) and the segments are placed side-by-side for simplicity of further description. These are: (i) from just south to Baridhara DOHS area to Madani Avenue (Gulshan 1-Badda Police station link road), (ii) from Madani Avenue to Bayjid road (near Manarat Dhaka International College), (iii) from Bayzid Road to South Avenue (Gulshan-Badda Link road), and (iv) from South Avenue to Gulshan Shooting Complex. Exclusive residential area surrounds northernmost (i.e. first) segment of Gulshan Lake; here the facility for Lakeside walking is also available. Second segment of the lake is surrounded by both developed and under construction buildings, some car workshops; some other small shops and market are located to southeastern side. Third segment of the lake has walking facility on western side, but eastern side provides no walking facility. Hence, slums and makeshift dwellings, mostly illegal, are observed on the eastern side, but the western side is compact with developed residential area. Besides, footpath and lakeside road for driving vehicles are also noticed up to third segment of lake. In the fourth segment, the western side has only footpath, while under-developed and informal structures are noticed on the eastern side. Almost every lake of Dhaka city is under threat. The following are the major threats to Gulshan Lake:

1. Encroachment
2. Land use conflict
3. Illegal discharge
4. Solid waste dumping

Encroachment, filling, dumping of waste and untreated wastewater discharging into the Lake are the major concerns for Gulshan Lake. The Lake is under threat of filling to generate new plots. This would not only destroy the beautiful open space but will also reduce the capacity of the lake in retaining water during monsoon. Moreover, some developer companies are planning to execute some major housing projects without attention to drainage. They are likely to fill up natural canals, which would have detrimental effects on ecological health of the Lake. Land use/ land cover upstream of Gulshan Lake is largely residential, while commercial establishments are located immediately adjacent to the Lake. Lake encroachment and unauthorized development on the Badda-Shahjadpur side is still continuing. As a result, during dry season, Gulshan Lake has a surface area of 0.48 square kilometers and an average depth of approximately 2.5 meter, thus volume of $12\times10^5$ cubic meter (Khan, 2006b). Contamination of lake is another problem and Gulshan Lake receives illegal discharge through outfalls in most areas. All household wastewaters of Gulshan, Badda and Shahjadpur areas find their destinations into the Lake and pollute the water, which is destroying the quality of the Lake water and its fish resources. The Lake has been leased out for fish cultivation and fish-feed is used for fish cultivation. This is another cause behind contamination of Lake water. Fish mortality is now very common and regular in the Lake due to contamination. In addition, many Lakeside residents indiscriminately dispose their household solid waste directly in the Lake.

Unplanned spatial development activities and growth of habitation in Gulshan-Baridhara-Badda-Shahjadpur area due to rapid population growth are causing encroachment on retention areas and natural drainage paths with little or no care of natural drainage system. Indiscriminate drainage outlets, lack of proper maintenance of existing drainage system, and disposal of solid waste into the lake and its drainage paths are the prime causes of pollution of the Lake. Lake management is very important to preserve and uphold the sanctity of this splendid Lake. Table 2.1 shows the Bangladesh standard for inland surface water bodies. It shows acceptable limits for only four parameters.

Table 2.1:Bangladesh standards for inland surface water [GoB 1997,Schedule 3(A)]

| Sl. No. | Best Practice Based Classification | Parameter | | |
|---|---|---|---|---|
| | | pH | BOD(mg/l) | DO (mg/l) |
| 1 | Source of drinking water for supply only after disinfection | 6.5-8.5 | ≤ 2 | ≥ 6 |
| 2 | Water usable for recreational activity | 6.5-8.5 | ≤ 3 | ≥ 5 |
| 3 | Source of drinking water for supply after conventional treatment | 6.5-8.5 | ≤ 6 | ≥ 6 |
| 4 | Water usable by fisheries | 6.5-8.5 | ≤ 6 | ≥ 5 |
| 5 | Water usable for by various process and cooling industries | 6.5-8.5 | ≤ 10 | ≥ 5 |
| 6 | Water usable for irrigation | 6.5-8.5 | ≤ 10 | ≥ 5 |

**Notes:**
(1) In water used for pisciculture, maximum limit of presence of ammonia as nitrogen is 1.2 mg/l
(2) Electrical conductivity for irrigation water 2250 µS/cm (at a temperature at 25 °C)

The United States Environment Protection Agency (USEPA, 1986) has set standards for a number of parameters for inland surface water bodies. Some of these standards related to the study are as follows:

1. pH is recommended of 6.5 - 9.0 for the protection of aquatic life.
2. The proposed standard for DO is > 5 mg/l for coldwater fisheries.
3. The beneficial use criteria for TSS is 25- 80 mg/l, whether TDS is ≤ 12,000 mg/l, for the protection of aquatic life.
4. The proposed standard for nitrate and nitrite is ≤ 90 mg-N/l and ≤ 0.06 mg-N/l respectively for the protection of aquatic life.
5. The proposed standard for total phosphorus is ≤ 0.82 mg-P/l for the protection of aquatic life.
6. Concentration in natural soil for Cd ranged from 0.01 to 0.7 mg/kg, while average concentration is 0.06 mg/kg; Cr from 1 to 1000 mg/kg, average 100 mg/kg and Pb from 2 to 200 mg/kg, average 10 mg/kg.

## 2.4 Parameters of Concern

This Section describes the significance of some major water quality parameters that are important for describing the overall health of a water body.

### pH

The pH is a measure of the hydrogen ion concentration in water. The pH scale ranges from 0 to 14; zero being a highly acidic solution and 14 being highly alkaline, 7 being neutral. The range of pH in a majority of open waters ranges from 6 to 9 (Wetzel, 1983). In a lake or pond, the pH of water is affected by its age and the chemicals discharged by communities and industries. Most lakes are basic (alkaline) when they are first formed and become more acidic with time due to the build-up of organic materials. As organic substances decay, carbon dioxide ($CO_2$) forms and combines with water to produce a weak acid, called "carbonic" acid. Large amounts of carbonic acid lower water's pH. When acidic waters (waters with low pH values) exposes to certain chemicals and metals, they often make them more toxic than normal. Table 2.2 shows the effect of pH on aquatic lives.

Table 2.2: Effects of pH on fish and aquatic life (H2OU)

| pH value | | Effects observed under research |
|---|---|---|
| Min | Max | |
| 3.8 | 10.0 | Fish eggs could be hatched, but deformed young were often produced. |
| 4.0 | 10.1 | Limits for the most resistant fish species. |
| 4.1 | 9.5 | Range tolerated by trout. |
| 4.3 | -- | Carp died in five days. |
| 4.5 | 9.0 | Trout eggs and larvae develop normally. |
| 4.6 | 9.5 | Limits for perch. |
| 5.0 | -- | Limits for stickleback fish. |
| 5.0 | 9.0 | Tolerable range for most fish. |
| -- | 8.7 | Upper limit for good fishing waters. |
| 5.4 | 11.4 | Fish avoided waters beyond these limits. |
| 6.0 | 7.2 | Optimum (best) range for fish eggs. |
| 1.0 | -- | Mosquito larvae were destroyed at this pH value. |
| 3.3 | 4.7 | Mosquito larva lived within this range. |
| 7.5 | 8.4 | Best range for the growth of algae. |

Fish that usually withstand pH values as low as 4.8 may die at pH 5.5 if the water contains 0.9 mg/L of iron. Shallow waters in subtropical regions that hold considerable organic matter often vary from pH 9.5 in the daytime to pH 7.3 at night. Organisms living in these waters are able to tolerate these extremes or swim into waters that are more neutral when the range exceeds their tolerance. Most fish can tolerate pH values of about 5.0 to 9.0, but serious anglers look for waters between pH 6.5 and 8.2.

### DO

Dissolved oxygen (DO) is oxygen that is dissolved in water. It gets there by diffusion from the surrounding air, aeration of water that has tumbled over falls and rapids, and as a waste product of photosynthesis. The oxygen freely available in water is vital to fish and other aquatic life and for the prevention of odors. DO level is considered a most important indicator of the ability of a water body to support desirable aquatic life. Secondary and advanced waste treatment are generally designed to ensure adequate DO in waste-receiving waters. An over simplified formula of Photosynthesis (in the presence of light and chlorophyll) is given below:

Carbon dioxide + Water → Oxygen + Carbon-rich foods

$CO_2$ $H_2O$ $O_2$ $C_6H_{12}O_6$

DO is a good indicator of water quality and its relation to the distribution and abundance of various algal species along with the degree of pollution by organic matter, destruction of organic matter and level of self purification of the water. The presence of DO in water may be due to direct diffusion from air and photosynthetic activity of autotrophs. The addition of a variety of biodegradable pollutants from domestic and industrial sources stimulates the growth of microorganisms, which consume the DO of water. The values further deplete during summers because at high temperature, the oxygen holding capacity of water decreases. Typically, as much oxygen as is produced by photosynthesis in a day, is used in respiration or uptake of oxygen, at night. The maximum oxygen concentration usually occurs in the afternoon on clear days, and the minimum immediately after dawn.

Dissolved oxygen concentrations normally change with the growth and decomposition of living organisms in a lake system. As algae and plants grow and carry out photosynthesis, they release oxygen into the water. When organisms die and decompose, the bacteria involved in the decomposition process, use oxygen from the system and replace it with carbon dioxide ($CO_2$). This process usually takes place near the sediment-water interface. Dissolved oxygen concentrations also change at the surface air-water interface. Wave action and other turbulence can increase surface oxygen levels of a lake.

Bacteria consume dissolved oxygen (DO) when large amounts of organic matter from sewage or other discharges are present in the water. DO is the actual amount of oxygen available in dissolved form in the water. When the DO drops below a certain level, the life forms in that water are unable to continue at a normal rate. The decrease in the oxygen supply in the water has a negative effect on the fish and other aquatic life. Fish kills and an invasion and growth of certain types of weeds can cause dramatic changes in a stream or other body of water. Numerous scientific studies suggest that 4-5 parts per million (ppm) of DO is the minimum amount that will support a large and diverse fish population. When DO levels drop below about 3.0 parts per million, even the rough fish die. The DO in stream is an inverse function of the microbial population that in turn is controlled by their food supply, the organic pollutants. Excessive organic pollution causes fish kill by oxygen depletion. Fish kill and odor problems are associated with zero oxygen level.

### $BOD_5$, COD

The decomposition of organic matter whether from natural or anthropogenic sources puts a demand on the dissolved oxygen concentrations in water bodies. Measures of this demand include biochemical oxygen demand (BOD), chemical oxygen demand (COD), and total organic carbon (TOC). Chemical and biochemical oxygen demand (COD and BOD) are measures of the amount of oxygen consumed when a substance degrades.

The amount of oxygen required by microorganisms to oxidize organic wastes aerobically is called the biochemical oxygen demand (BOD). The oxygen demand parameter for biodegradable materials in a study area is BOD, 5-day, 20 degrees, which is the amount of dissolved oxygen required by aerobic microorganism to decompose the organic matter in 1 liter of water over 5 days at 20 degrees Celsius. This measurement has been found to be approximately two-thirds of the total oxygen required to decompose all biodegradable organic matter in the sample. BOD may have various units, but most often, it is expressed in milligrams of oxygen required per liter of wastewater (mg/l). BOD is the laboratory measurement of the amount of oxygen consumed by microorganisms in the biological processes that break down organic matter in water. The greater the BOD, the greater is the degree of pollution. Materials such as food waste and dead plant or animal tissue use up dissolved oxygen in the water when they are degraded through chemical or biological processes. BOD levels are indicative of the effect of the waste on fish or other aquatic life, which require oxygen to live.

Chemical Oxygen Demand (COD) is the laboratory measurement of the amount of oxygen required to oxidize all organic compounds, both biodegradable and non-biodegradable organic matter, in water due to the addition of wastes. A major objective of conventional wastewater treatment is to reduce the chemical and biochemical oxygen demand.

### Electrical Conductivity (EC)

Electrical conductivity or specific conductance is a measure of a material's ability to conduct an electric current. Electrical conductivity (EC) estimates the amount of total dissolved salts (TDS), or the total amount of dissolved ions in the water. EC is controlled by geology (rock types), size of the watershed (lake basin) relative to the area of the lake and other sources of ions to lakes. There are a number of sources of pollutants, which may be signaled by increased EC.

## Ammonia, Nitrate and Nitrite

Nitrite and nitrate are forms of the element Nitrogen, which makes up about 80 percent of the air we breathe. Inorganic nitrogen may exist in the free state as a gas, as ammonia (when combined with hydrogen), or as nitrite or nitrate (when combined with oxygen). Nitrites and nitrates are produced naturally as part of the nitrogen cycle, when a bacteria 'production line' breaks down toxic ammonia wastes first into nitrite, and then into nitrate.

Pure ammonia is a strong-smelling, colorless gas. It is manufactured from nitrogen and hydrogen or is produced from coal gas. In nature, ammonia is formed by the action of bacteria on proteins and urea. Ammonia may speed the process of eutrophication in waterways. The danger ammonia poses for fish depends on the water's temperature and pH, along with the dissolved oxygen and carbon dioxide levels. The higher the pH and the warmer the temperature, the more toxic the ammonia. In addition, ammonia is much more toxic to fish and aquatic life when water contains very little dissolved oxygen and carbon dioxide. When ammonia level reaches 0.06 mg/L, fish can suffer gill damage. When levels reach 0.2 mg/L, sensitive fish like trout and salmon begin to die. As levels near 2.0 mg/L, even ammonia-tolerant fish like carp begin to die. Ammonia levels greater than approximately 0.1 mg/L usually indicate polluted waters (H2OU).

Nitrates stimulate the growth of plankton and waterweeds those provide food for fish. This may increase the fish population. However, if algae grow too wildly, oxygen levels will be reduced and fish will die. Nitrate-nitrogen levels below 90 mg/L and nitrite levels below 0.5 mg/L seem to have no effect on warm-water fish, but salmon and other cold-water fish are more sensitive. The recommended nitrite minimum for salmon is 0.06 mg/L.

## Phosphate

Nearly all fertilizers contain phosphates (chemical compounds containing the element, phosphorous). When it rains, varying amounts of phosphates wash from farm soils into nearby waterways. Overall, phosphates come from fertilizers, pesticides, industry and cleaning compounds. Natural sources include phosphate-containing rocks and solid or liquid wastes. Phosphates enter waterways from human and animal wastes (the human body releases about a pound of phosphorus per year), phosphate-rich rocks, wastes from laundries, cleaning and industrial processes and farm fertilizers. Phosphates stimulate the growth of plankton and water plants that provide food for fish. This may increase the fish population and improve the waterway's quality of life. If too much phosphate is present, algae and waterweeds grow wildly, choke the waterway and use up large amounts of oxygen. Many fish and aquatic organisms may die. Effects of phosphate in a water body are summarized in Table 2.3.

Table 2.3: Phosphate-phosphorus levels in waterbody and effects (H2OU)

| Serial | Total phosphate/ phosphorus* | Effects |
|---|---|---|
| 1 | 0.01-0.03 mg/L | Amount of phosphate-phosphorus in most uncontaminated lakes |
| 2 | 0.025 mg/L | Accelerates the eutrophication process in lakes |
| 3 | 0.1 mg/L | Recommended maximum for rivers and streams |

* If an orthophosphate test cube or ortho/metaphosphate color disk gives values above the total phosphate/ phosphorous values given above, there is cause for concern.

### Metal Concern in Lake

Metals are one of the most toxic forms of environmental pollutants, constituting a threat both to aquatic life and to the quality of the water. By analyzing lake sediments, it is possible to determine the provenance, distribution, extent and the possible hazards of metal contamination. Sedimentary cores, in particular, provide the means for evaluating the different influences from natural and anthropogenic sources; they represent a historical record of the metal accumulations, which have taken place during the past decades because of population growth and industrial development. Toxicity of metal(s) in an aqueous system depends entirely on the chemical form in which the metal exists in the aquatic environment, rather than the total concentration of the metal. Aquatic contamination by metals is very harmful since these elements are not degradable in the environment and may accumulate in living organisms (Jardim, 1983).

Constituents in sediment buried deeper than 10 cm are assumed to be buried and unavailable to biota (White, 2002). Aside from specific perturbations such as dredging, most heavy metals will stay buried in the system. However, an exception to this rule is mercury, which is mobile in sediments. Mercury can move from deeper sediments to the surface, where it is available for biological uptake. Most sediments are permanent deposits that might not be removed in the near future. Thus, their impact on the environment and the relevance to environmental risk analysis over the long-term merit examination are required. Erosion and resuspension of contaminated sediments might be responsible for contaminant uptake by plankton and nekton. Fine-grained sediments with high water contents, such as those forming point bars and other embankments, are unstable and subject to erosion, mainly by currents (reservoirs) and waves (lakes), gravity processes and human actions. The main environmental risk linked to the presence of contaminated sediments is remobilization of the contaminants and their return to the food chain, particularly by infiltration into the groundwater.

metal contamination in lakes and reservoirs is a common problem, especially when the lake/reservoir is confined in nature and receives inputs from various anthropogenic and natural sources. Heavy metal contamination poses a serious threat to aquatic lives as well as humans. In central Dhaka, one of the most densely populated cities in the world, there are three major lakes- Gulshan Lake, Dhanmondi Lake and Ramna Lake. Of the three lakes, Gulshan Lake is losing its cleanliness nature in recent times as it receives pollutant load in the form of clinical waste, municipal waste and sewerage waste. Sediments containing more sand and lower values of organic matter exhibit low concentration of metals in sediment (Franc et al., 2005 and Tsai et al., 2003). Also the pollutant concentrations in sediments increased with decreasing particle size in sediments. Sediment has certain limited capacity to absorb different ions from waters percolating through it. This capacity is lowest for carbonate-sandy fractions of sediments (Lake-sea area), and highest for clayey organic matter rich sediments. Among the metals, Cd, Cu and Pb are particularly important because of their pollution potential in lake water.

**Cadmium (Cd):** The earth's crust, all soils and rocks, including coal and mineral fertilizers contain some cadmium. Cadmium is found in relatively low concentrations in the earth's crust. It is a by-product from treatment of Cu, Pb and Fe ores. It is also used in metal plating, batteries, pigments, plastic stabilizers, pesticides, alloys and chemical reagent. Anthropogenic sources of cadmium include metal-plating operations, battery manufacture, pigment production and plastics manufacturing. It can also be found in fairly high concentrations in sewage sludge. Cadmium is used in metal plating, batteries, plastic stabilizers, pigments, pesticides and chemical reagents.

Cadmium is considered a potential human carcinogen and has also been shown to cause other adverse health effects including kidney damage, bone defects, high blood pressure and reproductive problems. Once in the aquatic environment, it quickly associates with particulate matter including organic matter, iron hydroxides, manganese hydroxides, carbonates and sulfides. Once in the sediments, cadmium is available to the aquatic organisms and can decrease benthic invertebrate abundance and increase mortality.

**Chromium (Cr):** Chromium (Cr) is found at relatively low levels within the earth's crust. Cr (III) occurs naturally in the environment and is found in rocks, animals, plants, soil, and in volcanic dust and gases. Cr is used in nuclear and high temperature research, refractories, drilling muds, metal-finishing, textiles, fungicides, wood preservatives, odor agents, leather treatment, industrial water treatment, photo-mechanical processing, dyes and pigments, catalytic manufacture, and in the production of chromic acid and specialty chemicals. Anthropogenic sources of chromium include chrome plating, the manufacture of pigments, leather tanning and treatment of wood products.

Once chromium enters the blood stream, chromium compounds can be distributed to all organs of the body. Cr (VI) is unstable in the body and is reduced ultimately to Cr (III) by many substances like ascorbate and glutathione. Once this reduction occurs, excretion can occur through urine, hair and nails. However, hair and nails provide minor pathways of excretion. Studies suggest that toxicity effects of Cr (VI) compounds result from the destruction of cellular components. Destruction of cells is caused by generation of free radicals. Chromium is a compound that should be dealt with caution because of its toxic effects.

It cannot be predicted how long the environment can integrate toxic wastes. Therefore, concentrations of heavy metals, including chromium, must be determined in order to evaluate their environmental effects. It is a well-known fact that chromium is essential for leather quality, such as strength, elasticity and thickness (Grozza, 1984). Chromium is essential for animals, being involved in glucose metabolism (Alloway, 1993), but heavy metals may accumulate in specific organs. A significant content in the tissues may indicate that its restraint capacity has been exceeded (Pereira, 1995). An evaluation of metal levels in fish may indicate environmental contamination, but these levels are usually low (Jordao et al., 1996).

**Lead (Pb):** Lead is a soft, malleable metal, also considered to be one of the heavy metals. The aqueous form of a contaminant may significantly affect environmental physicochemical behavior and bioavailability of toxic metals. Lead may be present in ionic state or as soluble complexes or in sorbed state in an aquatic system. Toxicity of lead depends on the chemical form in which it exists in the system (Moore and Ramamoorthy, 1984).

Smelters, incinerators and leaded gasoline are three main sources of lead in the air. A study in United States in 1975 revealed that about 755 of total lead consumption in USA is associated with the smelting industries (Moore et al., 1984). The most anthropogenic sources of metals are industrial, petroleum contamination and sewage disposal (Santos et al., 2005). Pipes, fittings, solder and the service connections of some household plumbing systems contain lead that contaminates the drinking water source. Mining and manufacturing also contribute lead. Lead also comes from materials used in batteries, ammunition, metals, circuit board manufacture, fillers, heat transferring agents, lubricants, additives, paints, printed circuit board manufacture and conductive agents. The high level of Pb in lake water can be attributed to heavily traveled roads that run along the lakes. Higher levels of Pb often occur in water of natural streams near highways and large cities due to high gasoline combustion (Banat et al., 1998). Besides, the high level of Pb in sediments of lake could be attributed to the industrial and agricultural discharge as well as from spill of leaded petrol from fishing boats. Also, dust which holds a huge amount of lead from the combustion of petrol in automobile cars led to increased Pb content (Hardman et al. 1994).

Lead is commonly found in industrial settings and lead exposure has the tendency to cause adverse health effects. Lead toxicity usually begins with the nervous system in both adults and children. Exposure to lead can cause weakness in fingers, wrists, or ankles. Studies show long-term exposure to lead at work can lead to decreased performance. High levels of lead can cause damage to the brain, kidney and can cause anemia in both adults and children. Pregnant women can experience a miscarriage if exposed to high levels of lead during their pregnancy. High levels of lead can also damage organs that are responsible for sperm production. Consistent and long exposures to lead can potentially produce noxious health effects. Lead can cause a variety of adverse health effects in humans. Lead may enter the environment during its mining, ore processing, smelting, refining, recycling or disposal. The initial means of entry is via the atmosphere. Lead may also enter the atmosphere from the weathering of soil and volcanoes, but these sources are minor compared with anthropogenic ones.

Lead usually retains in the upper 2-5 cm of soil, especially soils with at least 5% organic matter or a pH 5 or above. Leaching is not important under normal conditions. It is expected to slowly undergo speciation to the more insoluble sulfate, sulfide, oxide and phosphate salts. Lead enters water from atmospheric fallout, runoff or wastewater; little is transferred from natural ores. Lead is effectively removed from the water column to the sediment by adsorption to organic matter and clay minerals, precipitation as insoluble salt and reaction with hydrous iron and manganese oxide. Under most circumstances, adsorption predominates (H2OU).

## 2.5 Previous Studies

There are some previous studies carried out to characterize water and sediment quality of Gulshan Lake. Quaraishi et al., 2010 monitored conductivity values from 2002 to 2007 and reported on "Season- and year-wise distribution of some trace metals and anions in Gulshan Lake", which is as follows:

Table 2.4: Yearly average concentration of EC (µS/cm) in Gulshan Lake water

| Sl. | Year | EC (µS/cm) |
|---|---|---|
| 1 | 2002 | 397 |
| 2 | 2004 | 372 |
| 3 | 2005 | 367 |
| 4 | 2006 | 368 |
| 5 | 2007 | 373 |

Table 2.5 shows the water quality of Gulshan Lake from a previous study (JICA, 1991), naming "Master Plan for Greater Dhaka Protection Project", both in dry season and wet season.

Table 2.5: Water Quality of Gulshan Lake in both dry and wet season (JICA,1991)

| Sl. | Parameter | Unit | Dry season (Jan-Feb '91) | Wet season (Jul-Aug '91) |
|---|---|---|---|---|
| 1 | DO | mg/L | 7.6 | 6.6 |
| 2 | COD | mg/L | 69 | 11 |
| 3 | BOD | mg/L | 7 | 5.6 |
| 4 | pH | -- | 6.9 | 7 |
| 5 | EC | µS/cm | 159 | 129 |
| 6 | TDS | mg/L | 79 | 65 |
| 7 | TSS | mg/L | 228 | 17 |

Water quality of Gulshan and Banani Lake from the study of Khan (2006a), naming "A Study on Water Quality of Gulshan and Banani Lake", during May-August 2006 is presented in Table 2.6. This study constitutes eight sampling locations from both the lakes, among them four from Gulshan Lake (i.e. sampling points 1-4) and the remaining four from Banani Lake.

Table 2.6: Water Quality of Gulshan and Banani Lake during (May-August 2006)

| Sl. | Parameter | Unit | Average value | Sl. | Parameter | Unit | Average value |
|---|---|---|---|---|---|---|---|
| 1 | pH | - | 7.6 | 9 | $PO_4$ | mg/L | 0.3 |
| 2 | EC | µS/cm | 216 | 10 | $SO_4$ | mg/L | 15.9 |
| 3 | DO | mg/L | 5.4 | 11 | Turbidity | NTU | 43.5 |
| 4 | $BOD_5$ | mg/L | 6.9 | 12 | Alkalinity | mg/L | 210 |
| 5 | COD | mg/L | 23 | 13 | Temperature | °C | 26 |
| 6 | TDS | mg/L | 171 | 14 | Pb | µg/L | 4.75 |
| 7 | TSS | mg/L | 80 | 15 | Cr | µg/L | 0.561 |
| 8 | $NO_3$-N | mg/L | 0.4 |  |  |  |  |

Besides, Ahmed et al. (2005) reported Chromium and Lead concentration of Gulshan Lake sediment to vary from 105 to 124 mg/kg and 22 to 40 mg/kg respectively for samples collected in March 2002.

# CHAPTER 3

# IDENTIFICATION AND CHARACTERIZATION OF WASTEWATER OUTFALLS INTO GULSHAN LAKE

## 3.1 General

A number of storm sewer outfalls, carrying both storm water and domestic sewage, discharge into Gulshan Lake. These and other outfalls also bring in pollutants from a variety of other sources, e.g. runoff from streets, wastewaters from market places, automobile workshops, community centers, clinics and hospitals. Besides, there are numerous illegal domestic sewage outfalls discharging directly into the Lake. Storm runoff from its catchment area as well as illegal domestic and commercial discharges primarily constitutes the nonpoint sources of pollution of Gulshan Lake. A detailed inventory of outfalls of Gulshan Lake has been prepared, which included information on: (i) Outfall ID, (ii) GPS coordinates, (iii) Outfall type (e.g., open channel, closed pipe), (iv) Outfall shape and dimension, (v) Outfall status (hidden/active), (vi) photograph and wastewater through selected major outfalls have been characterized.

## 3.2 Source Assessment

Pollution can alter the integrity of water in one or more ways: chemical, physical, biological or radiological. Impairment occurs when the rate at which pollutant materials enter water bodies exceed their natural capacity to assimilate them. It is important that the source(s) of such pollution is/are identified. Inventories of outfalls discharging into a water body are needed for identification of point sources. Also the quality and quantity of wastewater flowing through each of the outfalls should be assessed. Sources are broadly categorized as either “point sources” or “nonpoint sources.”

### 3.2.1 Point source

Historically, the term “point sources” has meant discharges to surface waters that typically have a continuous flow via a discernable, confined and discrete conveyance, such as a pipe, ditch, channel, tunnel, conduit, well or container from concentrated animal feeding operations or from vessels or floating crafts from which pollutants are discharged to surface water bodies. Storm water discharges from separate storm sewer systems of cities and those associated with industry and construction are considered point sources of pollution. Point source pollution consists of waste products discharged from a specific point such as a sewage treatment plant or an industrial facility. The pollutants from these sources can usually be measured and traced to a pipe or a specific “point” of origin.

### 3.2.2 Nonpoint source

The term “nonpoint sources” is used to describe intermittent, rainfall-driven, diffuse sources of pollution associated with everyday human activities, including runoff from urban land uses, agriculture, silviculture, and mining; discharges from failing septic systems and atmospheric deposition. Nonpoint source pollution is diffuse in nature, both in terms of its origin and in the manner in which it enters surface and ground waters. It results when small amounts of contaminants from a large number of sources are carried by rainfall runoff from construction areas, farms, highways, agricultural activities, septic system discharge, eroding shorelines and washed off lawns and parking lots. The main substances added to the water by nonpoint source pollution are pathogens, sediments, nutrients, and toxic substances. These substances often upset the delicate balance that is necessary to maintain a healthy ecosystem. Hydro-modification (i.e. physical disturbance to a water resource caused by filling, draining, ditching, damming, or otherwise altering wetlands and stream courses) is also considered a nonpoint source problem. Nonpoint source pollution is difficult to control because it enters the lake from a wide geographic area rather than a specific pipe or point of origin, resulting from the everyday activities of many different people.

### ***Nonpoint source pollution for Gulshan Lake***

Nonpoint source pollution is carried to a lake through three mechanisms: stormwater runoff, atmospheric deposition and groundwater discharge. Storm water runoff consists of excess rainwater, which is not absorbed by the soil or vegetation that washes nutrients, sediments and other contaminants from the land into streams/rivers/lakes. Runoff occurs in both rural and urban areas. Urban areas which are covered with impenetrable materials like asphalt, concrete and buildings prevent rainwater from soaking into the ground; therefore runoff ends at natural water bodies. In Dhaka city, storm sewers have been designed to discharge into lakes and low-lands within the city, which act as retention basin. From these temporary detention basins, the storm water eventually discharges to the surrounding river system either by gravity drainage (e.g., in eastern Dhaka) or by pumped drainage (e.g., for western Dhaka). The Gulshan Lake receives discharges from many storm sewer outfalls of the surrounding areas. The storm water eventually flows out of the city through Begunbari-Norai khal system through Hatirjheel. Unfortunately, the storm sewers usually carry domestic sewage during the dry season and combined flows of domestic sewage and storm water during the wet season. Although many storm sewer outfalls discharge into Gulshan Lake at specific points, mainly through pipes, these cannot be strictly treated as “point sources” since the origin of water/wastewater entering into these sewers cannot be ascertained. As noted earlier, illegal domestic and industrial connections to storm sewers is common in Dhaka. Hence, the storm sewer outfalls in Gulshan Lake could be treated as “non-point source” pollution.

Atmospheric deposition is most likely to contribute additional amount of nonpoint source pollution to Gulshan Lake. As rain forms, it absorbs pollutants from the atmosphere. When it rains, the precipitation that falls within the basin can contain small amounts of pollutants. However, considering the gross pollution of Gulshan Lake from domestic sewage and other sources, contribution from atmospheric deposition is likely to be insignificant.

Groundwater discharge may also contribute nonpoint source pollution to Gulshan Lake. Discharges from septic systems, landfills and hazardous waste sites may seep into groundwater which then slowly flows into the lake. However, since groundwater table within Dhaka is located at considerable depths, non-point source pollution from groundwater discharges is not likely to be significant for Gulshan Lake.

## 3.3 Types of Outfalls

For Gulshan Lake, the major types of outfalls discharging into the lake have been classified as: (i) Storm sewer pipes, (ii) Open channels, (iii) Box culverts and (iv) Small private outfalls.

### 3.3.1 Storm sewer pipe outfalls

Pipe outfalls are the most easily identifiable outfalls in Gulshan Lake. These outfalls are primarily storm sewers discharging into the Gulshan Lake. But illegal connection is made from domestic and commercial establishment into storm sewer. These storm sewers are mostly made of concrete; plastic and metal pipes were also seen. There is often a rip-rap or concrete spillway at the outfall to minimize the potential erosion at the end of the pipe. Figure 3.1 shows two such storm sewer outfalls, discharging domestic sewage in the dry season (December 2009).

(a) (b)

Fig 3.1: Pipe outfalls, (a) near R#136 and (b) near Baridhara DOHS

### 3.3.2 Open channel outfalls

While not as easily recognized as pipe outfalls, a number of open channel outfalls have been identified along the banks of Gulshan Lake, especially along roads with no curb and gutter. Roadside drains are the most common open channel outfalls. Figure 3.2 shows two such channel outfalls discharging into Gulshan Lake.

(a) (b)

Fig 3.2: Open outfalls in first segment, (a) drain near R#6 and (b) drain near R#4

### 3.3.3 Box culverts

Box culverts carrying storm water from upstream areas and discharging into lake/ water body is common in Dhaka city. Two such box culverts also discharge into Gulshan Lake. However, such box culverts designed to carry storm water also carry domestic sewage and industrial wastewater. Figure 3.3 shows two box culverts discharging into Gulshan Lake near Baridhara DOHS.

Fig 3.3: Box culverts discharging into Gulshan Lake near Baridhara DOHS

If a culvert is used to connect two parts of a water body, the culvert is not considered an outfall – it is considered part of the stream. A typical road crossing may consist of one or more such culverts conveying the stream. Such culverts are observed across Madani Avenue, Bayzid Road and South Avenue (i.e. connecting segments of lake).

### 3.3.4 Small private outfalls

In the present study, small private outfalls were also included in the outfall inventory. Some common examples of private outfalls include:

- Roof drains (typically 6 inch diameter or smaller)
- Sump pump discharges
- Parking lot drainage
- Private development (condominium) storm sewer systems
- Direct discharge of domestic/ industrial wastewater

Figure 3.4 shows some small private outfalls, one from a parking lot and another from a private development/construction site, discharging into Gulshan Lake.

(a) (b)

Fig 3.4: Private Outfalls, (a) from a construction site near Outfall ID#105 and (b) from a parking lot near R#96

## 3.4 Outfall Inventory

### 3.4.1 Identification of outfalls

As noted earlier, Gulshan Lake receives water/ wastewater from storm sewers (in the form of pipes, channels, box culverts), which usually carry both storm runoff and wastewater from domestic/commercial (including hospitals and clinics)/industrial sources. Besides, wastewaters are also discharged into the Lake directly through a large number of small private outfalls (i.e. small diameter pipes, small channels etc). As a part of the present study, surveys were carried out for identification of outfalls discharging into Gulshan Lake during January 2010 to April 2010. It should be noted that it is often difficult to locate all outfalls by walking along the banks of a lake and searching for pipes for the following reasons:

- Banks often have dense vegetation that may hide outfalls.
- Banks are often rocky, muddy and/or slippery, which makes walking difficult.
- Pipes often end before the stream, and the channel conveying the flow to the stream may not be apparent.

As shown in Fig 3.5, there is walkway throughout western side of the Gulshan Lake. It was convenient to walk along this side of the Lake for identification of outfalls. However, only a section of the Lake on the eastern side has walkway. It was difficult to walk along the portion of the Lake which does not have any walkway. Boat was hired for documentation of outfalls in fourth segment of Lake (from both banks). Eastern side of third segment was almost inaccessible. Also non-point sources along the Lake were not possible to record.

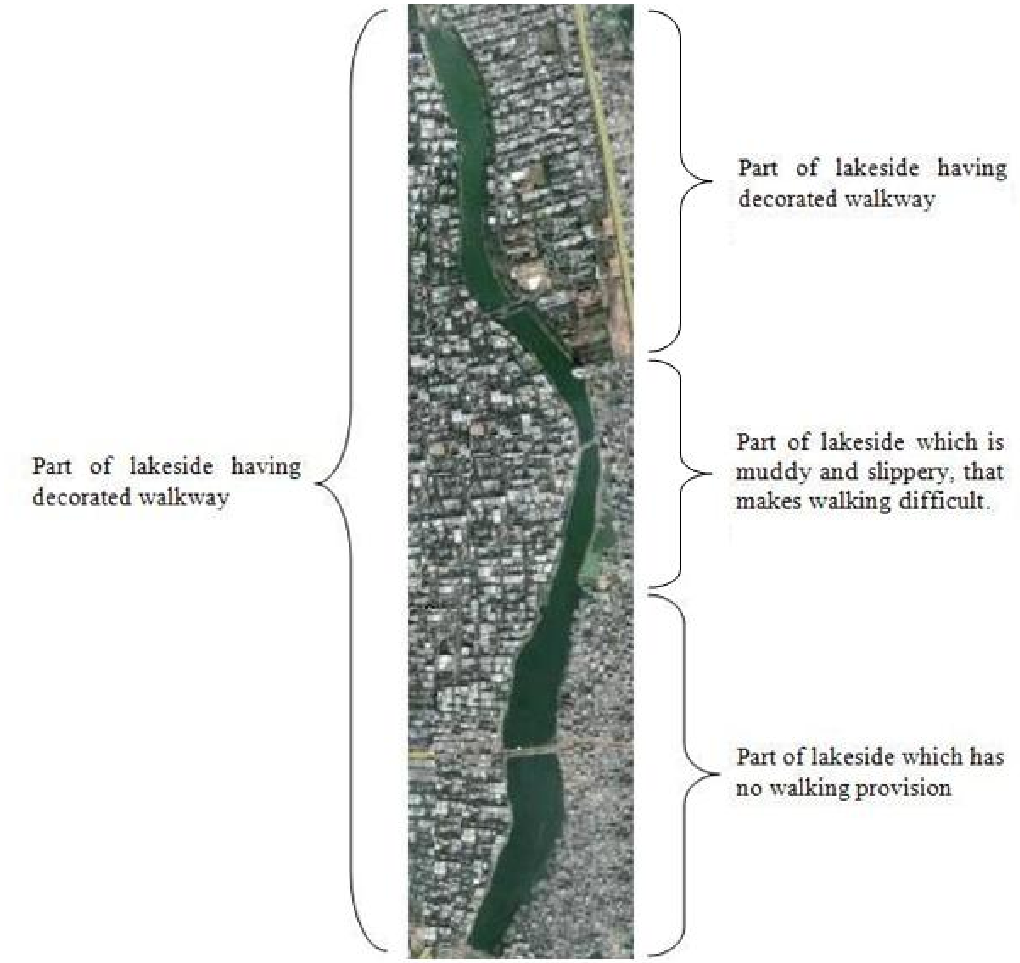

Fig 3.5: Walking provision around Lakeside

During identification of outfalls, it was not possible to trace back the source of the outfalls. Efforts were therefore made to identify the outfalls in terms of outfall shape, dimension, status, GPS location and nearest location of road/establishments. The following items have been listed in the inventory of outfalls of Gulshan Lake.

- Outfall ID
- GPS coordinates
- Outfall type (e.g., open channel, closed pipe)
- Outfall shape and dimension
- Outfall status (hidden/unusable)
- General outfall photo
- Photo showing presence or absence of flow.

Once the outfall is located, labeled and photographed, it is necessary to record the physical characteristics of the outfall, such as size and material.

### *Closed pipes*

For closed pipes, the following information is typically recorded:

- Shape – circular, elliptical, box, arch, other
- Material – reinforced concrete pipe (RCP), corrugated metal pipe (CMP), poly vinyl chloride (PVC), high density polyethylene (HDPE), steel, other
- Size – diameter (if circular) or height and width (if not circular)
- Submerged in water – not submerged, partially submerged, fully submerged
- Submerged in sediment – not submerged, partially submerged, fully submerged

When measuring the diameter of closed pipes, it is important to measure the inside diameter of the actual pipe. If an apron or other outfall structure is present, it may have a different diameter than the actual pipe.

### *Open channels*

For open channels, the following information is typically recorded:

- Shape – trapezoid, parabolic, other
- Material – concrete, asphalt, rip-rap, earthen, grass, other
- Depth
- Top width, Bottom width

It is more difficult to measure the dimensions for an open channel than a closed pipe. In general, the depth is measured from the top of the lowest bank to the channel bottom. This would be the maximum depth of flow before the water overtops the bank. The top width is measured from the top of the lowest bank to the point on the opposite bank at the same level. For a trapezoidal channel, the bottom width is also measured. On a parabolic or v-shaped channel, the bottom width is typically recorded as zero. In this study, almost all the open channel is drain of nearly same top and bottom width, no v-shaped outfall was observed. So, inner width is taken as satisfactory dimension without differentiating as top or bottom width.

Before commencing the survey for identification of outfalls of Gulshan Lake, the storm sewer network map of DWASA was studied to identify the major DWASA outfalls discharging into Gulshan Lake. However, DWASA storm sewer network map only shows the major outfalls, e.g., box culverts discharging into the Lake. In order to identify other outfalls, the configuration of the road networks surrounding the Lake was studied, since both storm sewers and domestic sewers are usually laid along roads. Standard practice is to record GPS location of each identified outfall. Also the location of each outfall can be marked on a map, with relevant notes, so that the outfall can be located again for future inspections. In this study, only major outfalls are shown on map (Appendix B).

Table 3.1 presents the inventory of outfalls of Gulshan Lake. It identifies the outfalls along with their size, GPS coordinates, status and location. The major outfalls responsible for significant discharges during the study period (i.e., dry season) have also been identified (see Appendix B). Table 3.1 shows that a total of 102 outfalls have been recorded in the present study. Among them, 24 major outfalls, 18 hidden, 6 private, 10 surface outfalls and 7 outfalls from latrine (direct disposal of solid waste) have been recorded. Some outfalls are marked as major outfall, since their diameter/ size and flow is significant. Hidden outfalls are those that are not clearly visible. Surface outfalls carry only street-wash to the Lake. Private outfall discharge comes from single residential /commercial establishment. “Unused” outfalls are those having no flow and clearly visible as damaged, i.e. filled or broken. Photographs were taken to show physical and geographical features of outfalls.

Table 3.1: Documentation of ID, GPS and status of Outfalls along Gulshan Lake

| Outfall ID | Specification (Dimension, Shape) | GPS Co-ordinate | | Status | Location | Segment of Lake |
|---|---|---|---|---|---|---|
| | | Latitude (N) | Longitude (E) | | | |
| 1 | Hidden | 23˚47'46.0" | 90˚25'05.1" | | near Madani Avenue | 1st |
| 2 | 3" dia pipe | 23˚47'49.1" | 90˚25'02.5" | Þ | along R#90 | |
| 3 | 3" dia pipe | 23˚47'49.5" | 90˚25'02.3" | Þ | along R#90 | |
| 4 | 3" dia pipe | 23˚47'49.6" | 90˚25'02.5" | Þ | along R#90 | |
| 5 | 6" dia pipe | 23˚47'50.0" | 90˚25'05.9" | | along R#90 | |
| 6 | Hidden | 23˚47'52.1" | 90˚25'00.8" | | between R#90 & R#87 | |
| 7 | 18" dia pipe | 23˚47'56.2" | 90˚25'01.3" | Ŝ | along R#87 | |
| 8 | 12" dia pipe | 23˚47'56.2" | 90˚25'01.3" | | along R#87 | |
| 9 | 18" drain | 23˚48'00.2" | 90˚25'01.2" | | between R#87 & R#84 | |
| 10 | 24" dia pipe | 23˚48'00.5" | 90˚25'01.3" | ® | along R#84 | |
| 11 | 18" dia pipe | 23˚48'00.9" | 90˚25'01.2" | Ŝ | along R#84 | |
| 12 | 24" dia pipe | 23˚48'04.5" | 90˚25'00.7" | Џ | along R#80 | |
| 13 | 12" dia pipe | 23˚48'05.0" | 90˚25'01.2" | | between R#80 & R#79 | |
| 14 | 24" dia pipe | 23˚48'10.9" | 90˚25'00.0" | ® | between R#80 & R#79 | |
| 15 | Hidden | 23˚48'11.2" | 90˚24'59.9" | ® | between R#78 & R#76 | |
| 16 | 18" dia pipe | 23˚48'13.3" | 90˚24'59.4" | | along R#76 | |
| 17 | Hidden | 23˚48'15.1" | 90˚24'58.4" | ® | along R#71 | |
| 18 | 3" dia pipe | 23˚48'16.3" | 90˚24'57.8" | Þ | near United Hospital | |
| 19 | 3" dia pipe | 23˚48'16.9" | 90˚24'57.8" | Þ | near United Hospital | |
| 20 | 3" dia pipe | 23˚48'17.8" | 90˚24'57.2" | Þ | near United Hospital | |
| 21 | Hidden | 23˚48'19.2" | 90˚24'57.2" | ® | along R#72 | |
| 22 | Box culvert | 23˚48'22.9" | 90˚24'56.3" | ® | along Baridahara DOHS | |
| 23 | Box culvert | 23˚48'23.6" | 90˚24'57.0" | ® | along Baridahara DOHS | |
| 24 | 24" dia pipe | 23˚48'24.1" | 90˚24'57.6" | | along Baridahara DOHS | |
| 25 | 48" dia pipe | 23˚48'24.1" | 90˚24'57.6" | ® | along Baridahara DOHS | |
| 26 | 18" dia pipe | 23˚48'23.5" | 90˚24'58.9" | | along R#12 | |
| 27 | Hidden | 23˚48'21.6" | 90˚25'00.7" | | along R#11 | |
| 28 | Hidden | 23˚48'20.6" | 90˚25'01.4" | ® | between R#11 & R#10 | |
| 29 | 24" dia pipe | 23˚48'18.3" | 90˚25'03.1" | | between R#10 & R#9 | |
| 30 | Hidden | 23˚48'17.5" | 90˚25'03.5" | | along R#9 | |
| 31 | Hidden | 23˚48'15.4" | 90˚25'04.4" | | along R#8 | |
| 32 | 24" dia pipe | 23˚48'13.4" | 90˚25'04.9" | ® | along R#7 | |
| 33 | 24" dia pipe | 23˚48'11.3" | 90˚25'05.2" | ® | along R#6 | |
| 34 | 24" dia pipe | 23˚48'08.6" | 90˚25'05.4" | ® | along R#5 | |
| 35 | 24" dia pipe | 23˚48'08.2" | 90˚25'05.5" | | between R#5 & R#4 | |
| 36 | 24" dia pipe | 23˚48'06.6" | 90˚25'05.8" | | along R#4 | |

| Outfall ID | Specification (Dimension, Shape) | GPS Co-ordinate | | Status | Location | Segment of Lake |
|---|---|---|---|---|---|---|
| | | Latitude (N) | Longitude (E) | | | |
| 37 | 24" drain | 23˚48'06.5" | 90˚25'05.9" | ® | along R#4 | 1st |
| 38 | 24" drain | 23˚48'00.7" | 90˚25'04.6" | | along R#2 | |
| 39 | Hidden | 23˚47'57.8" | 90˚25'05.0" | | along R#1 | |
| 40 | 24" drain | 23˚47'54.0" | 90˚25'05.8" | | along Dutabash Road | |
| 41 | Hidden | 23˚47'51.3" | 90˚25'06.7" | | near Madani Avenue | |
| 42 | 12" dia pipe | 23˚47'31.4" | 90˚25'17.5" | | along R#105 | 2nd |
| 43 | 36" dia pipe | 23˚47'34.0" | 90˚25'16.4" | | along R#103 | |
| 44 | 10" dia pipe | 23˚47'37.2" | 90˚25'14.5" | | between R#103 and R#96 | |
| 45 | Hidden | 23˚47'37. 5" | 90˚25'14. 3" | | between R#103 and R#96 | |
| 46 | Hidden | 23˚47'38.8" | 90˚25'13.2" | | between R#103 and R#96 | |
| 47 | 24" dia pipe | 23˚47'40.9" | 90˚25'11.3" | | along R#96 | |
| 48 | 12" dia pipe | 23˚47'41.7" | 90˚25'10.4" | | near R#96 | |
| 49 | 10" drain | 23˚47'42.4" | 90˚25'09.5" | Ŝ | near Madani Avenue | |
| 50 | 24" drain | 23˚47'46.5" | 90˚25'10.4" | | near Madani Avenue | |
| 51 | 24" drain | 23˚47'45.1" | 90˚25'12.3" | Ŝ | near HC of Nepal | |
| 52 | 24" drain | 23˚47'45.1" | 90˚25'12.3" | Ŝ | near Indian HC | |
| 53 | 24" dia pipe | 23˚47'38.6" | 90˚25'17.9" | ® | near Marium Tower-1 | |
| 54 | 18" dia pipe | 23˚47'36.0" | 90˚25'19.3" | | near Marium Road | |
| 55 | 24" dia pipe | 23˚46'50.1" | 90˚25'07.1" | ® | | 3rd |
| 56 | 18" dia pipe | 23˚46'55.6" | 90˚25'08.2" | ® | | |
| 57 | Hidden | 23˚46'57.6" | 90˚25'07.8" | | | |
| 58 | Hidden | 23˚46'59.5" | 90˚25'08.0" | | | |
| 59 | 18" dia pipe | 23˚47'01.8" | 90˚25'09.7" | ® | | |
| 60 | 18" dia pipe | 23˚47'02.3" | 90˚25'09.5" | ® | along R#128 | |
| 61 | 12" dia pipe | 23˚47'06.8" | 90˚25'11.9" | | along R#127 | |
| 62 | 18" drain | 23˚47'09.3" | 90˚25'10.4" | ® | along R#123 | |
| 63 | 24" dia pipe | 23˚47'11.4" | 90˚25'13.7" | | along R#122 | |
| 64 | 24" dia pipe | 23˚47'11.5" | 90˚25'13.6" | ® | along R#121 | |
| 65 | 12" dia pipe | 23˚47'14.0" | 90˚25'14.8" | | along R#120 | |
| 66 | 18" dia pipe | 23˚47'14.1" | 90˚25'14.8" | ® | along R#120 | |
| 67 | 10" dia pipe | 23˚47'17.8" | 90˚25'15.5" | Ŝ | along R#113 | |
| 68 | 12" dia pipe | 23˚47'17.9" | 90˚25'15.8" | Ŝ | along R#113 | |
| 69 | 12" dia pipe | 23˚47'19.1" | 90˚25'16.0" | | near R#104 | |
| 70 | 10" dia pipe | 23˚47'20.3" | 90˚25'16.2" | | near R#104 | |
| 71 | 10" dia pipe | 23˚47'21.8" | 90˚25'18.3" | Ŝ | near R#104 | |
| 72 | Hidden | 23˚47'28.9" | 90˚25'18.3" | | near Manarat University | |

| Outfall ID | Specification (Dimension, Shape) | GPS Co-ordinate | | Status | Location | Segment of Lake |
|---|---|---|---|---|---|---|
| | | Latitude (N) | Longitude (E) | | | |
| 73 | Hidden | 23˚47'24.7" | 90˚25'20.9" | | east side of lake | 3rd |
| 74 | 12" dia pipe | 23˚47'16.1" | 90˚25'19.7" | | east side of lake | |
| 75 | 24" dia pipe | 23˚46'26.7" | 90˚25'01.9" | Ц | near Gulshan Shooting Complex | 4th |
| 76 | 24" dia pipe | 23˚46'29.3" | 90˚25'03.2" | Ц | near R#141 | |
| 77 | 18" dia pipe | 23˚46'31.1" | 90˚25'04.4" | Ц | near R#141 | |
| 78 | 12" drain | 23˚46'32.5" | 90˚25'05.1" | | along R#141 | |
| 79 | 12" dia pipe | 23˚46'33.0" | 90˚25'05.1" | Ц | between R#141 & R#138 | |
| 80 | 12" drain | 23˚46'35.8" | 90˚25'06.4" | | along R#138 | |
| 81 | 10" drain | 23˚46'38.7" | 90˚25'07.8" | Ŝ | between R#138 & R#136 | |
| 82 | 10" drain | 23˚46'40.8" | 90˚25'08.3" | ® | along R#136 | |
| 83 | 24" dia pipe | 23˚46'43.0" | 90˚25'08.6" | ® | along R#135 | |
| 84 | 12" dia pipe | 23˚47'45.7" | 90˚25'07.4" | Ŝ | near Gudara Ghat | |
| 85 | 18" dia pipe | 23˚46'46.2" | 90˚25'07.5" | | near Gudara Ghat | |
| 86 | Hidden | 23˚46'48.2" | 90˚25'15.0" | | near Gulshan-Badda Link Road | |
| 87 | 6" dia pipe | 23˚46'46.7" | 90˚25'15.2" | | east side of lake | |
| 88 | 24" dia pipe | 23˚46'44.6" | 90˚25'15.5" | ® | east side of lake | |
| 89 | Latrine | 23˚46'43.7" | 90˚25'15.6" | | east side of lake | |
| 90 | Latrine | 23˚46'43.4" | 90˚25'15.6" | | east side of lake | |
| 91 | Latrine | 23˚46'42.7" | 90˚25'15.6" | | east side of lake | |
| 92 | Hidden | 23˚46'41.6" | 90˚25'15.5" | | east side of lake | |
| 93 | Hidden | 23˚46'39.8" | 90˚25'15.2" | | east side of lake | |
| 94 | Hidden | 23˚46'39.0" | 90˚25'14.7" | | east side of lake | |
| 95 | Latrine | 23˚46'38.5" | 90˚25'14.9" | | east side of lake | |
| 96 | Latrine | 23˚46'38.1" | 90˚25'14.4" | | east side of lake | |
| 97 | Hidden | 23˚46'37.1" | 90˚25'14.0" | | east side of lake | |
| 98 | Latrine | 23˚46'33.8" | 90˚25'11.6" | | east side of lake | |
| 99 | Hidden | 23˚46'30.5" | 90˚25'10.5" | | east side of lake | |
| 100 | Kutcha drain | 23˚46'28.7" | 90˚25'08.8" | | east side of lake | |
| 101 | Latrine | 23˚46'26.0" | 90˚25'07.5" | | east side of lake | |
| 102 | Hidden | 23˚46'25.0" | 90˚25'06.6" | | east side of lake | |

- Status " ® " stands for major outfall
- Status " ŝ " indicates surface /street-wash outfall
- Status "þ " stands for private outfall
- Status "Ц" is for unused outfalls
- Pipe diameter or drain width was assumed with eye-sight of their inner dimension

### 3.4.2 Physical indicators

Physical indicators are evidence that the discharge from an outfall contains more than just clean stormwater. The identified outfalls were inspected for the following physical indicators, regardless if there is flow present at the time of survey.

***Outfall damage***

Any concrete damage, such as cracking or chipping is considered as damage. Other signs of outfall damage, such as corrosion or paint can also be noted. The presence of outfall damage does not necessarily indicate that an illicit discharge is present or has occurred in the past. Many damaged outfalls have been observed in Gulshan Lake, which indicates poor maintenance of the outfalls. Figure 3.6 shows photographs of some damaged outfalls of Gulshan Lake.

(a) (b)

Fig 3.6: Damaged outfall,
(a) broken concrete pipe near R#1, and (b) pipe filled up with soil, outfall ID#76

***Deposits and stains***

Most pipes that have a periodic discharge will have a slight stain along the flow line. This stain is usually a dark gray color. If the flow line stain is a different color, it may indicate that the discharge contained something other than stormwater, and the flow line stains should be noted. Other substances, such as paint and oil, should not be present in the stormwater. If any dried paint or oil is found at the outfall, it may be evidence that an illicit discharge occurred in the past.

Fig 3.7: Stains inside pipe, near Moriom Tower-1

Figure 3.7 shows stain in a pipe (Outfall ID#53) discharging into Gulshan Lake. Similar stains were also observed in a number of other pipes. From figure, it is observed that the stain in the pipes is of dark grey color, possibly due to flow of sewage through these pipes. Presence of flow in the dry period, with no rainfall indicates that the pipes are discharging wastewater, which comes mainly from households and commercial establishments.

***Abnormal vegetation***

The vegetation around the outfall can be an indicator of the contents of the stormwater discharge. Many outfalls are surrounded by thick brush or grass, somewhere it was excessive (Fig 3.8).

(a) (b)

Fig 3.8: Abnormal vegetation at pipe outfall
(a) near Baridhara DOHS and (b) near United Hospital

However, if the vegetation around the outfall is excessively green or significantly thicker than the surrounding vegetation, there may be nutrients present in the stormwater. Conversely, if the outfall is surrounded by dead vegetation, the stormwater discharge may contain toxic materials. In case of Gulshan Lake, most of the outfall were surrounded by thick bush/ vegetation (Fig. 4.8), indicating excessive nutrient in the discharges. This is in fact expected because, as noted earlier, most of the outfalls carry domestic sewage.

### *Odor*

Odor is probably the most easily-noticed physical indicator in a flowing outfall. Clean stormwater has no odor, with the possible exception of a slight musty smell. If the discharge smells like sewage, petroleum, or sulfide (rotten eggs), those odors must be noted. During November 2009, when the present study commenced, there was minor odor close to the major outfalls. However, with the progress of the dry season, the odor became more intense, especially from January 2010. And during late dry season sampling, intense odor was smelt. The situation improved significantly in wet season.

### *Floatables*

Floatable is mainly the presence of any floating substances such as suds, oil sheen, or sewage should be noted. Any garbage present in the discharge is not considered as floatable. If sheen is present, it is important to determine if the sheen is likely a result of petroleum products or if it is a natural sheen produced by bacteria. For example, iron floc bacteria produces a natural sheen that may appear to be a petroleum sheen, but the sheen breaks apart if stirred with a stick. Petroleum sheens will tend to swirl rather than break apart. In general, natural sheens do not indicate an illicit discharge, so only petroleum sheens should be recorded as a physical indicator. Although a detailed survey throughout the Lake could not be conducted, floating oil sheens were not visible in the Lake during the survey and sampling campaigns.

### *Color*

Unless the color is severe, it may be difficult to observe the color in the discharge. If a sample is collected for analysis, collecting the sample in a clear container makes it easier to observe any color present in the sample. If the color is strong enough to be noticed in the flow, the severity will be high. During the study period, color of sampled water became darker with the advancement of dry season; and during wet season color was less due to mixing with fresh rainwater. Water through outfalls was dark colored during campaigns in March and May, 2010. Also color was generally observed to be intensified towards downstream of lake. In some places, some unusual colored discharges were observed. Fig 3.9 shows whitish color of discharge into Gulshan Lake near United Hospital, which might be imparted from clinical waste.

Fig 3.9: Abnormal (whitish) color of discharge through outfall
in front of United Hospital

### *Turbidity*

Turbidity refers to the cloudiness of the water. The outfall discharge is generally categorized as clear, slightly cloudy, cloudy, or opaque. Outfalls were generally observed to discharge slightly cloudy and cloudy water into Gulshan Lake.

## 3.5 Characterization of Outfall Discharges

### 3.5.1 Methodology

The quality of discharge into the Gulshan Lake was determined through analysis of samples collected from four major outfalls. The samples collected from the selected outfalls were analyzed for a wide range of parameters including $BOD_5$, COD, Color, TDS, TSS, $PO_4$, $NH_3$-N, $NO_3$-N, $NO_2$-N, $S^{2-}$ and $SO_4^{2-}$. Also the flow rates through these outfalls were determined.

***Selection of sampling points***

In this study, four major outfalls of Gulshan Lake were selected for sampling during dry season. As noted earlier, the Gulshan Lake is divided into four segments. For characterization of discharges, one major outfall from each segment was selected. The GPS coordinates of the selected outfalls are listed in Table 3.2 and Locations of these selected outfalls are shown in Fig 3.10.

Table 3.2: GPS coordinates of outfalls for discharge sample

| Outfall serial | Outfall ID | Outfall dimension | GPS Coordinate | | Surrounding Feature |
|---|---|---|---|---|---|
| | | | Latitude (N) | Longitude (E) | |
| O-1 | 37 | 24" drain | 23˚48'06.5" | 90˚25'05.9" | Along R#4 |
| O-2 | 53 | 24" dia pipe | 23˚47'38.6" | 90˚25'17.9" | Near MT-1 |
| O-3 | 62 | 18" drain | 23˚47'09.3" | 90˚25'10.4" | Along R#123 |
| O-4 | 83 | 24" dia pipe | 23˚46'43.0" | 90˚25'08.6" | Along R#135 |

- ❖ MT-1 stands for Moriom Tower-1

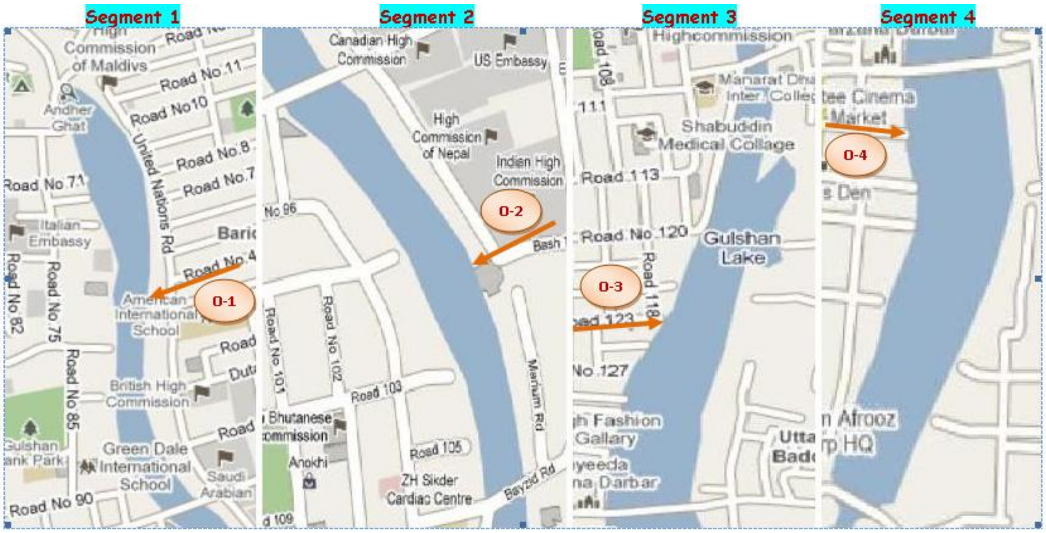

Fig 3.10: Outfalls selected for characterization of dry season discharge

### *Sample collection and analysis*

For characterization of outfall discharge, it was decided to collect sample only in dry season because dry season flow contains no rainfall, so actual characterization of discharge could be carried out. Wastewater samples were collected from 4 storm sewer outfall locations considered as major outfall during inventory. The wastewater samples were collected from outfall discharge just before falling into Lake in a plastic container, and then poured into 1L pre-washed pre-labeled plastic bottles (Figure 3.11). Earlier, the bottles were rinsed a couple of time with the wastewater samples to be collected. Samples were collected between 7 to 9 am on 25 May 2010.

Fig 3.11: Collection of outfall sewage sample from outfall O-4 near R#136

After collection, the samples were stored in ice-box and then transported to the BUET Environmental Engineering Laboratory, BUET for analysis. All samples were brought to the laboratory within 4 hours of collection.

### *Analysis of wastewater samples from outfalls*

The wastewater samples collected from the four outfalls were analyzed for $BOD_5$, COD, Color, TDS, TSS, $NH_3$-N, $NO_3$-N, $NO_2$-N, $PO_4$, $S^{2-}$ and $SO_4^{2-}$. During sampling, Ammonia, Nitrate, Nitrite, Phosphate and Sulfate concentrations were measured with a Spectrophotometer (HACH, DR 4000U). Ammonia was measured by the Nessler method, Nitrate by Cadmium Reduction method, Nitrite by the Diazotization method, Phosphate by the Molybdenum Blue method and Sulfate by the Sulfa Ver 4 method. Other parameters, e.g., $BOD_5$, COD, TDS and TSS were measured following Standard Methods.

***Measurement of dry weather flow through outfalls***

If an actual flow rate is required, there are two primary ways of measuring the flow in the field – the volume method and the distance method. The volume method works better for lower flow rates with a concentrated (narrow) discharge stream, and the distance method is more effective for higher flow rates. The volume method involves collecting the flow in a container for a specified time, and determining the flow rate using the collected volume and the collection time.

If the flow from the outfall is wide, it can be difficult to collect the entire discharge in the sampling container. The use of a funnel or other containment device may be required for certain outfalls. It is critical that the entire volume of the discharge be collected when using this method; otherwise, this technique will underestimate the total flow rate.

For larger flow rates, the distance method might be preferable. To use the distance method (also known as the "ping pong ball method"), the cross-sectional area of the flow is determined, and then velocity of the flow is determined by timing how long it takes an object to travel a specified distance. This is typically done using some type of disposable floating object.

Discharge rates of most outfalls of Gulshan Lake are typically low during the dry season, because they carry primarily domestic sewage. So the volume method was adopted for measurement of low rate through the selected four outfalls of Gulshan Lake. A 10 Liter container was used to collect flow through outfall and time required to fill the container was recorded. Flow rate in liters per second was calculated by dividing the volume by the time required to fill the container. All the samples were collected between 7 am to 9 am on 25 May 2010. Table 3.3 shows the measured flow rates of the four selected outfalls.

Table 3.3: Flow rate through selected outfalls

| Outfall Serial | Outfall ID | Volume (Liter) | Time (Second) | Flow Rate (Liter per Sec.) |
|---|---|---|---|---|
| O-1 | 37 | 10 | 3.58 | 2.8 |
| O-2 | 53 | 10 | 5.21 | 1.92 |
| O-3 | 62 | 10 | 4.63 | 2.16 |
| O-4 | 83 | 10 | 4.18 | 2.4 |

### 3.5.2 Outfall discharge characteristics

Discharges from four selected outfalls were tested for 11 parameters (COD, $BOD_5$, TDS, TSS, Color, $PO_4$, $NH_3$-N, $NO_3$-N, $NO_2$-N, $SO_4^{2-}$ and $S^{2-}$). Table 3.4 shows characteristics of wastewater samples collected from four major outfalls of Gulshan Lake; it also shows the corresponding discharge standard according to GoB 1997. Hence discharges are characterized by relatively high concentrations of COD, $BOD_5$, Ammonia, Phosphate and Color. The COD varies from 129 to 188 mg/l and $BOD_5$ from 56 to 160 mg/l. The high Ammonia concentration, varying from 16 to about 28 mg/l is characteristic of fresh domestic sewage. Phosphate concentration has also been found to be very high, varying from 3.55 to 13.4 mg/l. Table 3.4 shows that some of the parameters, e.g., $BOD_5$ and Ammonia, exceed the discharge standards (both for domestic sewage and industrial sewage) by a large margin.

Table 3.4: Parameter test result of selected outfall sewage falling into Gulshan Lake

| Sl. No. | Parameter | Unit | O-1 | O-2 | O-3 | O-4 | Average | Discharge Standard (GoB, 1997)* |
|---|---|---|---|---|---|---|---|---|
| 1 | COD | mg/L | 129 | 186 | 188 | 185 | 172 | 200 (b) |
| 2 | $BOD_5$ | mg/L | 56 | 135 | 80 | 160 | 108 | 40 (a); 50 (b) |
| 3 | $NH_3$-N | mg/L | 16.25 | 16 | 18 | 27.75 | 19.5 | 5 (b) |
| 4 | TDS | mg/L | 277 | 321 | 335 | 413 | 337 | 2100 (b) |
| 5 | TSS | mg/L | 11 | 53 | 24 | 7 | 24 | 100 (a); 150 (b) |
| 6 | Color | Pt-Co | 164 | 303 | 235 | 321 | 256 | -- |
| 7 | $PO_4$ | mg/L | 5.8 | 3.55 | 5.65 | 13.4 | 7.1 | 35 (a); 8 (as P) (b) |
| 8 | $NO_3$-N | mg/L | 0 | 0 | 0 | 0 | 0 | 100 (a); 10 (b) |
| 9 | $NO_2$-N | mg/L | 0 | 0 | 0 | 0 | 0 | -- |
| 10 | $SO_4^{2-}$ | mg/L | 10 | 20 | 15 | 50 | 23.8 | -- |
| 11 | $S^{2-}$ | μg/L | 0.07 | 0.085 | 0.076 | 0.102 | 0.083 | -- |

* a: standard for discharge into natural water body; a: domestic sewage; b: industrial wastewater

# CHAPTER 4

# EVALUATION OF WATER AND SEDIMENT QUALITY OF GULSHAN LAKE

## 4.1 General

The term "water quality" is a widely used expression, which has an extremely broad spectrum of meanings. Each individual has vested interests in water for his/ her particular use. The term quality therefore, must be considered relative to the proposed use of water. From the user's point of view, the term "water quality" is defined as "those physical, chemical or biological characteristics of water by which the user evaluates the acceptability of water" (Agarwal, 2003). Webster's dictionary defines monitoring as (1) to check and sometimes to adjust for quality or fidelity, (2) to watch, observe or check, especially for a special purpose, (3) to keep track of, regulate or control (as a process for the operation of a machine). It can be noted that both (1) and (3) involve adjustment, regulation, or control, which fit well with the various types of monitoring information. Water quality monitoring is carried out to acquire the knowledge on existing water quality of a water body. A variety of monitoring programs can be used to evaluate lake water or sediment. Typically this can include water column monitoring, biological monitoring or sediment monitoring. The quality of water in Gulshan Lake watershed is important from a water resource management perspective because the lake discharges into the Hatirjheel (a major storm water retention basin of Dhaka city), which is currently being restored through implementation of a major project. Water managers are concerned that continuing development and land use changes in the watershed of Gulshan Lake can threaten the quality of water in the Lake and also efficacy of the restoration project subsequently.

Gulshan Lake is mainly used for pisciculture on a professional leasing system. However, this lake is widely used by people for bathing, washing of clothes and utensils, etc. Sediment of Gulshan Lake is likely to accumulate trace contaminants such as metals with passage of time and may act as a source of such contaminants. Therefore, it is important to assess water and sediment qualities of Gulshan Lake. This Chapter presents an assessment of water quality of Gulshan Lake, which is based on systematic collection and analysis of the water samples from the lake during both dry and wet seasons. This Chapter also presents an analysis of sediment quality in Gulshan Lake bed.

Water quality along Gulshan Lake has been monitored during November 2009 to August 2010. Water samples were collected at 16 near-shore locations along 8 cross sections (Fig 4.1, 4.2); sediment samples were collected at 4 locations, one from each of four segments (approximately at the middle of lake width at that cross section, Fig 4.3) during the study period.

## 4.2 Methodology

Water quality of all natural water bodies vary both spatially and temporally, therefore can rarely be adequately represented by a single sample collected from a single point. It is important to note that seasonal and spatial variation in lake flow may affect interpretation of water quality trends. Other factors affecting the monitoring of water quality trends include the selection of sampling points, their geographic locations, sample collection schedules, sample collection methods, sample processing methods, analytical methods and the period of sample collection. This section describes methodology followed for characterization of water quality and sediment characteristics of Gulshan Lake.

### 4.2.1 Characterization of water quality

Water quality monitoring in a natural water body is a valuable tool for understanding how surrounding factors are affecting water quality and also for identifying emerging problems. This requires assessment of the physical, chemical and biological characteristics of the water and sediment of the lake. So a monitoring program covering dry and wet seasons was adopted to characterize the water and sediment quality of Gulshan Lake.

#### *4.2.1.1 Selection of sampling points*

The number of sampling sites in a water body during any study depends on a number of factors such as possible spatial variation of pollutants, detection of pollution peaks and frequency of sample collection, and physical limitations of laboratory facilities. In this study, 16 different locations of Gulshan Lake were selected for sampling water. Selection of location for sampling was based on the following criteria:

(i) Sampling locations should be selected in such a way that they cover the entire lake in order to obtain a clear understanding of the spatial variation of water characteristics. Figure 4.1 shows an image Google Earth of Gulshan Lake and surrounding areas.

From Fig 4.1, it is clear that Gulshan Lake is composed of four segments, stretching from north to south. These are: (i) from just south to Baridhara DOHS area to Madani Avenue (Gulshan 1-Badda Police station link road), (ii) from Madani Avenue to Bayjid road (near Manarat Dhaka International College), (iii) from Bayjid Road to South Avenue (Gulshan-Badda Link road), and (iv) from South Avenue to Gulshan Shooting Complex. For simplicity, all four limbs of Gulshan Lake are shown from left to right, instead of north to south direction. As shown in Fig 4.2, from each segment of Gulshan Lake, a total of 4 locations along two cross-sections have been selected for collection of water sample during each sampling. Accordingly, sixteen sampling locations were selected; these are identified as W1 to W16 in Fig 4.2.

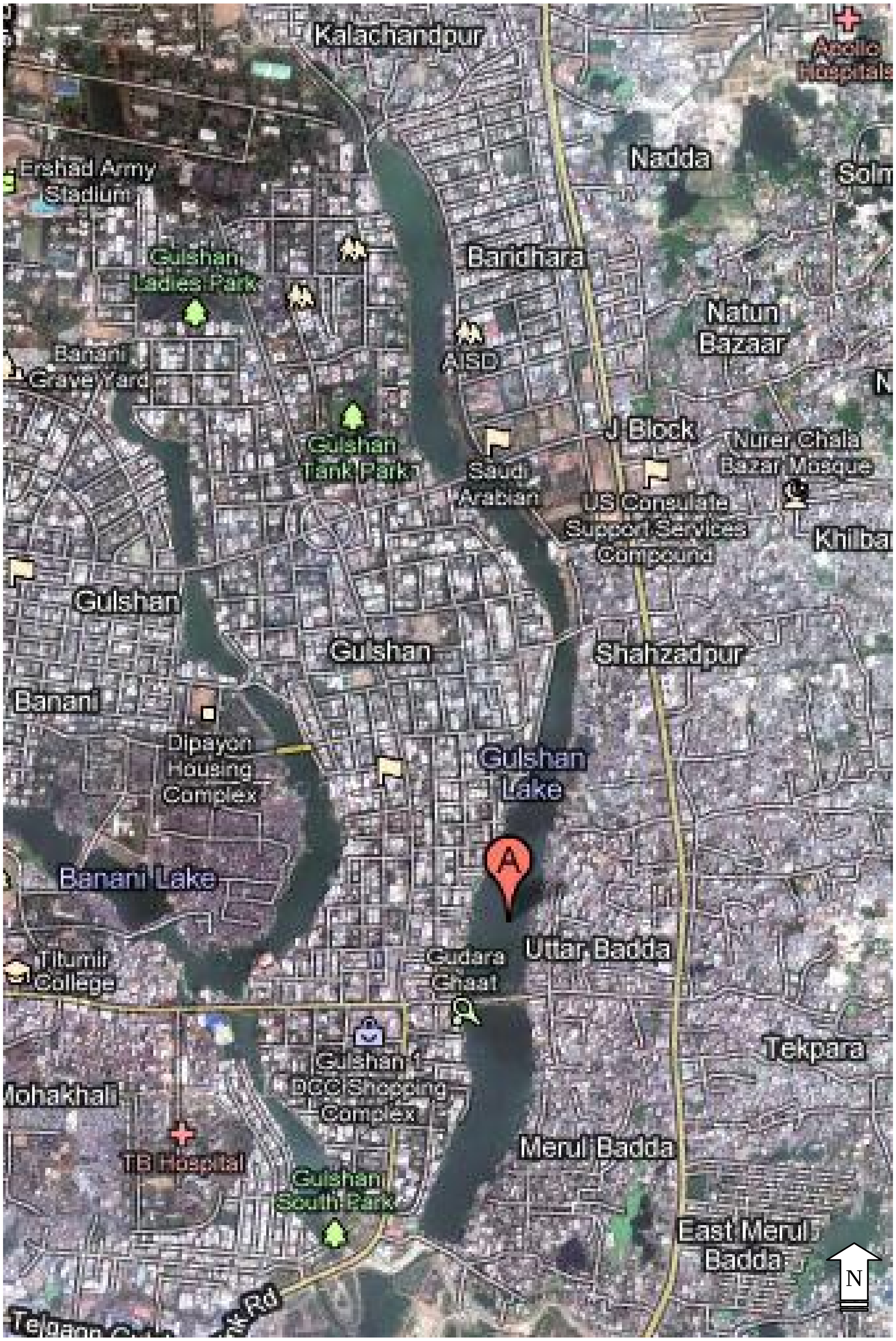

Figure 4.1: Gulshan Lake in Bird's Eye (source: Google earth map)

Figure 4.2: Water Sampling Points in Gulshan Lake

(ii) Sampling locations should generally be chosen such that the samples are adequately representative of the system as a whole. In this regard, samples were collected from well-mixed sections of the lake. Every sampling point was carefully chosen at a considerable distance downstream of major outfalls into the Lake. GPS coordinates of the sampling points are shown in Table 4.1.

#### *4.2.1.2 Collection of sample*

Measurement of certain water quality parameters could be done at the source (i.e., in the field), while measurement of other parameters need to be carried out in the laboratory. The measurement in a laboratory requires sampling in an appropriate manner. Analysis through sophisticated equipment does not actually ensure correct results as it only analyzes the sample that is brought into the laboratory. The representativeness of any laboratory test result depends on the integrity of the sample collection. The sample must also be kept in such a way that the concentration of the species is to be analyzed remains unchanged during transportation and possible storage.

Table 4.1: Locations of the water sampling points/cross-sections of Gulshan Lake

| Sampling x-section | Sampling Location | GPS coordinates | | Area/Infrastructure at close Proximity to |
|---|---|---|---|---|
| | | Latitude (N) | Longitude | |
| 1 | W-1* | 23°48´07.4´´ | 90°25´01.0´´ | Between Poly Clinic and Club |
| | W-2 | 23°48´07.2´´ | 90°25´05.6´´ | American Int’l School |
| 2 | W-3 | 23°47´50.5´´ | 90°25´01.5´´ | Green Dale Int’l School |
| | W-4 | 23°47´51.8´´ | 90°25´06.6´´ | British High Commission |
| 3 | W-5 | 23°47´41.5´´ | 90°25´12.3´´ | Road no. 96 |
| | W-6 | 23°47´42.7´´ | 90°25´14.9´´ | High Commission of Nepal |
| 4 | W-7 | 23°47´33.0´´ | 90°25´17.1´´ | Road no. 103 |
| | W-8 | 23°47´36.0´´ | 90°25´19.3´´ | Marium Tower-1 |
| 5 | W-9 | 23°47´22.4´´ | 90°25´16.9´´ | Manarat Int’l School and University |
| | W-10 | 23°47´23.8´´ | 90°25´20.8´´ | Marium Tower-2 |
| 6 | W-11 | 23°46´56.0´´ | 90°25´06.8´´ | Near Sayeeda Farzana Darbar |
| | W-12 | 23°46´53.3´´ | 90°25´15.2´´ | Uttar Badda |
| 7 | W-13 | 23°46´42.3´´ | 90°25´07.9´´ | Road no. 135 |
| | W-14 | 23°46´39.5´´ | 90°25´14.0´´ | Merul Badda |
| 8 | W-15 | 23°46´30.9´´ | 90°25´02.6´´ | Gulshan Shooting Complex |
| | W-16 | 23°46´29.0´´ | 90°25´08.9´´ | South Badda Bazar |

* Odd number sampling locations (i.e. W-1, W-3, W-5 etc) are from west side, others from east side

In this study, 16 locations along 8 cross sections of the lake were chosen for collection of water sample. At every sampling location, water sample from approximately one meter away from bank and one ft depth from surface was considered to be representative of that location. For a slowly flowing lake like Gulshan Lake, various chemical constituents in a water column can be considered to be in equilibrium at any location. However, speciation and distribution of chemical constituents in water close to the bottom sediment may differ to some extent from that in water at the surface of the lake. Considering time and resource constraints, it was decided that water samples would be collected from points nearly one meter away from the bank of the lake and at a depth of about one ft (0.3048 meter) from water surface at all locations. The water samples were collected in two 1 liter pre-labeled plastic bottles from each location. Samples were collected with precaution so that sampling bottles are free from air bubbles. After sampling, the sampling bottles were stored in ice box and then carried to the Environmental Engineering Laboratory of BUET for analysis. During collection, surface scum was avoided and sufficient distance was kept from major sources of pollution. These samples could be considered to represent the chemical composition at the sampling locations on the particular day of sampling.

Figure 4.3: Collection of Water Sample from Gulshan Lake

Samples were collected during both dry and we seasons to assess seasonal variation of pre-selected water quality parameters. For assessment of water quality, water samples were collected at six different times covering, approximately once a month during ten months from November 2009 to August 2010. Since water quality during the dry season is of prime concern, among the six sampling campaigns, five were carried out during the dry season and one (August 2010) during the wet season. During each sampling campaign, samples were collected in the morning (between 7:00 to 10:00 am). Each sampling campaign took two days; sampling from half of the total sampling stations (i.e. from W-1 to W-8 or from W-9 to W-16) was carried out in one day and sampling from the rest on another day. From each sampling point, two liters of samples were collected in pre-washed plastic bottles with polypropylene caps; the bottles were also rinsed with lake water at the sampling location three times before collecting water samples from that particular point. Table 4.2 shows the sampling times for the six cycles of sampling campaign.

Table 4.2: Seasonal sampling schedule of Gulshan Lake water

| Campaign | Sampling Date | Comments |
|---|---|---|
| 1 | 14 and 17 November 2009 | Dry season |
| 2 | 5 and 8 December 2009 | Dry season |
| 3 | 2 and 5 January 2010 | Dry season |
| 4 | 27 and 29 March 2010 | Dry season |
| 5 | 15 and 17 May 2010 | Dry season |
| 6 | 14 and 16 Aug 2010 | Wet season |

### *4.2.1.3 Analysis of water samples*

In this study, samples were transported from the field to the Environmental Engineering Laboratory within three hours of sampling. Table 4.3 shows the schedule of sample analysis.

Table 4.3: The parameter test schedule of water sample collected from Gulshan Lake

| Campaign | Date | Sampling Pt<br>Parameter | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 14-Nov-09 | COD | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ |
| | | $NO_3$-N | √ | | √ | | √ | | √ | | √ | | √ | | √ | | √ | |
| | | $NO_2$-N | | | √ | | | | √ | | | | √ | | | | √ | |
| | | FC | | | √ | | | | √ | | | | √ | | | | √ | |
| | | $S^{2-}$ | | | √ | | | | √ | | | | √ | | | | √ | |
| | | Pb | | | √ | | | | √ | | | | √ | | | | √ | |
| 2 | 5-Dec-09 | COD | | | | | | | | | | | | | | | | |
| | | $NO_3$-N | √ | | √ | | √ | | √ | | √ | | √ | | √ | | √ | |
| | | $NO_2$-N | | | √ | | | | √ | | | | √ | | | | √ | |
| | | FC | | | | | | | | | | | | | | | | |
| | | $S^{2-}$ | | | | | | | | | | | | | | | | |
| | | Pb | | | | | | | | | | | | | | | | |
| 3 | 2-Jan-10 | COD | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ |
| | | $NO_3$-N | √ | | √ | | √ | | √ | | √ | | √ | | √ | | √ | |
| | | $NO_2$-N | | | √ | | | | √ | | | | √ | | | | √ | |
| | | FC | | | √ | | | | √ | | | | √ | | | | √ | |
| | | $S^{2-}$ | | | √ | | | | √ | | | | √ | | | | √ | |
| | | Pb | | | √ | | | | √ | | | | √ | | | | √ | |
| 4 | 27-Mar-10 | COD | | | | | | | | | | | | | | | | |
| | | $NO_3$-N | √ | | √ | | √ | | √ | | √ | | √ | | √ | | √ | |
| | | $NO_2$-N | | | √ | | | | √ | | | | √ | | | | √ | |
| | | FC | | | | | | | | | | | | | | | | |
| | | $S^{2-}$ | | | | | | | | | | | | | | | | |
| | | Pb | | | | | | | | | | | | | | | | |
| 5 | 15-May-10 | COD | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ |
| | | $NO_3$-N | √ | | √ | | √ | | √ | | √ | | √ | | √ | | √ | |
| | | $NO_2$-N | | | √ | | | | √ | | | | √ | | | | √ | |
| | | FC | | | √ | | | | √ | | | | √ | | | | √ | |
| | | $S^{2-}$ | | | √ | | | | √ | | | | √ | | | | √ | |
| | | Pb | | | √ | | | | √ | | | | √ | | | | √ | |
| 6 | 14-Aug-10 | COD | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ |
| | | $NO_3$-N | √ | | √ | | √ | | √ | | √ | | √ | | √ | | √ | |
| | | $NO_2$-N | | | √ | | | | √ | | | | √ | | | | √ | |
| | | FC | | | √ | | | | √ | | | | √ | | | | √ | |
| | | $S^{2-}$ | | | √ | | | | √ | | | | √ | | | | √ | |
| | | Pb | | | | | | | | | | | | | | | | |

The collected water samples were analyzed for Dissolved Oxygen (DO), pH, Electrical Conductivity (EC), Color, Turbidity, Bio-chemical Oxygen Demand ($BOD_5$), Ammonia ($NH_3$-N), Phosphate ($PO_4$), Total Dissolved solids (TDS) and Total Suspended Solids (TSS) for all samples; and Chemical Oxygen Demand (COD), Faecal Coliform (FC), Nitrate ($NO_3$-N), Nitrite ($NO_2$-N), Sulphides ($S^{2-}$) and Lead (Pb) for alternate campaigns. In the laboratory, pH was measured by a pH meter (Geotech) attached with a pH electrode (WTW, Sen Tix 41) and Conductivity was measured by a Conductivity meter (Hach). Ammonia, Nitrate, Nitrite, Phosphate and Sulfide concentrations were analyzed with a Spectrophotometer (HACH, DR4000U). $NH_3$-N was measured by the Nessler method, $NO_3$-N by the Cadmium Reduction Method, $NO_2$-N by the Diazotization method, and $PO_4$ by the Molybdenum Blue method. Lead concentration was determined with an Atomic Absorption Spectrophotometer (Shimadzu, AA6800). Other parameters (e.g. TDS, TSS) were measured following Standard Methods (see Appendix E).

### 4.2.2 Assessment of bed sediments of Gulshan Lake

Sediments are normally the final pathway of both natural and anthropogenic components produced in or derived from the environment of a lake. Sediment quality is a good indicator of pollution in water column, where it tends to concentrate the metals and other organic pollutants. The present work aimed to investigate sediment samples for total concentration of Cadmium, Chromium and Lead after digestion with aqua-regia. Moisture content and organic matter content of the sediment samples were also determined. Also, Sediment Oxygen Demand (SOD) of the collected sediments was also measured using an ex-situ method.

#### *4.2.2.1 Selection of sampling points*

In this study, 4 different locations (one from each of the four segments of the Lake) of Gulshan Lake were selected for sediment sampling. Locations of the sampling points are shown in Fig 4.4 and GPS coordinates are shown in Table 4.4.

Figure 4.4: Sediment sampling points in Gulshan Lake

Table 4.4: Features of the sampling points of bed sediments in Gulshan Lake

| Sampling point | GPS co-ordinate | | Area/Infrastructure at close proximity to sampling location |
|---|---|---|---|
| | Latitude (N) | Longitude (E) | |
| S-1 | 23°48´07.2´´ | 90°25´05.6´´ | Road #3 |
| S-2 | 23°47´38.6´´ | 90°25´17.9´´ | Moriom tower-1 |
| S-3 | 23°47´23.8´´ | 90°25´20.8´´ | Road #123 |
| S-4 | 23°46´40.8´´ | 90°25´08.3´´ | Road #135 |

#### *4.2.2.2 Collection of sample*

For monitoring of bed sediment quality of Gulshan Lake, sediment samples were collected on 31 May 2010 from the aforementioned four sampling points: S-1, S-2, S-3 and S-4. At each location, top 20 cm of sediment was collected, which represents the most biologically active depositional layer in relatively low flowing streams. All the sediment samples were collected from approximately middle of cross section of Lake at each sampling location (Fig 4.5). A boat was hired to collect bed sediment, using a sediment sampler device from deck of boat. About half kilogram sample was collected from each sampling point. The coring tubes were rinsed in Lake water before re-sampling. Care was taken to ensure that the sampling procedure created minimal disturbance at the sediment-water interface. The collected samples were quickly extruded from the corer, emptied into pre-labeled clean polyethylene bags and kept in ice box for transport to the laboratory, and then samples were stored at 4°C in a refrigerator before analysis.

Figure 4.5: Sediment sample collection with a sediment sampler from Gulshan Lake

### *4.2.2.3 Analysis of sediment sample*

Sample preservation is difficult because almost all preservatives interfere with some of the tests. Immediate analysis is ideal for getting correct results. Storage at low temperature (4°C) is perhaps the best way to preserve most samples, which retard chemical and biological changes that continue after sample collection. No single method of preservation is entirely satisfactory. For sediment samples requiring heavy metal analysis, no special type of preservation technique is required. CPCB, India refers samples containing microgram/L metal level, should be stored at 4°C and analyzed as soon as possible. In this study, analysis of sediment samples started from the day of collection and ended within 9 days. In this study, sediment analysis includes moisture content, organic matter content, metal content (i.e. Cd, Cr and Pb) and potential sediment oxygen demand (pSOD).

### *Moisture content, organic matter content and specific gravity*

For determination of moisture content, sediment samples were taken into different crucibles and weighed. Then they were dried in an oven at approximately 110°C for exactly 24 h and weighed. Moisture content was determined from the difference of weight. Then the samples were further heated in oven at 550°C for approximately 1 h and then cooled and weighed. The difference in latter two weights determines organic matter contents of sediment samples.

### *Sediment metal (Cd, Cr, Pb) determination*

For determination of aqua-regia extractable heavy metals (Cd, Cr, Pb), the selected soil sample was dried in an oven at 110°C for 24 h and grinded. For digestion, 5g of the dried sample was weighed into a 500 mL flask and mixed with 2.5 mL of concentrated nitric acid and 7.5 mL of concentrated hydrochloric acid. The suspension was kept overnight in the flask, followed by dilution with deionized water to 500 mL. Then the setup was heated for 2 h, kept to cool down, stirred for 5 min and filtered (0.8 µm) after cooling. The filtrate was stored in a glass bottle for analysis of Cd, Cr and Pb using an AAS attached with a graphite furnace (Shimadzu, Japan, AA6800).

### *Ex-situ SOD measurement*

The sediment oxygen demand (SOD) was estimated using the ex-situ method outlined by Matlock et al. (2003). For measurement of SOD, 5 g of sediment sample was placed into a 300 ml $BOD_5$ bottle, which was then filled with aerated distilled water saturated with oxygen. Then a magnet and a DO meter probe were placed in the bottle which was then thoroughly airtight by parafilm (Figure 4.6). The DO was measured with a DO meter probe at roughly one-minute increments for 45 minutes while stirring the sediment in the bottle with that magnet. After the initial reading, the $BOD_5$ bottle was continuously stirred and DO concentrations were measured after fixed time periods for 24 hours or until the oxygen was driven to below detection level, i.e. 0.02 mg/L. The overall oxygen consumption in the bottle was measured for the given sample size resulting in a measurement of oxygen consumed in mg $O_2$/gram of sediment/day. Using specific gravity (assumed 2.65 for natural soil), these values were converted into “mg $O_2/m^3$ sediment/day”. Laboratory set up of SOD measurement is shown in Figure 4.6.

Fig 4.6: Laboratory setup for ex-situ SOD measurement

## 4.3 Results and Discussions

### 4.3.1 Water quality of Gulshan Lake

As mentioned earlier, water samples from Gulshan Lake were analyzed for DO, $BOD_5$, pH, EC, Turbidity, Color, $NH_3$-N, TDS, TSS and $PO_4$. Selected water samples were analyzed for COD, $NO_3$-N, $NO_2$-N, FC and $S^{2-}$. This Section describes the water quality characteristics of Gulshan Lake based on analysis of test results and visual inspections.

**pH**

pH is one of the most important factors, serving as an index for pollution. Figure 4.7 shows the spatial variation of pH along the Lake during each of the 6 sampling campaigns. The pH value of water samples did not show significant spatial variation during a particular sampling campaign. During the study period November to May (dry season) and August (wet season), no particular trend in spatial pH variation could be observed. In general, pH value increased slightly along the Lake towards downstream. Samples from east and west bank of Lake were quite compatible with respect to water quality, which indicates Lake water is well mixed.

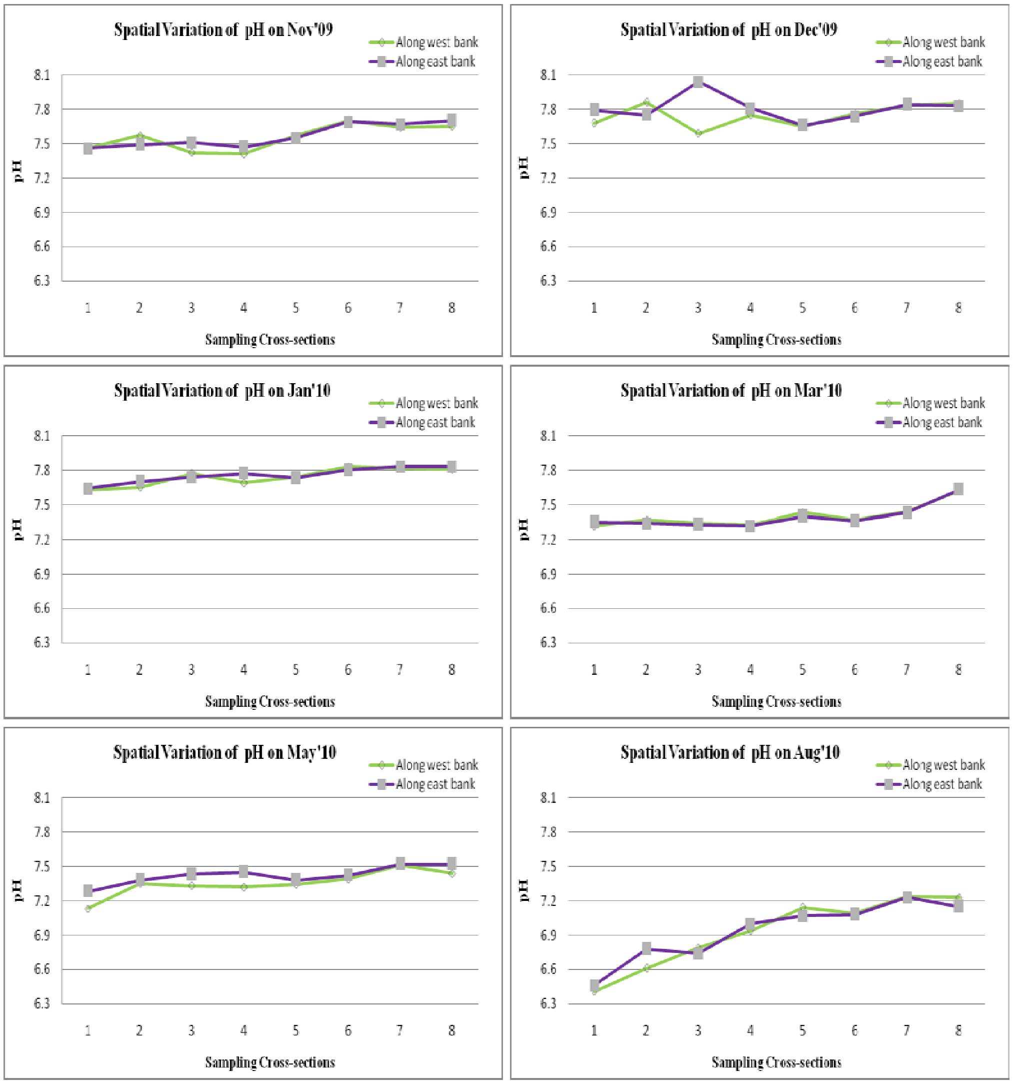

Fig 4.7: Spatial variation of pH on different campaigns.

Figure 4.8 shows Seasonal variation of pH at sampling points W-1, W-3, W-5, W-7, W-9, W-11, W-13 and W-15, i.e. along west bank of Gulshan Lake. The alkaline nature of water was characteristic throughout the study period with slight seasonal variations (pH 6.41 to 8.04). The pH of Gulshan Lake water was relatively high in dry season (highest 8.04 at W-6 location/3rd cross section, east bank on 2nd campaign/Dec 2009) and low in wet season (lowest 6.41 at W-1 location/1st cross section, west bank on 6th campaign/16 Aug 2010). Ahmed et al. (2005) also found alkaline pH values (7.4-8.4) of water near surface (up to 1.5 m depth) in March 2002.

During dry season (from Nov’09 to May’10), pH varied from a low of 7.13 (at 1st cross section, west bank/W-1 location on May’10) to a high of 8.04 (at 3rd cross section, east bank/W-6 location on Dec’09). During wet season (i.e. Aug), pH varied from a low of 6.41 at 1st cross section, west bank/W-1 location to a high of 7.24 at 7th cross section, west bank/W-13 location (see data in Appendix D). Average dry season value of pH was 7.58, while wet season avg. was 6.94. Lowering of pH occurred during the wet season, most likely due to the dilution of alkaline substances by rainwater/ storm runoff. Relatively higher pH in the dry season could be partly attributed to high growth rate of algal population.

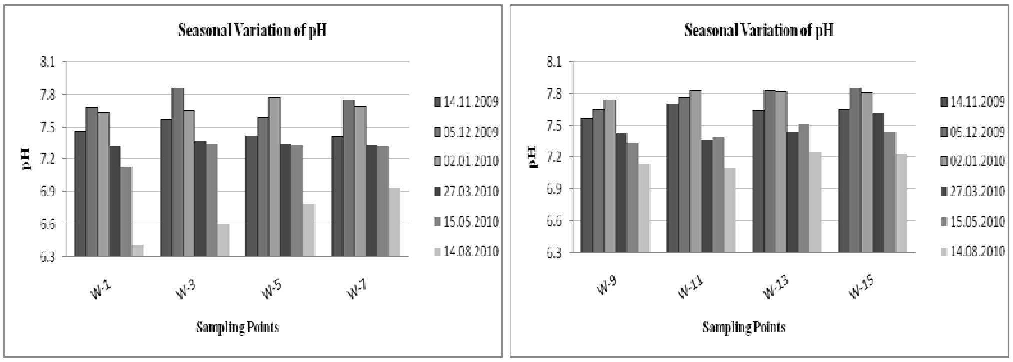

Fig 4.8: Seasonal variation of pH at sampling points along west bank of Lake

In the present study, almost all pH values recorded were within the USEPA (1986) standards (6.0 to 9.0), and within Bangladesh Environmental Conservation Rules, 1997 standard (6.5 to 8.5), for water in natural lake usable mainly for pisciculture. Only the two data in the first cross section were slightly below the range, (i.e. 6.41 at W-1 and 6.46 at W-2) in the wet season on Aug’10.

### Electrical Conductivity (EC)

Electrical Conductivity is an indirect measure of dissolved ions in water. Spatial variation of EC value of Gulshan Lake is shown in Figure 4.9. It shows that in general, EC increased as one moves toward downstream during each sampling campaign. This is most likely due to wastewater discharge enriched with dissolved matter into the Lake from either side, which would obviously increase the dissolved solids concentration towards downstream of the Lake water. Samples from east and west bank of Lake were quite compatible with respect to water quality.

Figure 4.10 shows Seasonal variation of EC along west bank of Gulshan Lake. The EC values recorded in August (i.e., wet season) are relatively lower compared to those during the dry season, due to dilution of Lake water with rainwater/ storm runoff. During dry season, conductivity ranged from a low of 421 µS/cm (at 3rd cross section, west bank/W-5 location on Nov'09) to a high of 643 µS/cm (at W-14 and W-15 locations on Mar'10). Similar EC values (varying from 426 to 510 µS/cm) for Gulshan Lake water column have been reported by Ahmed et al. (2005).

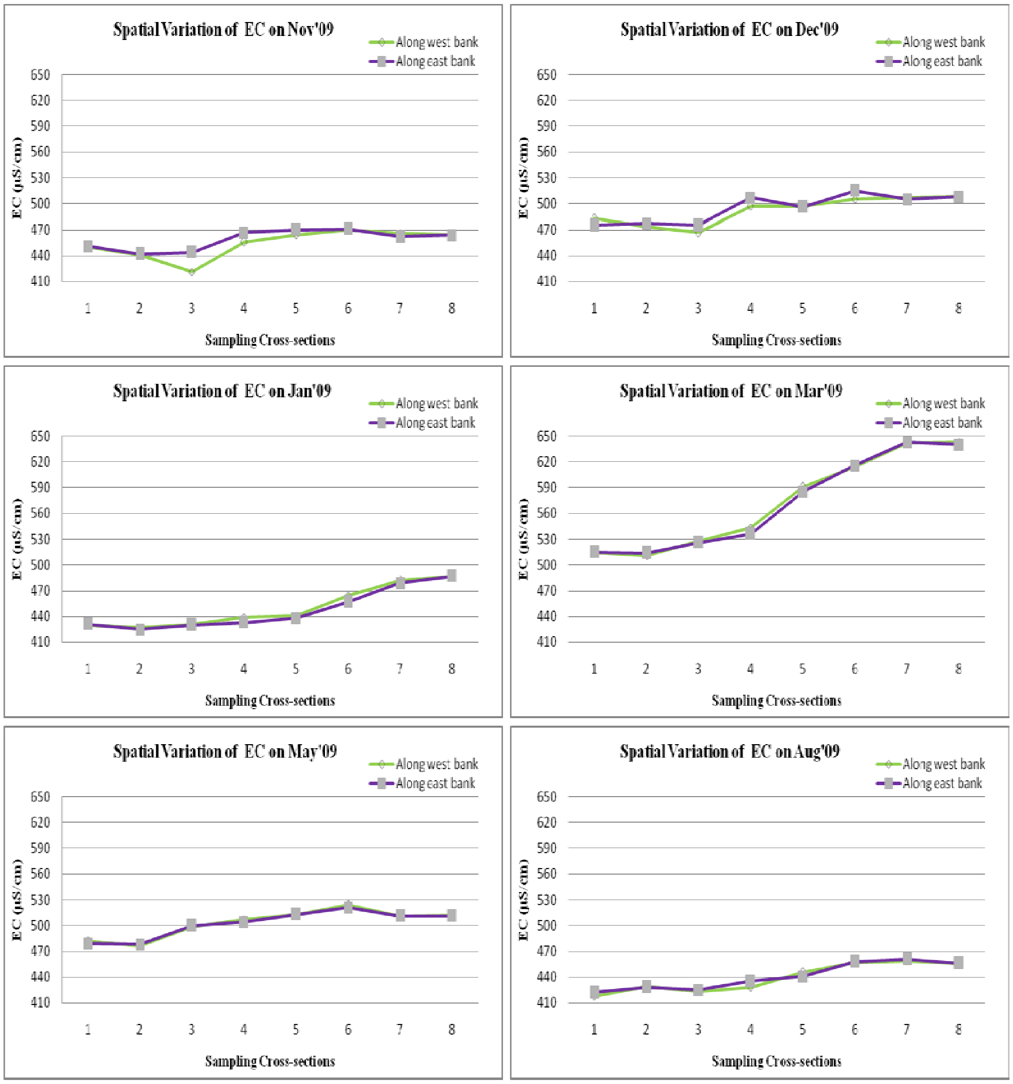

Fig 4.9: Spatial variation of EC on different campaigns

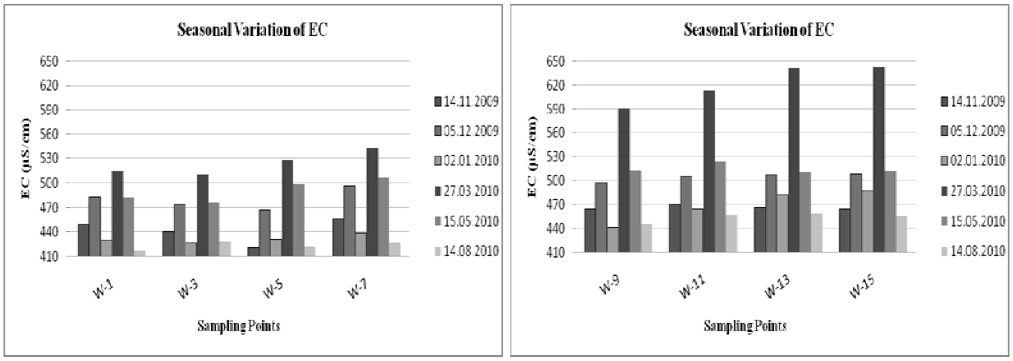

Fig 4.10: Seasonal variation of EC at sampling points along west bank of Lake

In the wet season (i.e.Aug), the conductivity ranged from a low of 418 µS/cm at W-1 location to a high of 461 µS/cm at W-14 location (see data in Appendix D). Average dry season value of EC was 495 µS/cm, while wet season avg. was 440 µS/cm, i.e. not much seasonal variation. So, Gulshan Lake water has been found almost well mixed. ECR (1997) recommends EC for irrigation water 2250 µS/cm, which is far above the present values. Quaraishi et al. (2010) conducted monitoring of EC over 5 years in Gulshan Lake. Table 4.5 compares that study with the present one. This comparison shows drastic increase of EC in recent times. Present study shows EC has increased over 30% from 2007 to 2009-10, which reveals receiving of more dissolved materials by Gulshan Lake in recent years.

Table 4.5: Comparison of yearly average concentration of Electrical Conductivities (µS/cm) in water of Gulshan Lake with previous studies

| Sl. | Year | EC (µS/cm) | Reference |
|---|---|---|---|
| 1 | 2002 | 397 | Quaraishi et al., 2010 |
| 2 | 2004 | 372 | |
| 3 | 2005 | 367 | |
| 4 | 2006 | 368 | |
| 5 | 2007 | 373 | |
| 6 | 2009-10 | 486* | Present study |

* Not the yearly average, rather average value of EC in the present study period (i.e. Nov 2009 to Aug 2010)

### *Color*

During the study period, color has been recorded as a physical parameter at the sampling locations. It was seen that color of the Lake water undergoes darker with the advancement of dry season and in the wet season, color improves significantly.

Waterways with dark-colored water, or those with dark muddy bottoms, absorb heat more. Thus, Gulshan Lake water is likely to get warmer during dry season. Color of water is also expressed in numbers of a platinum cobalt scale based on laboratory test. Figure 4.11 shows variation of Color along Gulshan Lake during each of the 6 sampling campaigns.

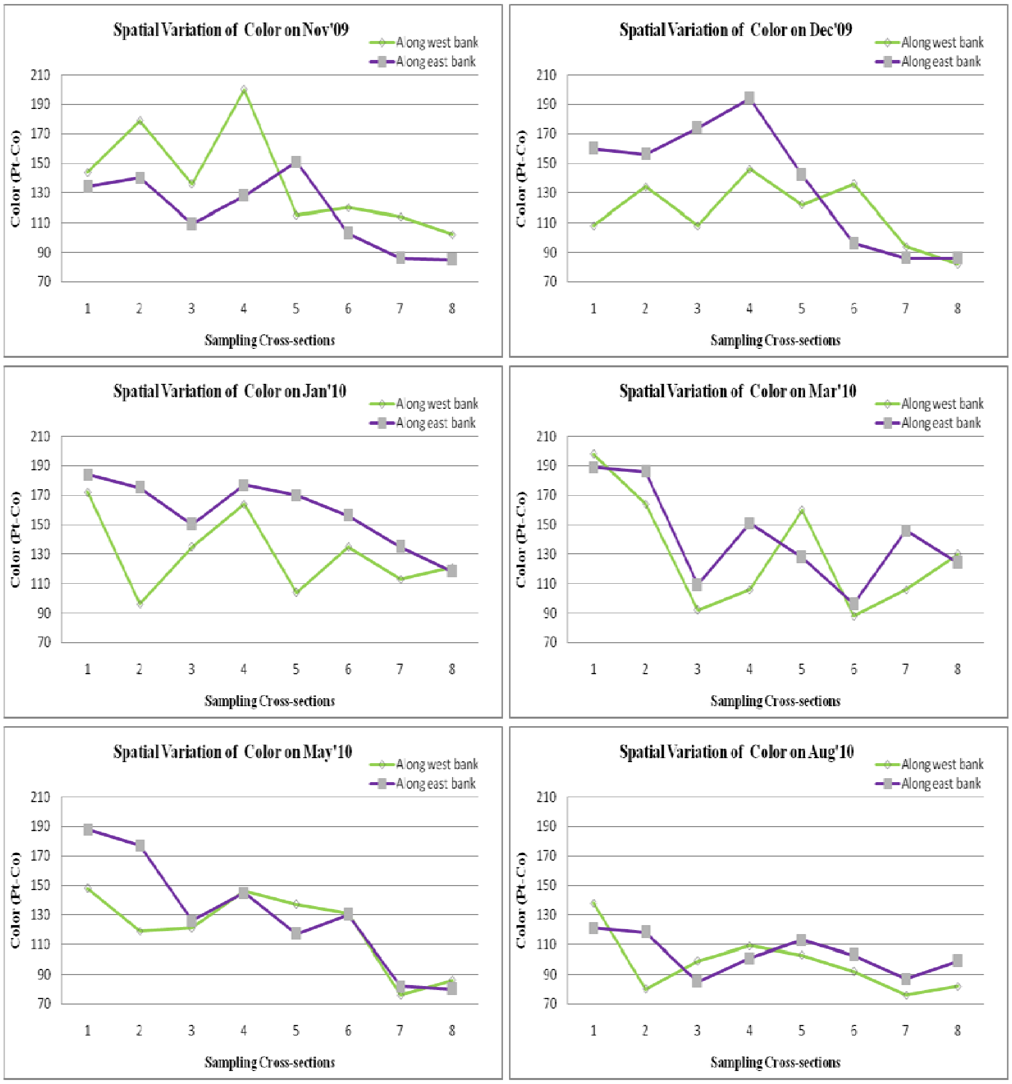

Fig 4.11: Spatial variation of Color on different campaigns.

Figure indicates no particular trend of color along the Lake. High color values (close to 200 Pt-Co unit) have been recorded, especially for samples collected from the upstream section of the Lake. During the study period, color was found to be inconsistent along the Lake, even at a single cross section. Wet season (i.e. August) data shows relatively lower fluctuation along the downstream of Lake. Even then, slightly decreasing trend of color towards downstream of Lake is noticed. Last segment of the Lake (i.e. sampling cross sections 7 and 8) shows lowest intensity of color based on average data of all seasons at a particular sampling point, less than 105 Pt-Co units.

Figure 4.12 shows seasonal variation of Color in water samples collected during all 6 sampling campaigns. It shows relatively high color values, especially for the five sampling campaigns carried out during the dry season. Relatively lower color values have been found for samples collected in the wet season (i.e., August'10); most values were below 120 Pt-Co.

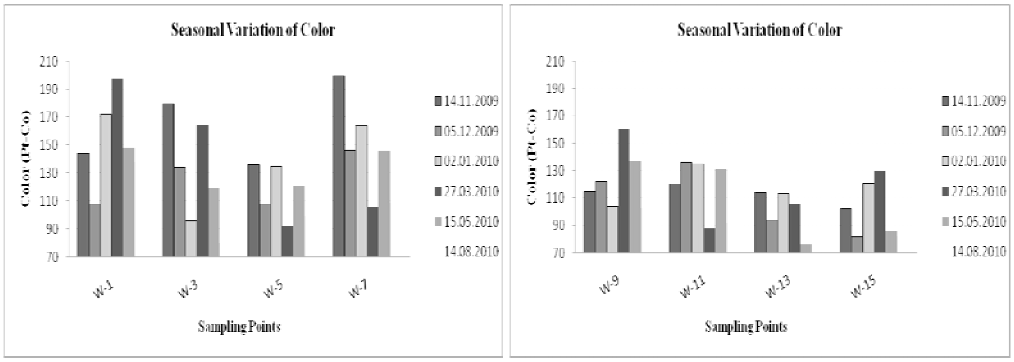

Fig 4.12: Seasonal variation of Color at sampling points along west bank of Lake.

Color ranged from 76 to 200 Pt-Co during dry season (from Nov'09 to May'10) and from 76 to 138 Pt-Co during wet season. In this study, average dry season value of color was 131.97 Pt-Co, while it was 100.38 Pt-Co in wet season. Dilution of Lake water with rainwater and storm runoff is most likely responsible for relatively low color values during the wet season. The maximum permissible color for domestic supplies is 10 to 20 Pt-Co, thus Lake water is unusable in this purpose. But during field survey, some domestic usage of Lake water is observed in the area of eastern side of third segment,

***TSS***

Total Suspended Solids (TSS) is a measure of the suspended solids in wastewater, effluent, or water bodies, determined by tests for "total suspended non-filterable solids." Total suspended solids are operationally defined as the mass retained on the filter per unit volume of water. Figure 4.13 shows variation of TSS along the Lake during the six sampling campaigns. No particular trend in observed in the TSS values along the Lake. The TSS concentrations during a particular sampling date appear to be governed by local factors, e.g., discharge of wastewater upstream of the sampling location. Percentage variation of TSS data along the Lake in a particular campaign was more than 90% during all the campaigns in dry season, indicating lack of mixing of Lake water against continuous intrusion of suspended solids through outfalls. In wet season, maximum variation of TSS at the locations along the Lake was less than 60%. Possible disturbance in sediments may also be responsible for the variation of TSS concentrations.

Figure 4.14 shows seasonal variation of TSS for selected sampling points. It shows relatively high concentrations of TSS for all the samples collected in August 2010, which may be due to input of suspended materials into Lake with storm runoff. This trend is observed for most natural water bodies. During the study period, TSS varied from negligible, recorded at 6th cross section, east bank on Nov’09, to high of 144 mg/L, recorded at 4th cross section, western bank on Dec’09. During dry season, TSS ranged from negligible to 141 mg/L, with an average of 35mg/L. During wet season, TSS varied from 56 to 139 mg/L, with an average of 104 mg/L. Though the average TSS value was higher in wet season, yet the highest recorded value (i.e. 141 mg/L) was on Dec’09, which may be due to some local factor. USEPA (1986) recommends TSS to vary from 25 to 80 mg/l for the beneficial use criteria, but Gulshan Lake violates the range in both seasons.

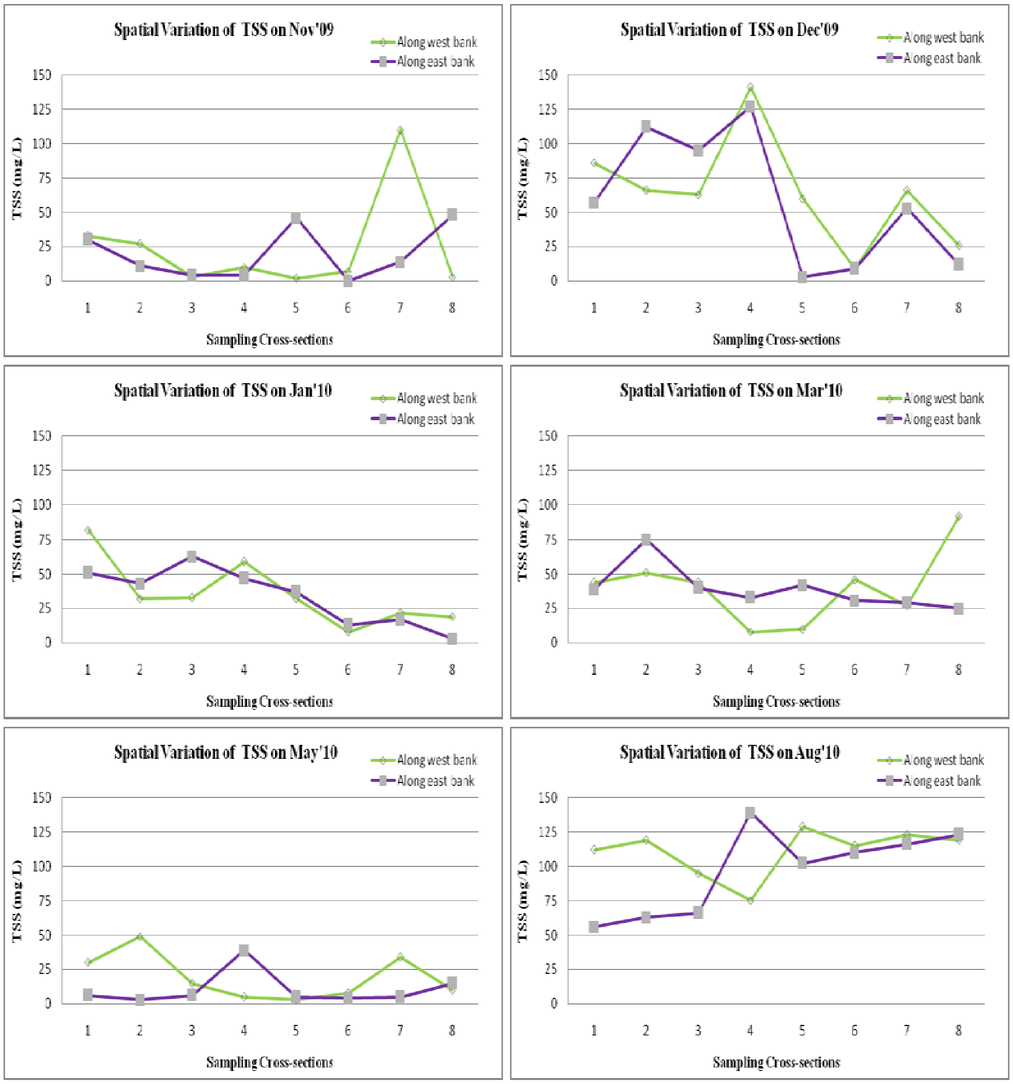

Fig 4.13: Spatial variation of TSS on different campaigns.

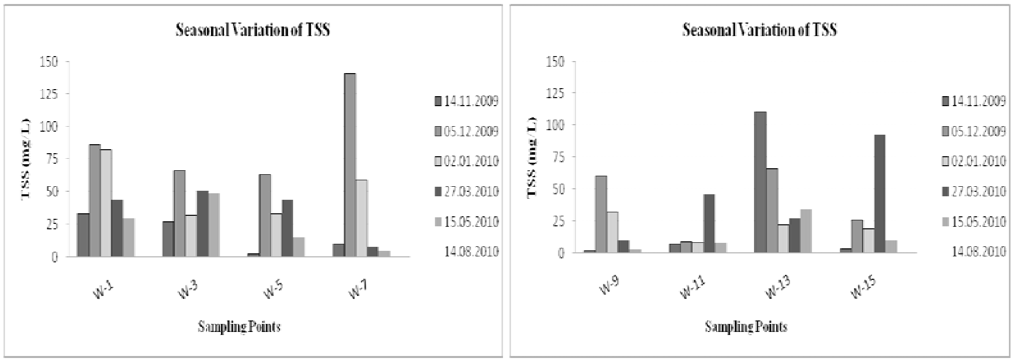

Fig 4.14: Seasonal variation of TSS at sampling points along west bank of Lake.

### *TDS*

Total Dissolved Solids (TDS) is the concentration of all substances dissolved in water (solids remaining after evaporation of a water sample), now called total filterable residue. Figure 4.15 shows variation of TDS of water samples along the Gulshan Lake for all 6 sampling campaigns. It shows no particular spatial trend in TDS data. But late dry season data (i.e. Mar'10 and May'10) show slightly increasing trend along the downstream of Lake.

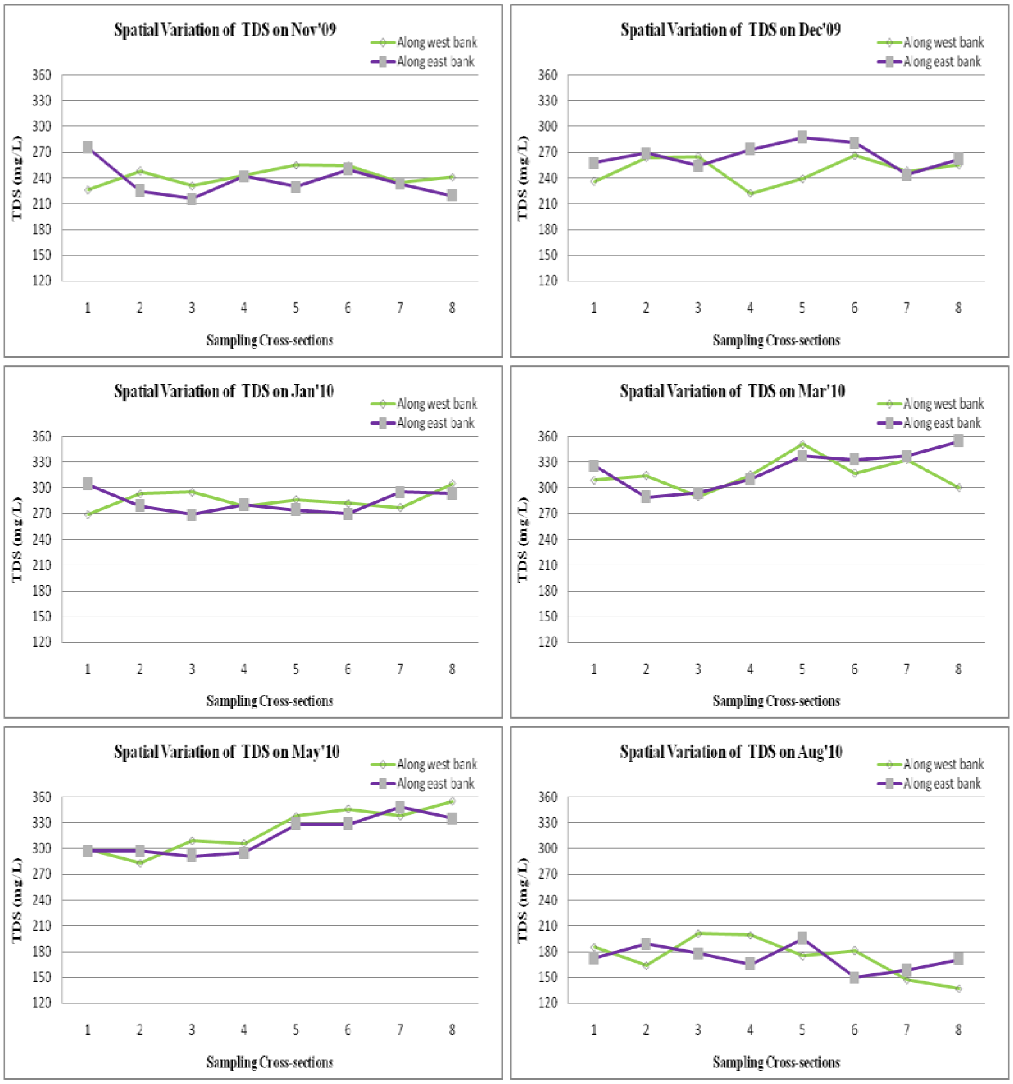

Fig 4.15: Spatial variation of TDS on different campaigns.

Figure 4.16 shows seasonal variation of TDS at sampling points along western bank of the Lake. It shows relatively high TDS values, especially for the five sampling campaigns carried out during the dry season. Higher TDS values (exceeding 350 mg/L unit) have been recorded during late dry season. As expected, relatively lower TDS values have been found for samples collected in the wet season (i.e., in August 2010); most values are below 200 mg/L. During dry season, TDS ranged from 216 to 355 mg/L, with an average of 284 mg/L. During wet season, TDS varied from 137 to 201 mg/L, with an average of 173 mg/L, i.e. TSS reduced 39% compared to dry season value. USEPA (1986) recommends TDS to keep below 12,000 mg/l for the protection of aquatic life, which is far above the present study value. Dilution of outfall discharge with rainwater and storm runoff is most likely responsible for relatively low TDS values during the wet season. It should be noted that TDS values did not correlate well with the Electrical Conductivity (EC) values.

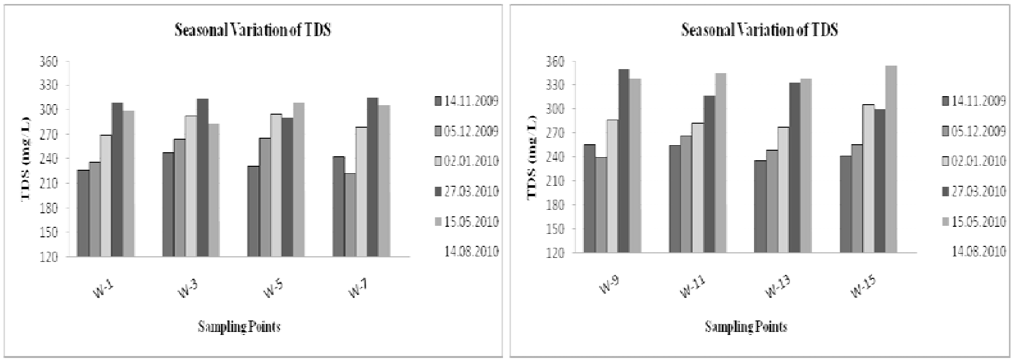

Fig 4.16: Seasonal variation of TDS at sampling points along west bank of Lake.

***DO***

DO is the actual amount of oxygen available in dissolved form in the water. The maximum oxygen concentration usually occurs in the afternoon on clear days, and the minimum immediately after dawn. During the study, the sampling time was early morning (between 7 AM to 10 AM), and therefore the recorded DO values are likely to be in the lower range. Figure 4.17 shows variation of DO along Gulshan Lake during each of the six sampling campaigns and Figure 4.18 shows subsequent seasonal variation.

Fig 4.17: Spatial variation of DO on different campaigns.

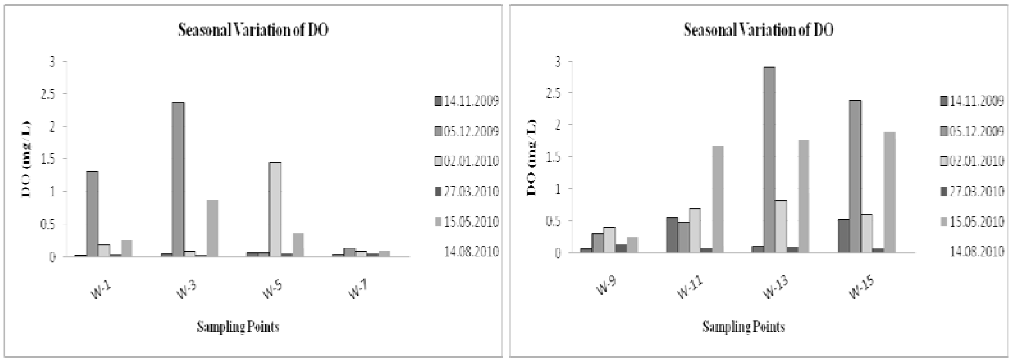

Fig 4.18: Seasonal variation of DO at sampling points along west bank of Lake.

Except for the Dec'09 sampling cycle (which shows some DO values up to 3.74 mg/l), all recorded DO values are very low; varying from negligible to less than 2 mg/l. The situation remained unchanged even during the wet season. This can be attributed to addition of wastewater containing oxidizable organic matter and consequent biodegradation and decay of vegetation at higher temperature leading to consumption of oxygen from water. Minimum dissolved oxygen concentration during the study period was 0.03 mg/L at W-1 location, 1st sampling cross section, west bank on Nov'09, and the maximum DO concentration was 3.74 mg/L at W-6 location, 3rd sampling cross section, east side on Dec'09 (see Appendix E), which was most likely a product of instant fresh water intrusion through outfalls. Cool water temperatures increase the solubility of oxygen (i.e. cool water can hold more oxygen). During the study period, dry season average DO was 0.68 mg/L, while that was 0.32 mg/L in wet season, i.e. interestingly 53% reduction in wet season. With the starting of wet season, the situation was expected to get much better, but one of the reasons may be Gulshan Lake outlet at Hatirjheel was closed; so, even after raining, the water quality with respect to DO did not improve much.

Table 2.1 in Chapter 2 shows the ECR (1997) standards of DO (and also pH, $BOD_5$) for inland surface water bodies for different uses. It shows a minimum DO requirement of 5 mg/l for different purposes including pisciculture, which is also recommended by USEPA (1986) for coldwater fisheries. DO concentration in Gulshan Lake remained far below this level throughout the study period, which may adversely affect the functioning and survival of biological communities and below 2 mg/L may lead to fish mortality. Excessive organic pollution causes fish kill by oxygen depletion. Fish kill and odor problems are associated with zero oxygen level. During this study, total 96 DO data were recorded, among these, only 6 values were above 2 mg/L, 32 values were below 0.1 mg/L, which reveals that Gulshan Lake remains extremely polluted from November to May. Fishes were observed dead and afloat in some places of Lake. Also Lake water exerted intense odor at increased rate with the advancement of dry season, while odor problem was lessened in wet season.

### *Biochemical Oxygen Demand ($BOD_5$)*

$BOD_5$ is one of the most common measures of pollutant organic material in water/wastewater. $BOD_5$ indicates the amount of biodegradable organic matter present in water. Therefore, a low $BOD_5$ is an indicator of good quality water, while a high $BOD_5$ indicates polluted water. Figure 4.19 presents variation of $BOD_5$ along Gulshan Lake during each of the 6 sampling campaigns. It shows slightly decreasing trend of $BOD_5$ towards downstream of Gulshan Lake during most of the sampling campaigns. Late dry season (i.e. May'10) data shows greater inconsistency in spatial variation of $BOD_5$ between sampling points in west bank and east bank of lake. At sampling point W-16, average of all season $BOD_5$ values is the lowest 9.65 mg/L, while that of

# CHAPTER 5

# CONCLUSIONS AND RECOMMENDATIONS

## 5.1 General

Gulshan Lake is one of the largest lakes and an important recreational place in Dhaka. Due to the discharge of untreated domestic and industrial wastewater, the quality of the water bodies in Dhaka, including Gulshan Lake, has been deteriorating. The present focuses on the assessment of the present water quality of Gulshan Lake, including seasonal, and identification of major wastewater outfalls and wastewater quality discharging into Gulshan Lake. The assessment was carried out during November 2009 to August 2010. This Chapter presents the major conclusions of the present study and recommendations for future works.

## 5.2 Conclusions

**Pollution sources and characteristics:**

1. The major types of wastewater/ storm water outfalls contributing to the pollution of Gulshan Lake include (i) Storm sewer pipes, (ii) Open channels, (iii) Box culverts, and (iv) Small private outfalls.
2. A detailed inventory of outfalls of Gulshan Lake has been prepared, which included information on: (i) Outfall ID, (ii) GPS coordinates, (iii) Outfall type (e.g., open channel, closed pipe), (iv) Outfall shape and dimension, (v) Outfall status (hidden/active), (vi) photograph
3. A total of 102 outfalls have been identified, which included 24 major (i.e. diameter/ size and flow is significant) outfalls.
4. Measured dry weather flow rate through 4 major outfalls varied from about 2 to 2.8 L/sec. Outfall discharges are characterized by high concentrations of $BOD_5$ (56-160 mg/l), COD (129-188 mg/l), Ammonia (16-28 mg/l), Phosphate (3.55-13.4 mg/l), TDS (277-413 mg/l) and Color (164-321 Pt-Co). These are comparable to the characteristics of raw sewage.

**Water and sediment quality of Gulshan Lake:**

5. The pH of Gulshan Lake water varied from 6.41 to 8.04; pH remained slightly alkaline most of the time. No significant seasonal variation of pH has been observed, which indicates that the lake water is well buffered.
6. The Lake water is characterized by very low Dissolved Oxygen (DO, mostly below 2 mg/l), relatively high BOD (up to 46.0 mg/l), and COD (up to 130 mg/l). There is a trend of decreasing DO and increasing BOD with the advancement of dry season; indicating severe organic pollution of the water body.
7. The Lake water is characterized by very high fecal coliform (FC) throughout the study period, indicating fecal pollution of the water body.
8. The Lake water has been found to contain high concentration of nutrients [Ammonia (mostly between 10 and 20 mg/l), and Phosphate (up to 8.55 mg/l)], especially during the dry season.
9. Among the parameters tested, Color, TDS and Ammonia showed the most significant seasonal variation due to the influence of rain and storm runoff; decreasing concentration of Color, TDS and Ammonia and increasing concentration of TSS was observed during the wet season (i.e., August).
10. Among the parameters, EC and phosphate showed most significant spatial variation, with increasing concentration downstream.
11. Except some scattered data, Gulshan Lake can be considered as well mixed. Virtually stagnant water of Gulshan Lake increases pollution level and decreases self cleansing capacity.
12. Gulshan Lake is hydraulically connected to the Hatirjheel lowlands, where a major restoration project is underway. The polluted water of Gulshan Lake would be a major pollution source of Hatirjheel, if steps are not taken to remedy the situation.
13. Relatively high concentrations of Cadmium and Lead have been found in the lake sediments. The lake sediments also have very high oxygen demand (SOD); the high SOD may be responsible for persistent low DO of lake water throughout the year. Also, SOD most likely contributes to the contamination in water-column.

## 5.3 Recommendations

1. More intensive sampling and analysis, including sampling of water from different depths and more spatial locations, would better describe the Lake water quality.
2. Outfall discharges during both dry and wet seasons should be measured and analyzed more comprehensively in order to assess the effect of these discharges on Lake water quality.
3. Characterization of Lake sediment as a function of depth could be carried out to evaluate the history of pollution of the Lake, and also to assess contribution of sediments to the pollution of water column of Gulshan Lake.
4. The floral and faunal population (including fish) of Gulshan Lake should be carefully monitored in order to assess the effect of water quality on the local ecology.

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# Appendix A

Figure A1: Four segments of Gulshan Lake