**Pollution index and the modified degree of contamination**

The limitations of single metal indices led to the development of multi-metal indices. The two most widely used such indices, developed by Hakinson (1980) and Nemerow (1991), include the modified degree of contamination (*mCd*) and the pollution index (PI). Brady et al. (2015) developed a modified pollution index (MPI) considering enrichment factor. The highest PI values were observed of 29.59 and 22.71 in winter and rainy season respectively, both in Shitalakshya river indicating heavily polluted condition (PI>3). In all five rivers the PI values were >3 indicating heavily polluted condition in all five rivers having heavily pollution sequence of Shitalakshya > Buriganga > Turag > Dhaleshwari > Balu in both seasons. The maximum *mCd* values were observed in Shitalakshya river in both seasons having the values of 9.2 and 6.67 in winter and rainy season respectively, indicating severely polluted (8< *mCd* < 16) which is also observed in Buriganga in winter season having value of 8.15. In winter Turag and in rainy season Buriganga were moderately polluted to heavily polluted (4< *mCd* <8). Dhaleshwari and Balu were moderately polluted (2< *mCd* <4) in winter which was also in Turag in rainy season. Dhaleshwari and Balu in rainy season were slightly polluted (1.5<*mCd* <2). According to MPI, Shitalakshya and Buriganga were in heavily polluted condition in both seasons (MPI>10). In Turag and Dhaleshwari in winter season the MPI values indicated severely polluted (5<MPI<10). In Dhaleshwari, Turag, Balu in rainy season were moderately to heavily polluted (3<MPI<5) which was also in Balu in winter season. According to MPI, the sequence of rivers was Shitalakshya > Buriganga > Turag ≥ Dhaleshwari > Balu in both seasons.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Rivers | PLI | | PI | | MPI | | *mCd* | |
| Winter | Rainy | Winter | Rainy | Winter | Rainy | Winter | Rainy |
| Balu | 1.08 | 0.78 | 4.76 | 3.82 | 4.75 | 3.94 | 2.08 | 1.52 |
| Buriganga | 3.54 | 2.56 | 19.94 | 16.48 | 14.49 | 11.31 | 8.15 | 6.07 |
| Dhaleshwari | 1.94 | 1.27 | 6.61 | 4.53 | 6.62 | 4.72 | 3.03 | 1.98 |
| Shitalakshya | 3.08 | 2.07 | 29.59 | 22.71 | 29.5 | 23.23 | 9.2 | 6.67 |
| Turag | 2.06 | 1.45 | 10.12 | 7.1 | 6.96 | 4.57 | 4.91 | 3.23 |
| Maximum (*Mmax*) | 3.54 | 2.56 | 29.59 | 22.71 | 29.5 | 23.23 | 9.2 | 6.67 |
| Minimum (*Mmin*) | 1.08 | 0.78 | 4.76 | 3.82 | 4.75 | 3.94 | 2.08 | 1.52 |
| Mean (N=5) | 2.34 | 1.63 | 14.20 | 10.93 | 12.46 | 9.55 | 5.47 | 3.90 |

Toxic Risk Index TRI

The toxic risk index developed by Zhang et al. was applied to provide a more comprehensive of their risk to the biota in the aquatic environment. In S16 the TRI value was 15.73 by Cd in winter which indicate considerable toxic risk (15> TRI ≥ 20). S17, S12 in winter season and S16 in rainy season have moderate toxic risk (10> TRI ≥ 15) by Cd,Cu and Cd respectively. The sample site S6,S11 and S17 in winter and S11,S12 in rainy season by Cu have low toxic risk (5 > TRI ≥ 10) and in S9,S11,S12,S15 in winter and S11,S12,S15,S16 in rainy season the TRI value of Cd ranges in low toxic risk respectively which was also in S8-S12,S17 by Pb in winter season. All the others TRI values of Cr,Ni,Cu,As,Cd,Pb in both seasons were in range of TRI<5 having no toxic risk concern.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Sites | Rivers | Cr | | Ni | | Cu | | As | | Cd | | Pb | |  |
|  |  | Winter | Rainy | Winter | Rainy | Winter | Rainy | Winter | Rainy | Winter | Rainy | Winter | Rainy |  |
| S1 | Dhaleshwari | 1.52 | 1.32 | 1.63 | 0.91 | 2.68 | 1.55 | 0.9 | 0.79 | 4.67 | 2.8 | 2.57 | 1.23 |  |
| S2 | Dhaleshwari | 1.48 | 1.26 | 1.29 | 0.82 | 2.88 | 1.59 | 1.37 | 0.98 | 4.02 | 3.13 | 2.33 | 0.94 |  |
| S3 | Dhaleshwari | 1.28 | 0.95 | 2.81 | 1.78 | 2.73 | 1.9 | 2.59 | 1.53 | 3.11 | 2.21 | 1.88 | 0.8 |  |
| S4 | Dhaleshwari | 1.02 | 0.79 | 2.33 | 1.24 | 3.54 | 2.68 | 2.51 | 1.86 | 2.49 | 1.89 | 2.19 | 1.05 |  |
| S5 | Dhaleshwari | 1.42 | 0.92 | 2.4 | 1.45 | 3.85 | 2.81 | 2.81 | 2.08 | 2.21 | 1.53 | 1.92 | 1.3 |  |
| S6 | Dhaleshwari | 1.23 | 0.86 | 1.11 | 0.56 | 7.26 | 3.77 | 1.41 | 1.03 | 1.58 | 0.86 | 1.54 | 0.92 |  |
| S7 | Dhaleshwari | 1.5 | 0.99 | 1.05 | 0.71 | 4.31 | 3.71 | 2.12 | 1.97 | 1.43 | 1.02 | 0.98 | 0.81 |  |
| S8 | Turag | 0.26 | 0.22 | 3.85 | 1.93 | 3.84 | 2.83 | 1.24 | 1.13 | 3.89 | 2.29 | 5.66 | 2.38 |  |
| S9 | Turag | 0.24 | 0.18 | 4.04 | 1.87 | 4.05 | 3.35 | 1.41 | 1.07 | 5.41 | 3.79 | 6.07 | 4.13 |  |
| S10 | Turag | 0.19 | 0.16 | 2.73 | 2.23 | 3.79 | 3.1 | 1.97 | 1.87 | 3.05 | 2.94 | 5.28 | 2.63 |  |
| S11 | Buriganga | 1.33 | 1.06 | 3.4 | 2.37 | 6.81 | 5.43 | 1.27 | 0.98 | 7.48 | 5.86 | 6.28 | 3.77 |  |
| S12 | Buriganga | 1.68 | 1.23 | 3.76 | 2.65 | 10.02 | 5.68 | 0.92 | 0.79 | 9.59 | 8.36 | 7.21 | 4.31 |  |
| S13 | Balu | 0.24 | 0.15 | 1.87 | 1.41 | 2.88 | 2.17 | 0.74 | 0.66 | 2.43 | 2.06 | 1.55 | 0.87 |  |
| S14 | Balu | 0.18 | 0.13 | 1.22 | 1.04 | 3.05 | 2.06 | 0.85 | 0.68 | 1.61 | 1.21 | 1.45 | 0.76 |  |
| S15 | Shitalakshya | 1.14 | 0.73 | 1.33 | 0.8 | 4.04 | 2.76 | 2.05 | 1.56 | 9.6 | 9.16 | 2.35 | 1.86 |  |
| S16 | Shitalakshya | 0.88 | 0.58 | 3.38 | 2.19 | 4.43 | 3.28 | 1.97 | 1.38 | 15.73 | 10.7 | 4.62 | 2.39 |  |
| S17 | Shitalakshya | 0.84 | 0.64 | 3.3 | 2.4 | 6.5 | 3.5 | 2.16 | 1.57 | 13.38 | 9.92 | 5.11 | 2.31 |  |
| Maximum (*Mmax*) |  | 1.68 | 1.32 | 4.04 | 2.65 | 10.02 | 5.68 | 2.81 | 2.08 | 15.73 | 10.7 | 7.21 | 4.31 |  |
| Minimum (*Mmin*) |  | 0.18 | 0.13 | 1.05 | 0.56 | 2.68 | 1.55 | 0.74 | 0.66 | 1.43 | 0.86 | 0.98 | 0.76 |  |
| Mean (N=17) |  | 0.97 | 0.72 | 2.44 | 1.55 | 4.51 | 3.07 | 1.66 | 1.29 | 5.39 | 4.10 | 3.47 | 1.91 |  |

Ecological Risk Index (RI)

Potential ecological risk factor (Eir) of the studied HMs follows the order as Pb>Cu>Cr>Ni~Cd>As in all five rivers. Single factor pollution in S8-S12, S17 of Pb in winter season exceeded Eir >320 indicating very high risk. Single factor of Pb in S8-S12 in rainy season were in high risk (160<Eir≤320). In winter the single factor values of Pb in S2-S6, S13-S15, Cu in S12 and in rainy season, Pb in S5, S8, S15-S17 were in considerable risk (80<Eir≤160). Moderate risk (40<Eir≤80) was observed in Cu in S6, S11, S16, S17, Pb in S7 in winter and S11, S12 of Cu, S1-S4, S6, S7, S13, S14 of Pb in rainy season. All the other sites were below the values of 40 indicating low risk. According to the classification of Potential ecological risk (RI), S8-S12, S16, S17 in winter was observed a severe risk (RI≥400) by Cr,Ni,Cu,As,Cd and Pb. S1-S6 and S15 in winter and S8-S12, S16, S17 in rainy season, the RI value indicate a considerable risk (200≤ RI < 400). Moderate risk (110≤ RI < 200) was observed in S7, S13, S14 in winter and S1, S2, S4-S7, S15 in rainy season. All the other sampling point were having low potential ecological risk (RI<110). The RI values in winter in Buriganga (S11, S12), Turag (S8-S10) and Shitalakshya (S16, S17) revealed a severe risk and in rainy season it was considerable potential ecological risk. The RI values of Dhaleshwari and Balu rivers indicated considerable and moderate risk respectively in winter which was moderate and low risk in rainy season.

Table

Potential Ecological Risk Factor and Potential Ecological risk index of HMs in Shitalakshya, Buriganga, Turag, Dhaleshwari and Balu River sediment.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Sites | Rivers | Potential ecological risk factor (Eir) | | | | | | | | | | | | Risk Index (RI) = Σ Eir | |
| Cr | | Ni | | Cu | | As | | Cd | | Pb | |
|  |  | Winter | Rainy | Winter | Rainy | Winter | Rainy | Winter | Rainy | Winter | Rainy | Winter | Rainy | Winter | Rainy |
| S1 | Dhaleshwari | 30.79 | 26.78 | 8.08 | 4.51 | 24.87 | 14.34 | 4.21 | 3.67 | 8.86 | 5.32 | 164.15 | 78.63 | 240.96 | 133.26 |
| S2 | Dhaleshwari | 30.13 | 25.54 | 6.38 | 4.05 | 26.71 | 14.78 | 6.36 | 4.56 | 7.64 | 5.94 | 149.02 | 60.29 | 226.23 | 115.16 |
| S3 | Dhaleshwari | 25.93 | 19.33 | 13.96 | 8.83 | 25.29 | 17.59 | 12.08 | 7.14 | 5.9 | 4.2 | 119.91 | 50.82 | 203.07 | 107.92 |
| S4 | Dhaleshwari | 20.67 | 16.05 | 11.57 | 6.14 | 32.83 | 24.81 | 11.7 | 8.66 | 4.72 | 3.58 | 140.24 | 67.27 | 221.74 | 126.51 |
| S5 | Dhaleshwari | 28.93 | 18.63 | 11.92 | 7.2 | 35.63 | 26.02 | 13.09 | 9.67 | 4.2 | 2.9 | 122.6 | 83 | 216.39 | 147.44 |
| S6 | Dhaleshwari | 24.9 | 17.43 | 5.49 | 2.76 | 67.25 | 34.94 | 6.55 | 4.81 | 3 | 1.64 | 98.33 | 58.71 | 205.52 | 120.3 |
| S7 | Dhaleshwari | 30.49 | 20.04 | 5.22 | 3.52 | 39.9 | 34.39 | 9.86 | 9.18 | 2.72 | 1.94 | 62.85 | 51.88 | 151.04 | 120.94 |
| S8 | Turag | 5.25 | 4.54 | 19.1 | 9.59 | 35.62 | 26.26 | 5.79 | 5.24 | 7.38 | 4.34 | 361.88 | 152.05 | 435.02 | 202.03 |
| S9 | Turag | 4.96 | 3.68 | 20.05 | 9.28 | 37.56 | 31 | 6.57 | 4.98 | 10.28 | 7.2 | 387.67 | 264.12 | 467.09 | 320.26 |
| S10 | Turag | 3.92 | 3.22 | 13.55 | 11.06 | 35.08 | 28.72 | 9.17 | 8.72 | 5.8 | 5.58 | 337.59 | 168.33 | 405.1 | 225.63 |
| S11 | Buriganga | 26.95 | 21.51 | 16.85 | 11.75 | 63.06 | 50.28 | 5.91 | 4.56 | 14.2 | 11.12 | 401.61 | 240.87 | 528.59 | 340.09 |
| S12 | Buriganga | 34.12 | 25.08 | 18.65 | 13.15 | 92.84 | 52.59 | 4.3 | 3.68 | 18.2 | 15.88 | 460.97 | 275.75 | 629.07 | 386.12 |
| S13 | Balu | 4.94 | 3 | 9.27 | 7 | 26.72 | 20.08 | 3.46 | 3.08 | 4.62 | 3.92 | 99.35 | 55.77 | 148.37 | 92.84 |
| S14 | Balu | 3.73 | 2.73 | 6.07 | 5.16 | 28.29 | 19.1 | 3.94 | 3.18 | 3.06 | 2.3 | 92.69 | 48.79 | 137.77 | 81.26 |
| S15 | Shitalakshya | 23.12 | 14.84 | 6.61 | 3.95 | 37.4 | 25.56 | 9.54 | 7.25 | 18.22 | 17.4 | 150.15 | 118.61 | 245.05 | 187.61 |
| S16 | Shitalakshya | 17.95 | 11.77 | 16.76 | 10.86 | 41.06 | 30.42 | 9.15 | 6.42 | 29.86 | 20.32 | 295.12 | 152.63 | 409.9 | 232.42 |
| S17 | Shitalakshya | 16.99 | 12.95 | 16.36 | 11.91 | 60.19 | 32.47 | 10.05 | 7.31 | 25.4 | 18.84 | 326.51 | 147.93 | 455.49 | 231.42 |
| Maximum (*Mmax*) |  | 34.12 | 26.78 | 20.05 | 13.15 | 92.84 | 52.59 | 13.09 | 9.67 | 29.86 | 20.32 | 460.97 | 275.75 | 629.07 | 386.12 |
| Minimum (*Mmin*) |  | 3.73 | 2.73 | 5.22 | 2.76 | 24.87 | 14.34 | 3.46 | 3.08 | 2.72 | 1.64 | 62.85 | 48.79 | 137.77 | 81.26 |
| Mean (N=17) |  | 19.63 | 14.54 | 12.11 | 7.69 | 41.78 | 28.43 | 7.75 | 6.01 | 10.24 | 7.79 | 221.80 | 122.09 | 313.32 | 186.54 |

Modified Hazard Quotient (*mHQ*)

The *mHQ* distribution of each HMs varies the sampling sites, and it is particularly similar from the trend shown by the other comprehensive risk indicators. According to the average values of *mHQ* in all sites*,* attention should be given to Cd, Cu, Pb, Ni in all sites, contributing high to considerable severity of contamination in winter and considerable to moderate severity of contamination in rainy season.While in both seasons As,Cr were having moderate to low severity of contamination. The average value of *mHQ* in Buriganaga, Pb,Cd,Cu in winter and Cd in Shitalakshya in both seasons showed extreme severity of contamination. In Buriganga Cu,Cd in rainy season and in Shitalakshya and Turag Cu in winter and rainy season respectively the *mHQ* values revealed very high severity of contamination. Ni, Cu, Cd, Pb in winter in Buriganga, Dhaleshwari and Turag, Turag, Shitalakshya respectively and Pb in rainy season in Buriganga revealed high severity of contamination. The average values of *mHQ* of Ni, Cu, Cd, Pb in Turag and Cu in Dhaleshwari and Shitalakshya, Pb in Shitalakshya and Ni in Buriganga in rainy and Cd in Dhaleshwari, Cu in Balu and Ni in Shitalakshya in winter indicated considerable severity of contamination. Most other average values of *mHQ* of Cd, Cu, Pb, Ni, As and Cr were in range of moderate to low severity of contamination in all the five rivers.

*mERMQ* and *CSI*

Mean ERM quotient (*mERMQ*) is proposed for assessing the potential effects of multiple HMs contamination in sediment and the contamination severity index (*CSI*) is new index based on ERL (effect range low) and ERM (effect range medium) values to study severity of HM contamination in sediments which was first proposed by Pejman et al. for the toxicity boundaries and adverse effect on the biota as well as weighted values for each heavy metal attributed by the ratio of PCA/FA as site-specific factor (Jafrabad et al). In S8-S12 (Turag and Buriganga), S15-S17 (Shitalakshya) the *mERMQ* and *CSI* value indicated 49% probability of toxicity and ultra-high contamintaion severity in winter and very high severity of contamination in rainy season. 21% probability of toxicity and moderate severity to low severity was found in S2, S6, S7 (Dhaleshwari), S13, S14 (Balu) in winter and low to moderate to low severity in S1-S8 (Dhaleshwari), S13-S14 found in rainy season. The other 79% sampling sites had low to very low severity of contamination in both seasons, but severity was higher in winter than rainy season. Severity degree and toxicity degree revealed that sampling sites of Buriganga, Shitalakshya and Turag were highly contaminated and toxic and the sampling sites of Balu and Dhaleshwari were moderate to low contaminated and toxic in both seasons.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| River | | Dhaleshwari | | | | | | | Turag | | | Buriganga | | Balu | | Shitalakshya | | |
| Sites | | S1 | S2 | S3 | S4 | S5 | S6 | S7 | S8 | S9 | S10 | S11 | S12 | S13 | S14 | S15 | S16 | S17 |
| ***CSI*** | W | 2.61 | 2.2 | 3.07 | 2.79 | 2.72 | 1.73 | 1.3 | 8.51 | 9.68 | 6.53 | 9.76 | 12.75 | 1.85 | 1.36 | 3.28 | 9.21 | 9.18 |
| R | 1.63 | 1.48 | 1.76 | 1.47 | 1.75 | 1.11 | 1.26 | 2.42 | 4.18 | 2.94 | 4.88 | 6.32 | 1.19 | 0.91 | 2.58 | 4.08 | 4.07 |
| ***mERMQ*** | W | 0.53 | 0.49 | 0.55 | 0.52 | 0.54 | 0.41 | 0.37 | 0.78 | 0.85 | 0.67 | 0.97 | 1.15 | 0.34 | 0.27 | 0.59 | 0.96 | 0.97 |
| R | 0.33 | 0.31 | 0.34 | 0.32 | 0.36 | 0.24 | 0.28 | 0.4 | 0.53 | 0.46 | 0.67 | 0.78 | 0.24 | 0.19 | 0.45 | 0.6 | 0.61 |

W – Winter, R- Rainy