**Heavy Metals and Metalloids Contamination Trend, Water Quality with Bacteriological Pollution Estimation and Probabilistic Health Risk Assessment in Urban River Water Near the Industrial Effluent Sources**

**ABSTRACT**

The present study was undertaken to investigate the dissolved heavy metals and metalloids (Cr, Mn, Ni, Cu, Zn, As, Cd, Hg and Pb) and bacteriological parameters in seasonal water samples of the Buriganga River, Bangladesh, using multivariate statistical analysis, analyze pollution status through different indices, compositional and contamination trends of heavy metals and their spatial distribution using geospatial techniques (Inverse Distance Weighting interpolation); and assess the associated human health risk. The order of relative abundance of the studied metals and metalloids is Mn >Cu >Pb >Zn >Cr >Ni >Cd >As >Hg, respectively. Some elements were somehow buffered despite the severe pollution level, while the trace metals seemed to be highly responsive. Most of the physicochemical properties were leading in summer except for pH, NH4+, PO43-, Ca2+, Mg2+ due to the elevated temperature and rainless summer. Heavy metals and metalloids showed detrimentally higher concentrations in both seasons and were caused by the significant amount of industrial discharge and toxicological compounds. Bacterial population, that is, Total heterotrophic bacteria, Total coliform, Fecal coliform, Fecal Streptococci, Vibrio Cholerae and Escherichia coli were detected in both seasons of the river water and the trend was TC >FC >FS >E. coli >THB >Vibrio C. However, except for E. coli and FS, other bacterial parameters such as total heterotrophic bacteria, total coliform, fecal coliform, and Vibrio cholerae counts showed significant differences (p < 0.01) among the seasons, while difference among the sites was insignificant (p < 0.01). The result also showed that all the bacterial parameters were higher during summer compared to winter season. Untreated sewage and industrial effluents together with reduced water flow and water level were found to increase bacterial counts during summer. The analytical results also revealed that 100% of water quality indices exceeded the permissible limits suggested by different agencies, which represents the unsuitability of the Buriganga River water for industrial and utility purposes. The outcome of water quality index, heavy metal pollution index and nemerow index indicate that anthropogenic activity like tanneries, industrial and sewage input and oil disposal gravely affects and obliterates the aquatic environment of the river water. Interpretation of microbial and heavy metal (HMs) data identified predominance of anthropogenic activities as the major source of contamination in the urban river water. In assessing health risks, the main pollutants to human health, Cr, As, Cd and Pb, revealed a significant cancer risk, especially for children. Multivariate statistics, including factor analysis and cluster analysis, indicate the origin of heavy metals from several sources, mostly anthropogenic and partly geogenic. The findings of this research may be a valuable input for the respective management authority to control river pollution and improve aquatic ecosystem health of the urban rivers near the industrial effluent sources.

***Keywords***: Contamination status, Watershed distribution, Microbial pollution, Pollution indices, Probabilistic health risk, Geospatial variation, Source identification.

**1. Introduction**

Expeditious population growth and thriving industrialization are the dominating factors that drastically influence environmental components, ecology, and human health. The hydrosphere, particularly surface water, which is more prone to pollution and metal exposures, is in an inauspicious and precarious state (Shil and Singh, 2019) globally, and vulnerable to rapidly developing industrial area's watercourses like urban rivers (Jolly et al., 2023). Industrial effluents, municipal sewage, microbial contamination from biological waste and stormwater runoff, agricultural wastewater, the influx of waste from the surrounding watershed, landfill leachate, and urban runoff are considered to be the main sources of surface water pollution (Mokarram et al., 2020; Uddin and Jeong, 2021; Chai et al., 2021; Syeed et al., 2023). The pollutants from these sources enter the river water, thereby jeopardize the water resources and consequently alter physicochemical properties (Ahsan et al., 2019; Rahman et al., 2021; Jolly et al., 2023), chemical composition (Reddy and Osborne 2020; Hoang et al., 2021) and of course microorganisms (Holcomb and Stewart, 2020; Syeed et al., 2023) of water bodies.

Heavy metals and microbial pathogens pollution in rivers have attracted global attention, especially in rapidly developing South-Asian countries, where increased industrialization has led to hundreds to thousands of neighboring factories discharging untreated hazardous waste towards the Ganges River system and contaminating the riverine environment of Ganges watershed (Paul, 2017; Dwivedi et al., 2018;). Sigdel et al. (2023) reported that plastic debris (Sigdel et al., 2023), heavy metal concentrations (Dubey, 2021; Paul, 2017), arsenic (Acharyya et al., 1999) total and faecal coliforms, and carcinogenic inorganic pollutants are the common contaminants in the Ganges rivers. Anthropogenic activities have put many Ganges tributaries in jeopardy. For instance, metal concentrations have increased heavily in urban watercourses such as in Buriganga River (a tributary of the Ganges River) basin as a result of industrial establishment with municipal sewage (Nargis et al., 2021; Jolly et al., 2023), which cause extreme river contamination through drainage channels and outflow (Sigdel et al., 2023).

Across the five continents, rivers, especially in the vicinity of the cities, are becoming increasingly polluted and choked by unplanned industrialization, waste discharge, mining, and manufacturing (Zhou et al., 2022). For instance, Oum Er Rbia, Xiangjiang, Huaihe, Akpabuyo-Odukpani, Mahananda, Kor River, Catalan, Tigris, and Guandu are the surrounding rivers of the megacities of Morocco, China, Nigeria, India, Iran, Spain, Turkey, and Brazil, which are currently in severe condition (Xiao et al., 2019; Khan et al., 2005; Barakat et al., 2016; Zeng et al., 2015; Edet and Offiong 2002; Chai et al., 2021; Mokarram et al., 2020; Varol and Sen, 2012). The deterioration of river water quality in the Ganges River system is not an outlier in terms of pollution.

      Despite being surrounded by four urban rivers, the megacity Dhaka, is facing tremendous water scarcity. Of them, Buriganga, one of the Ganges River system's tributaries, is one of the world's most polluted rivers (Uddin and Jeong, 2021; Kibria et al., 2016, Jolly et al. 2023). The Buriganga River water is largely used by the peripheral and related populations, those who depend on river water on a daily basis and having oral and dermal contact with this. The country's largest leather tannery and textile industries have been built in the vicinity of this river. Correspondingly, this waterway has been serving as the drainage outlet of Ganges River towards Bay of Bengal. However, Chemical toxicants originating from tanning and washing effluents, textile dyes, municipal sewage, domestic wastage, synthetic materials, batteries, medical waste and petroleum components are some of the urban river pollutants which cause organic and metal pollution and also lower the dissolved oxygen in the river water (Rahman et al., 2021). Biochemical substances and metals turned Buriganga river water unsuitable for drinking, irrigation, agriculture, recreation, fisheries and aquaculture (Kibria et al., 2016; Uddin and Jeong, 2021) and thus the river is now become biologically and hydrologically deadlock.

Heavy metals such as cadmium, chromium, mercury, lead, and arsenic can turn into persistent metallic compounds with high toxicity (Nomngongo et al., 2018). Some metals like copper, sodium, potassium, calcium, manganese, iron, and zinc are essential metals for living organisms (Ahmed et al., 2015) but may also bioaccumulate and expose to toxic levels that can have deleterious effects on aquatic life and at length human health (Cao et al., 2016, Hoang et al., 2021). Consumption or dermal contact with water contaminated with high levels of heavy metals can lead to physical maladies in the human body. Chronic exposure to heavy metal toxication at a low dose (Shil and Singh, 2019) over a long period of time can cause several types of cancer, neurological complications (Shil and Singh, 2019) etc. In contrast, immunological and cardiovascular disorders as well as dermal lesions can be caused by acute chronic exposure (Whitehead et al., 2018; Whitehead et al., 2019). A landmark report by the Lancet Commission on Pollution and Health reported that pollution caused more than 9 million premature deaths annually (Whitehead et al., 2019; Fuller et al., 2022). For these reasons, monitoring of the physicochemical properties of water and heavy metal concentrations (Shil and Singh, 2019), their information regarding the extent of geospatial distribution with identifying the pollution sources (Shil and Singh, 2019), and assessing the public health risk of urban river water near industrial effluent sources are of great importance (Uddin and Jeong, 2021; Rahman et al., 2021; Shil and Singh, 2019, Jolly et al., 2022; Jolly et al., 2023; Sigdel et al., 2023).

The presence of pathogenic microbes in waterbody also affects its usable state and acts as a pollution indicator for organisms. Internationally accredited health regulatory entities such as the World Health Organization (WHO) and the United Nations Environmental Protection Agency (UN EPA) prescribe that safe potable water for the populace needs to be free of all pathogenic microbes that are responsible for waterborne diseases (Akhtar et al., 2019; Ganiyu et al., 2021). Pathogens can enter water sources via unsanitary practices, inappropriate solid waste disposal, and the presence of corroded metals inside the water supply (Ganiyu et al., 2021; Adimalla, 2019). Microorganisms from both human and animal excretion are the main source of bacterial infections in surface/groundwater sources, which eventually enter humans via ingestion of polluted water (Ganiyu et al., 2021; Akhtar et al., 2019). Total coliform, fecal coliform, heterotrophic bacteria, vibrio cholera, Fecal Streptococci, Escherichia coli, and Clostridium perfringens are some of the microbial indicators that can contaminate water sources (Stupar et al., 2022). In urban watercourses of the Ganges River basin, pathogenic microbes were detected at a small scale (Uddin and Jeong, 2021; Stupar et al., 2022). Thus, it is crucial to investigate the microbial content of Gangetic River water sources regarding water potability.

Metal pollution indices, including the Heavy Metal Pollution Index (HPI), Nemerow Index (Pn) and Contamination Index (Cd), have been recurrently applied to assess the comprehensive pollution of heavy metals (Mohan et al., 1996; Mazurek et al., 2016; Shil and Singh 2019; Nargis et al., 2021). Findings of a study by Whitehead et al. (2019) of the river system of the Greater Dhaka Watershed area using an Integrated Catchments Dynamic Model (INCA-Metals model) showed that the observed and simulated metal concentrations were high in the downstream, and metal deposition was evident. Their study also reported that tanneries use many heavy metals in the processing of hides to form leather, including Al, As, Cd, Cr, Cu, Fe, Pb, Hg, Ni, and Zn.

      Multivariate statistical analysis has been widely used as the most common method for assessing water quality and determining the factors responsible for pollution. Zeng et al. (2015) in Xiangjiang River, China, and Barakat et al. (2016) in Oum Er Rbia River, Morocco, performed principal component analysis (PCA) to delineate pollution sources. Mokarram et al. (2020) found that the water quality of Kor River (Mokarram et al., 2020) in Iran is severely affected by surrounding industrial units, and Cr, PO43-, Cd, Ni, Cu, Cl-, and NO3- were the influential factors of water contamination in the river (Mokarram et al., 2020). Xiao et al. (2019) applied multivariate techniques to assess the water quality of Fenhe River (Xiao et al., 2019) basin in the Chinese Loess Plateau. They categorized the river pollution level into three classes (Xiao et al., 2019; Mokarram et al., 2020) of low, medium, and high pollution and reported that Cr, Pb, Cd, Cu, Ag, Ni, Mn, and Tl enter the river water mainly from anthropogenic sources.

      Previous studies on Gangetic River system have investigated heavy metal concentrations in fish (Nargis et al., 2019; Mishra et al., 2022), water (Islam et al., 2016; Dwivedi et al., 2018; Whitehead et al., 2019; Akbor et al., 2020) and sediments (Tamim et al. 2016; Akbor et al., 2020; Mishra et al., 2022), whereas another study was attributed to the release of contaminant(s) from continuous polluting sources (Mokarram et al., 2020; Tamim et al. 2016). Taking one of the Gangetic River, Buriganga into consideration, no study has been done regarding microbial water quality with heavy metal contamination assessment and associated health risk. Yet, multivariate statistical approaches combined with geographic information system (GIS) techniques to investigate the water quality as well as heavy metal contamination in Buriganga's surface water have not been conducted. Moreover, to date, there have hardly been any risk assessment studies concerning the spatial distribution of health indices to depict the danger/pollution scenario and identify the potential hotspot zones. Additionally, to understand pollution sources, the microbial aspect was not focused on in any study all together. Considering these things, the present study was sketched: (i) to determine the physicochemical characteristics (water temperature, pH, EC, TSS, turbidity, salinity, DO, TDS, COD), cationic (NH4+, K+, Ca2+, Mg2+), anionic concentrations (NO3-, PO43-, SO42-, Cl-) and heavy metals (Ni, As, Cd, Cu, Cr, Hg, Pb and Zn); (ii) to assess the water quality based on seasonal variation and microbial contamination; (iii) to identify the sources and spatial distribution of pollution; and (v) to estimate spatial health risks for children and adults exposed to heavy metals in the Buriganga River water; (iv) assessment of microbial content and their effects on human health. Hence, the study results may be used in management policies to determine and delineate the primary sources of pollution and potentially risk-prone zones from upstream to downstream of the Ganges River system. The outcomes of this work are of global and national importance and can significantly improve the protection of public health, the operation of drinking water infrastructure, microbial water quality, and sustainability.

**2.** **Materials and methods**

*2.1 Study area and sampling stations*

The Gangotri glacier, located in Gomukh (30°36′ N; 79°04′ E) in the Uttar Kashi district of the Indian province of Uttarakhand, at an altitude of around 3800 m above mean sea level in the Garhwal Himalaya, is the origin of the Gangetic rivers (Vass et al., 2010). The Ganges basin sustains more than 300 million people in South-Asia (Gopal, 2000), one of the densely populated areas in the world. In ancient times one course of the Ganges used to reach the Bay of Bengal through Dhaleshwari. That watercourse progressively shifted, eventually lost contact with the Ganges principal channel, and was given the new name Buriganga (Afroz et al., 2020). The Buriganga River flows into the Dhaleshwari River following Meghna River, one of the largest rivers in South-Asia, and conclusively flows into the Bay of Bengal (Afroz et al., 2020). Serving as the largest river port since ancient times, it connects Megacity Dhaka with the cities in other parts of the world through waterways. Significant transportation occurs through this river to reach the country's southern coastal areas. The total length is about 27 km with an average depth of about 10 m. The ambient climatic condition of this river basin area is tropical monsoon type, which may influence the hydrodynamic features of this urban river.

There are numerous city-drains along the Buriganga River and outfall from sewerage treatment plants. The indiscriminate disposal of contaminants has turned it into a polluted and biologically dead river. Among the sources of industrial waste, dying and chemical industries densely located in Postogola and Shyampur area, tannery industries in Rayerbazar area and metal industries in Zinzira area is shown in Figure 1, enhance continual pollution in this river tremendously. These industries are interlinked directly or indirectly by surface or underground drainage systems with this river. Meanwhile, the river system carries an enormous amount of sludge and industrial effluents, which accelerates the sedimentation rate and thus interrupts normal flow of water.

**Land use and land cover information**:

Gradual decrease in the area of water bodies, agricultural land, natural vegetation cover and wetlands, and the substantial increase in formal and informal settlements in Greater Dhaka (Dewan and Yamaguchi, 2009) watershed, particularly around the Buriganga River in Dhaka, is starkly visible through multispectral satellite data over the past few decades (Alam et al., 2023; Faridatul et al., 2019). Urbanization-induced land cover changes entail the extent of alterations in surface water. Buriganga River, once a vital transportation way, was also one of the city's main attractions to the residents; at present is radically reduced its aboriginal shape into a shrunken water body and become incessantly polluted in a way, that ultimately leads to environmental degradation. The current sanitation coverage of Dhaka megacity is a combined drainage and sewage system, and over 50% of the municipal waste is disposed into the water bodies (Arafat Rahman et al., 2021) without wastewater treatment, which represents lack of proper waste management system disposal. Since 1984, a massive shift has been observed in the land use map created by SPARSO, from cultivated uplands with scattered settlements to completely unplanned urban housing and industrial areas (Mahmud-ul-islam, 2011). From 1960 to 2017, the bank of the lower reaches of the Buriganga was home to nearly 90% (Whitehead et al., 2019) of the country's total tanneries (more than 500 units). There are four river ports developed on the banks of Buriganga river. About 7,000 units of multifarious industries such as textiles, leather, cement, pharmaceuticals, rubber, chemicals, food processing, petroleum refining, metals, fertilizer, brickfields, pulp and paper boards are pouring about 1.3 million cubic meters of their untreated toxic effluents along with noxious, hazardous solid wastes into the Buriganga River system (Jolly et al., 2023; Nargis et al., 2021; Arafat Rahman et al., 2021; Whitehead et al., 2019; Ahsan et al., 2019). Previous studies observed notable changes in the land-use patterns (Arafat Rahman et al., 2021) and surface water body in Dhaka City using remote sensing and described almost 20% industrial growth in the city, with an increase of 5% in the total number of brickfields (Arafat Rahman et al., 2021), and 35% of Dhaka belongs to the very highly vulnerable zone of surface water-area decreasing and water logging hazards (Alam et al., 2023), as well as floodplain areas are being encroached for informal settlements. The west bank of the Buriganga River in the Kaliganj area is surrounded by numerous dockyards at a stretch, grabbing a good chunk of the river and narrowing the original river channel. Dozens of washing plants have been established in the Keraniganj area near the Buriganga River, and these plants are discharging pitch-dark wastewater with toxicological chemicals, which directly flows into the river. On the other hand, the east bank of the river is highly industrialized and dense with urban formal and informal settlements.

*2.2 Water samples collection along the river*

Samples were collected for 7 months, from November 2021 to May 2022, representing the winter and summer seasons, respectively. Specific sampling locations are shown in Fig. 1. A total of thirty-six river water samples were obtained from nine stations (Gabtoli Dhalweswary point to Postogola point) for both seasons, which extend from upstream to downstream along the entire length of the 27-kilometer-long river. At each station, water samples were taken at a depth of approximately 0.3 m to 1.0 m beneath the water surface using a Niskin-bottle water sampler (Model: 1010-1) in 2 L non-transparent cleaned plastic bottles. This device is used to take water samples at the desired depth without the risk of mixing water from other depths. The sampler was submerged vertically by wire with its open valves into the water until the top of it was approximately 12 inches from the water's surface. It was then closed in situ by allowing a weight (called metal messenger: a metal messenger "trips" each bottle on the cable individually, causing it to fill with water and close securely) to slide down the wire and strike the reversing mechanism. The collected water samples were processed, brought to the laboratory and preserved following standard techniques (Ganiyu et al., 2021). For heavy metal analysis, water samples were collected from the Niskin sampler in separate non-transparent 1 L polyethylene bottles and immediately acidified with 3 mL of 65% concentrated nitric acid (HNO3) whereas, the non-acidified samples were used for the analysis of the physicochemical parameters and cations and anions (Ahsan et al., 2019).

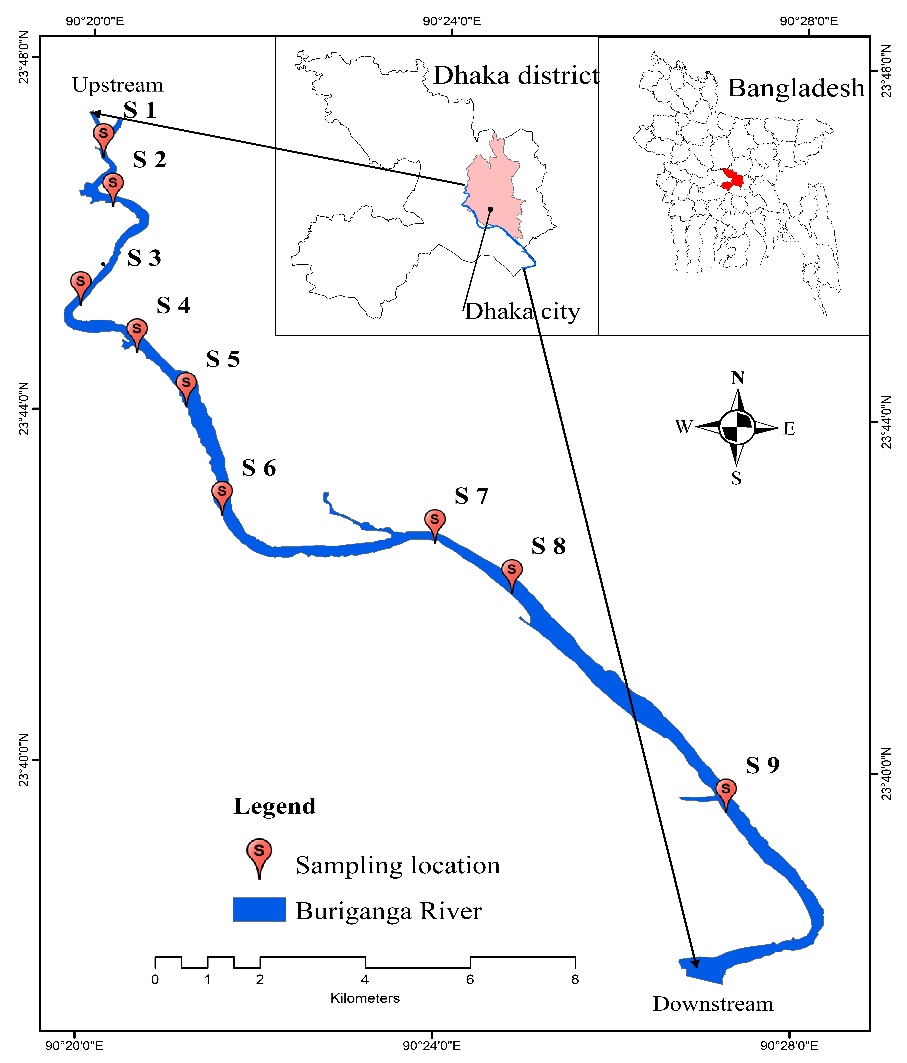


Figure 1. Water sampling stations map of Buriganga river, Bangladesh (Generated from ArcGIS 10.3 ESRI, Redlands, California, USA). Red dots indicate the river water sampling stations.

Table 1. Description of major anthropogenic activities at each sampling station along the course of the Buriganga watershed

|  |  |  |
| --- | --- | --- |
| Sampling station | Pollution source due to anthropogenic activities | Stream |
| Station 1- Gabtoli\_Dhalweswary (GD) | Agricultural farming (rice); Dying and textile industry cluster; Sewage discharge; Sedimentation in upstream, brick fields, dradging | Upstream |
| Station 2- Gabtoli\_turag(GT) | One of the major river ports, Agricultural practice (rice), land fill leachets (Aminbazar), Dry doc, Soil erosion, One of the main discharge points of domestic, city and industrial wastes of Dhaka (sewage, textile, dying effluents) | Upstream |
| Station 3- Shah Cement ghat (SC) | Agricultural practice, solid waste dumping, Domestic wastewater and sewage, Small holding industries (plastic, metals, dye, fertilizer) | Upstream |
| Station 4- Hazaribag (HZ) | Tannery industries, paint industries ( Roxy paint, Pailac paint, etc), sister of tanning industries ( footware, leather, animal glue, rubber),Fruit- veg cold storage of city, Municipal sewage | Midstream |
| Station 5- Rayerbazar (RB) | Continued tannery cluster, Domestic and industrial solid waste and sewage, minor agricultural practice in the river bank | Midstream |
| Station 6- Kholamora Bazar (KB) | Metal industries, Paint industries, Plastic industries, Pipe industries, Agricultural practice, Ship break yard, One of the main discharge points of domestic, city and industrial solid wastes of Dhaka (sewage, textile, dying effluents) | Midstream |
| Station 7- Zinzira (ZI) | One of the main discharge points of industrial effluents (metal, paint, battery, chemicals, electronics, saw mill, pulp and paper, pipe), Medical wastes (Sir Salimullah Medical College), and domestic wastes of densely populate Old-Dhaka. | Downstream |
| Station 8- Sadarghat\_Terminal (ST) | Main riverport of Dhaka city, dockyards, Paint industries, Metal industries, floating restaurants, one of the main discharge points of domestic, city and industrial wastes of Dhaka (sewage, tannery, dying effluents), land fill leachets (Matuail). | Downstream |
| Station 9- Postogola Bridge (PB) | Shipyard industries, Paint industries (Asian paint), Agricultural practice (rice), Dense industrial cluster (tanneries, alluminium, dyeing, plastic, iron and steel, metal, pharmaceuticals, battery, washing, hardware and cold storage), Solid waste. | Downstream |

**Result e likhbo, done by rakib: The physicochemical parameters of different seasons and sites of river water measured during the study period with their interactions are presented in Table. According to paired student *t* test, the metal concentrations showed significant (*p* < 0.05) seasonal variation among different sampling sites, except for Ni and As. Except TSS, Salinity, Nitrate, Sulfate and Chloride, all the physicochemical parameters showed significant differences (*p* < 0.05) between the seasons**. **Also, the physico-chemical parameters showed significant (*p* < 0.01) differences among the study sites in winter and summer season.**

Factor Analysis:

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Parameters | **Factor 1** | | **Factor 2** | | **Factor 3** | | **Factor 4** | |
|  | Winter | Summer | Winter | Summer | Winter | Summer | Winter | Summer |
| Temperature | **0.91** | **0.94** | -0.04 | 0.08 | -0.04 | 0.09 | -0.19 | 0.1 |
| pH | **-0.92** | **-0.97** | 0.50 | 0.08 | 0.01 | -0.19 | -0.08 | 0.01 |
| EC | 0.21 | 0.18 | **0.94** | **0.97** | 0.14 | -0.10 | 0.05 | -0.01 |
| TSS | 0.51 | **0.78** | -0.13 | 0.2 | 0.13 | 0.40 | **0.60** | 0.001 |
| Turbidity | **0.82** | **0.76** | 0.31 | 0.39 | -0.04 | 0.35 | -0.39 | -0.31 |
| Salinity | -0.21 | 0.27 | **0.75** | **0.86** | 0.09 | 0.13 | 0.18 | 0.15 |
| TDS | 0.43 | 0.40 | -0.10 | 0.25 | 0.04 | **0.59** | **0.75** | 0.33 |
| DO | **-0.88** | **-0.98** | -0.08 | 0.02 | 0.05 | 0.0006 | -0.15 | 0.11 |
| COD | **0.89** | **0.91** | -0.05 | 0.08 | 0.14 | 0.2 | 0.41 | -0.25 |
| NH4. | **0.92** | **0.93** | 0.05 | 0.11 | -0.03 | 0.17 | 0.32 | -0.2 |
| NO3 | **0.90** | **0.81** | 0.01 | -0.23 | -0.20 | 0.05 | 0.32 | 0.29 |
| Phosphate | 0.21 | 0.51 | **0.87** | **0.76** | 0.28 | 0.03 | 0.24 | -0.32 |
| Sulfates | 0.02 | 0.16 | **0.70** | 0.007 | 0.42 | -0.03 | 0.49 | **-0.68** |
| K | -0.25 | **-0.49** | 0.37 | 0.44 | **0.80** | -0.16 | -0.35 | 0.08 |
| Ca | -0.04 | -0.37 | 0.44 | **0.59** | **0.87** | 0.18 | -0.16 | 0.42 |
| Mg | 0.05 | **-0.66** | 0.38 | 0.41 | **0.87** | 0.27 | -0.06 | 0.29 |
| Cl | 0.22 | 0.52 | **0.75** | **0.80** | 0.52 | -0.24 | -0.09 | -0.33 |
| Br | -0.13 | -0.24 | 0.15 | **0.82** | 0.001 | 0.42 | **0.71** | 0.18 |
| Cd | 0.33 | 0.31 | **-0.74** | **-0.60** | 0.10 | **0.65** | 0.31 | -0.01 |
| Cr | **0.75** | **0.63** | -0.49 | -0.18 | 0.02 | **0.73** | 0.36 | -0.13 |
| Ni | 0.34 | -0.34 | **-0.55** | **0.61** | 0.45 | 0.49 | **0.62** | 0.35 |
| Cu | 0.01 | 0.03 | 0.02 | 0.06 | **0.92** | 0.02 | 0.1 | **0.92** |
| Zn | -0.09 | 0.06 | -0.14 | -0.06 | **0.74** | 0.18 | 0.07 | **0.85** |
| Mn | 0.45 | 0.08 | **-0.49** | -0.16 | 0.47 | **0.97** | 0.48 | 0.18 |
| Hg | **0.86** | **0.63** | -0.002 | 0.12 | 0.26 | 0.55 | 0.38 | -0.42 |
| As | -0.11 | 0.17 | -0.23 | 0.22 | 0.24 | **0.56** | **-0.75** | 0.19 |
| Pb | **0.87** | **0.71** | -0.25 | 0.12 | -0.08 | **0.91** | 0.24 | -0.02 |
| THB | **0.95** | **0.89** | -0.07 | 0.1 | -0.1 | 0.41 | 0.19 | -0.11 |
| TC | **0.95** | **0.88** | 0.04 | 0.23 | -0.16 | 0.29 | 0.08 | -0.07 |
| FC | **0.97** | **0.91** | -0.005 | 0.19 | -0.14 | 0.14 | 0.13 | -0.18 |
| FS | 0.40 | **0.80** | -0.04 | 0.36 | **-0.73** | 0.18 | -0.16 | -0.25 |
| Vibrio C | **0.90** | **0.97** | 0.02 | 0.01 | -0.03 | 0.18 | 0.22 | 0.16 |
| E Coli | **0.93** | **0.89** | 0.08 | 0.26 | 0.001 | 0.24 | 0.04 | 0.17 |
| Initial eigen value | 13.12 | 13.66 | 5.48 | 5.47 | 5.34 | 4.92 | 4.3 | 3.53 |
| Percent variance of initial value | 39.75 | 41.41 | 16.60 | 16.59 | 16.18 | 14.90 | 13.02 | 10.71 |
| Cumulative percent of initial eigenvalue | 39.75 | 41.41 | 56.35 | 58 | 72.53 | 72.90 | 85.55 | 83.61 |

*2.3 Analytical methods*

*Chemical reagents*:

All solutions were prepared with analytical reagent grade chemicals. Ultrapure-quality HNO3 (65%) was purchased from Merck KGaA 64271 Darmstadt (Germany). All dilutions were conducted with double deionized (Barnstead, USA) water. Single-element standard solutions from Merck were prepared by diluting a stock solution containing 1000 mg/L singleelement atomic absorption spectrophotometer (AAS)- grade standard and then used for calibration. Ultrapure- quality phosphoric acid (H3PO4), sodium dihydrogen phosphate potassium iodide, sodium hydroxide, and oxalic acid were also used for sample preparation (Merck, Germany). All used glassware and tubes were soaked overnight in 20% (v/v) HNO3, rinsed with deionized water, and dried before use.

*Analysis of physicochemical properties*

Eighteen important parameters were selected for physicochemical analysis, including cations and anions in water, namely temperature, turbidity, total suspended solids (TSS), total dissolved solids (TDS), electrical conductivity (EC), salinity, pH, dissolve Oxygen (DO), chemical oxygen demand (COD), potassium (K+), calcium (Ca2+), magnesium (Mg2+), ammonium-N (NH4+-N), chloride (Cl-), nitrate-N (NO3−-N), sulfates (SO42−), phosphates (PO43−), and boron (B(OH)3 as tetraborate ion). Water temperature was recorded immediately in situ by using a calibrated mercury thermometer. The turbidity was measured with portable turbidimeter (Model: Hach 2100Q, HACH, USA) where serial standard solutions (20NTU-100NTU) of turbidity were used to calibrate the meter. The TSS were determined gravimetrically by filtration and thereafter dried in an oven (Radojevic and Bashkin, 1999). The TDS, EC and salinity were measured instrumentally using Jenway™ Bench Multiparameter-Meter (Model 4510), while pH of water was determined in situ by calibrated portable pH meter (Model: Hanna 99171). The Multiparameter-Meter and pH meter was calibrated with 1000 μS cm−1 of NaCl solution and buffer solutions pH: 4.0 and 7.0, respectively. Rapid determination of dissolved oxygen in water samples was measured in situ using a portable DO meter (Model: Jenway 9200), while COD was analyzed by USEPA Reactor micro digestion colorimetric method (Jirka and Carter, 1975). Powder-free AMEX gloves and masks were used to prevent further contamination during the entire sampling and testing process. The NH4+ were determined by micro-Kjeldahl's distillation method (Jackson, 1967). NO3– and SO42– were determined using the spectrophotometric method as stated by Armstrong (1963). This involved mechanical shaking of 50 mL of water samples immersed in 100 mL deionized water for 10 minutes. Extracting reagents such as 0.02 N Ag2SO4, phenol-di-sulphonic acid and NH4OH were introduced for digestion of nitrate, while conditioning agents (50 mL glycerol+30 mL concentrated HCl+100 mL ethanol+300 mL distilled water+75 g NaCl) and BaCl2 salt were introduced for sulfate analysis. The absorbances of the extracting solution were determined at 410 nm for nitrate and 420 nm for sulfate using UV/Visible Spectrophotometer (Milton Roy Spectronic 21D). Calibration curves were prepared in the series of 0–20 mg/L for nitrate and 0-200 mg/L for sulfate, respectively. Potassium was measured by flame photometer at 766 nm wavelength (Model: JEENWAY PFP7) (Jackson, 1967). Major anions like Cl– and PO43– content of water were determined by Mohr titration method (Jackson, 1967) and ascorbic acid blue color method (Murphy and Riley, 1962), respectively. Boron B(OH)3 as tetraborate ion was evaluated by curcumin colorimetric method at 550 nm wavelength in a spectrophotometer (Choi and Chen, 1979).

*2.4 Atomic absorption spectroscopy*

For heavy metal analysis by means of atomic absorption spectrometer, water samples were filtered through a nylon membrane filter (Whatman, pore size 0.8 μm, diam. 47 mm) before the digestion procedure. 150 mL of mixed effluents-contaminated water samples were digested with 10 mL of concentrated HNO3 (1M) at 40◦C and covered with ribbed watch glass. The samples were then evaporated to 10 mL on a hot plate before adding 5 mL of concentrated HNO3 and 3 mL of HClO4. The samples were then evaporated again to the lowest possible volume until the digestion was complete and cooled down. After cooling, some deionized water was added to the samples. Subsequently, the samples were filtered through Whatman no. 42 filter paper and synchronously, the filtrate was diluted with deionized water up to the volume of 50 mL and preserved in a screw-top plastic bottle. Then the samples were analyzed in an air-acetylene flame atomic absorption spectrometer (AAS, Model: AA-280, Varian, Australia) for calcium (Ca2+) and Magnesium (Mg2+) cations and heavy metal (Cd, Cr, Ni, Cu, Zn) contents. The atomic absorption spectroscopy is an appropriate technique to analyze multi-elements with moderately low detection limits compared to other analytical methods like energy dispersive X-ray fluorescence (EDXRF) technique. The measured data of standard solutions were well consistent with their certified values, indicating the accuracy of the measurement. For each measurement, the mean value of three consecutive replicates was adopted. Heavy metal standards were prepared by mixing anhydrous salts of CdCl2, CrCl3, ZnCl2, Ca3(AsO4)2 and CuSO4(H2O). The blank during the measurements was very low, with most of them below the method detection limit (MDL). The MDL for Ca, Mg, Cd, Cr, Ni, Cu and Zn was 0.001, 0.002, 0.0003, 0.0004, 0.0190, 0.0062 and 0.0075 mg/L at wavelengths of 422.7, 285.2, 228.8, 357.9, 232.0, 324.7 and 213.9 nm, respectively. The AAS was calibrated for all the metals by running different concentrations of standard solutions. Calibration curves have been experimented by assessment of quality control standards aforetime, midst, and later the analyses of a set of samples. The spike recovery of ions (Ca2+, Mg2+), and metals (Cd, Cr, Cu, Ni, and Zn) was calculated using the following equation, where the results lied mostly within 90 to 110% recovery.

Where, ‘x’ is the concentration of spiked sample, ‘y’ is the concentration of un-spiked sample and ‘z’, the total amount of spike used. When the recovery rate become out of the recommended range (90–110 %), samples were reanalyzed with a new calibration curve.

The analytical quality and data reliability was ensured by quality reagents, replicated samples from each sampling station and calibrated apparatus and instruments. Replicated samples were collected and analyzed from each sampling station and their average value was considered (relative standard deviations, RSD for all measurements were less than 20%). All acids and reagents used were of analytical grade and deionized water was used for diluting acids and metal salts. Before use, all appliances were thoroughly cleaned to prevent contamination by soaking them overnight in 8% (v/v) HNO3 solution, rinsing them several times in deionized water and then drying them in an electric oven at 80 °C. The deionized water with an electrical conductivity and a resistance of 0.2 μS/cm and 18.8 MΩ-cm at 25 °C was treated in an Easypure-II RF water purification system, which was used throughout the experiment. The precision of all analytical methods was observed by measuring replicated samples randomly selected (RSD < 5%). The accuracy of the AAS analysis technique was tested by measuring the concentration of known standard solutions after three samples and a blank method after five samples.

*2.5 Water pollution indices*

2.5.1 Water quality index

Water Quality Index (WQI) reflects the combined influence of the water quality parameters. The water quality for drinking purpose is calculated applying the Eq. (1) (Meng et al., 2016; Şener et al., 2017).

Where the Relative Weights (Wi) of each selected parameter is presented using the Eq. (2).

Where, wi is the weight attributed to the element according to its relative apperceptive effects on human health and significance on drinking purpose (Meng et al., 2016; Şener et al., 2017), and n is the number of parameters. ∑Wi is the sum of the wi. Ci is the measured element concentrations, and Si is the standard for drinking water in Bangladesh according to DPHE (DPHE, 2020). Each parameter is assigned a weight (wi) ranging from 1 to 5 based on its importance in affecting the water quality for domestic and health purposes, whereby 1 is assigned to parameters with least potential effect and 5 to parameters whose concentrations beyond a certain range are considered critical for health i.e. Cr and Cd. According to the WQI value water quality is classed as Excellent Water: WQI < 50; Good Water: 50 ≤ WQI ≤100; Poor Water: 100 ≤ WQI ≤200; Very Poor Water: 200 ≤ WQI ≤300; and Water unsuitable for drinking: WQI ≥ 300 (Xiao et al., 2019).

2.5.2 Nemerow index (Pn)

The Nemerow index reflects the interaction between the average pollution level and the maximum pollution factor. Since different properties have different impacts on same site, this method will provide a rational interpretation of the contaminating properties at each sampling site as a whole (Shil and Singh, 2019; Yan et al., 2016). In this method, first Pi (a single factor index of individual metal) is accounted (Eq. 3), and then using Pi a composite index Nemerow index (Pn) value is calculated (Eq. 4), which indicates the degree of elemental pollution in the water, as per following formula (Liu et al., 2015; Mazurek et al., 2016; Zhang et al., 2017);

A single factor index

Nemerow index

Where Pi represents single factor index that refers to the exceeding multiple of each index, Ci represents the actual measured concentration of metals and other properties in water. Si represents the standard guideline concentration of the respective element (DPHE, 2020; USEPA, 2012; WHO, 2017). The Nemerow index method divides water quality into three categories where a Pn<0.7: uncontaminated water; 0.7 ≤ Pn ≤ 1: water under the threat of contamination; and Pn>1 : heavily contaminated water (Liu et al., 2015; Zhang et al., 2017).

2.5.3 Heavy Metal Pollution Index (HPI)

Heavy metal pollution index (HPI) designed by Mohan et al., (1996) is a rating method that considers the composite influence of individual heavy metals on overall inclusive water based on the weighted arithmetic quality mean (Edet and Offiong, 2002; Herojeet et al., 2015; Shil and Singh, 2019).

Sub-index,

In this indexing method, Wi is taken as value inversely proportional to the recommended standard admissible values (Si) of the respective metals. (Mohan et al., 1996; Rakotondrabe et al., 2018). Si values (in ppm) used here are Cd (0.005), Cr (0.05), Ni (0.1), Cu (1) and Zn (5) (DPHE, 2020; EPA, 2001; USEPA, 2012). Qi is the sub-index of the ith parameter, and n is the total number of parameters investigated. Qi of the parameter is computed by Eq. (6). Here, Mi is the observed average concentration of particular examined heavy metal and Ii belongs to the highest desirable (Ideal) value of the ith parameter. The Ii values (in ppm) were considered as Cd (0.0), Cr (0.0), Ni (0.02), Cu (0.05) and Zn (0.2) (EPA, 2001; Mohan et al., 1996; WHO, 2017). HPI index (Eq. 5) was proposed for the purpose of classifying drinking water and critical or permissible value was determined as 100 (Mohan et al., 1996).

2.5.4 Health Risk Assessment (non carcinogenic and carcinogenic)

The human health hazard assessment method, as prescribed by US Environmental Protection Agency (USEPA, 2004), applied to calculate human health hazards from Buriganga River water. Two main exposure pathways i.e., direct ingestion and dermal absorption (Wang et al., 2017) and two age group of population i.e., adults and children were considered separately for evaluation of non-carcinogenic health hazards also known as health risk assessment. The human health hazards quotient (HQ) is calculated (Eq. 9) by dividing chronic daily intake (ADD) (Eq. 7,8) values with chronic reference dose (RfD) (Chen et al., 2018; Xiao et al., 2019). For Cd, Cr, Ni, Cu, and Zn RfDingestion are 0.5, 3, 20, 40, 300 and RfDdermal are 0.025,0.075, 0.8, 12, 60 respectively (Xiao et al., 2019). Finally, hazard index (HI) is obtained by summation of all the HQs of individual elements from both the applicable pathways i.e., ingestion and dermal (Eq. 10) (Wang et al., 2017). Based on the risk guidelines of USEPA (2004), the exposure dose for direct ingestion (ADDingestion) and dermal absorption (ADDdermal) were shown as follows:

Detailes of the equations are given in Table 2 using the health risk assessment-based data approach from Zeng et al., 2015; Schecter and Li, 1997; USEPA, 2004; Wang et al., 2017; Yang et al., 2015.

Table 2 The parameters of exposure assessment for River Buriganga.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Parameter | Meaning | Value for Adult | Value for Child | Unit |
| Cw | the mean concentrations of trace elements in samples |  | | mg/L |
| IR | the ingestion rate | 2.0 | 0.64 | L/day |
| ABSg | the gastrointestinal absorption factor, which is dimensionless | In this study, 5.0% for Cd, 3.8% for Cr, 57% for Cu, 4.0% for Ni, 20% for Zn. | |  |
| EF | the exposure frequency | 365 | | days/year |
| ED | exposure duration | 70 | 6 | Years |
| ET | exposure time | 0.58 | 1 | h/day |
| SA | exposed skin area | 18000 | 6600 | cm2 |
| Kp | the dermal permeability coefficient in samples | 0.001 for Cd and Cu, 0.003 for Cr, 0.004 for Ni, 0.0006 for Zn | | cm/h |
| CF | a unit transfer factor | 1×10−3 (value for water) | |  |
| BW | body weight | 65 | 20 | Kg |
| AT | the average time for non-carcinogens | 25550 | 2190 | Days |

The potential non-carcinogenic risks were assessed by HQ (USEPA, 2004; Xiao et al.,2019). When values of HQ were >1, non-carcinogenic effects should be considered.

Hazard Quotient

where RfD was the reference dose,. Besides, the total potential non-carcinogenic risks caused by different pathways were assessed by HI.

Hazard Index

Similarly, if the HI were <1, the existence of heavy metal pollution without health risk should be considered (USEPA, 2004; Xiao et al., 2019).

Carcinogenic health risk assessment is appraised, using the incremental lifetime cancer risk (ILCR) model proposed by USEPA (2005) as the product of exposure dose for direct ingestion (ADD) and the cancer slope factor (CSF) (Wu et al., 2016; Cao et al., 2017; Shil and Singh, 2019), as follows (Eq. 11):

The total carcinogenic risk is evaluated by adding up (assuming additive effects) all the ICLRs from all carcinogens and applicable exposure routes for multiple carcinogenic metals (Cao et al., 2017). Cd and Cr are considered potential carcinogens and carcinogenic toxicity have been studied on these metals. CSFIngestion values (in [mg kg−1 day−1]−1) are available for metals as Cd (0.38) and Cr(0.5) (USEPA, 2005; Miguel et al., 2007; Mirzabeygi et al., 2017; Singh et al., 2018; Shil and Singh, 2019).

*2.6 GIS and statistical analysis*

Geospatial maps of Water quality index, Nemerow index, and Health risk assessment were derived using ArcGIS-10.3 software developed by ESRI. Interpolation IDW was drawn for distribution pattern of individual metal concentration, WQI, health indices, and for pollution status indices. IDW is a geo-statistical tool that shows the spatial distribution of values of variables from the sampling site which is assigned and indicated by a geographic coordinate. Nine sampling stations were integrated with IDW geostatistical procedure to get a spatial distribution map of metals and their indices to identify the potential risk-prone zones. Administrative areas located in a 5 km buffer zone of the river were considered for spatial distribution mapping. The area was under consideration owing to high population density in its surrounding. Microsoft Excel-2016 and IBM-SPSS V. (25) were used to perform statistical analysis.

Multivariate and geo-statistical analysis approach

The relationship between the physicochemical properties and heavy metals in the river water and their sources were identified by PCA along with the correlation matrix by using IBM SPSS Statistics 23.0 (International Business Machines Corp., Armonk, NY). PCA can reduce variables of the datasets into a smaller number of new factors known as components. Before performing PCA, the assumption of normalization was checked and the dataset was log normalized.

Geo-statistical approaches are used to assess and present the spatial distribution of pollution status and health indices caused by the contaminants in the river water (Shil and Singh, 2019; Xiao et al., 2019). It estimates unbiased values for unsampled location based on spatial correlations with the sampled sites and thus reduces the variance in estimated error. Although ordinary kriging interpolation method is the most widely used method for prediction of the contaminated area/stations, studies indicated the higher potential of inverse distance weighting (IDW) in the prediction of contamination hot spots (Shil and Singh, 2019; Xiao et al., 2019). IDW interpolation mapping was done by using ESRI ArcMap 10.2 (Environmental Systems Resource Institute, Redlands, CA).

The methodology flow chart is given in the following:



Fig: Methodology flow chart

**3. Results**

Table 3: Descriptive statistics of water quality parameters of river Buriganga on seasonal basis (Winter and Summer)

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Parameters | Winter | | | | | | Summer | | | | | | |
| **Mean** | **Max** | **Min** | **CV** | **Skew** | **Kurt** | | **Mean** | **Max** | **Min** | **CV** | **Skew** | **Kurt** |
| **Temperature (◦C)** | 21.16±1.19 | 22.8 | 19.3 | 5.65 | -0.56 | -0.64 | | 27.9±0.77 | 29.3 | 27.1 | 2.76 | 0.94 | -0.56 |
| **pH** | 7.2±1.05 | 8.82 | 5.55 | 14.62 | -0.19 | -0.75 | | 7.06±0.77 | 7.81 | 5.28 | 10.93 | -1.63 | 3.51 |
| **EC (μS/cm)** | 1216±567.73 | 2302 | 367 | 46.69 | 0.29 | 1.12 | | 1260.11±417.9 | 1823 | 538 | 33.16 | -0.74 | -0.24 |
| **TSS (mg/l)** | 264±111.47 | 465 | 95 | 42.22 | 0.3 | 0.05 | | 350.33±94.21 | 464 | 178 | 26.89 | -0.39 | -0.26 |
| **Turbidity (NTU)** | 61.83±23.46 | 97.4 | 28.8 | 37.94 | 0.11 | -1.38 | | 200.56±48.28 | 274 | 122 | 24.07 | 0.09 | -0.4 |
| **Salinity (mg/l)** | 558.33±364.17 | 1280 | 108 | 65.22 | 0.75 | 0.79 | | 693.89±315.32 | 1332 | 244 | 45.44 | 0.75 | 1.47 |
| **TDS (mg/l)** | 688.78±361.09 | 1350 | 195 | 52.42 | 0.25 | 0.35 | | 779.11±331.63 | 1155 | 208 | 42.57 | -0.85 | -0.6 |
| **DO (mg/l)** | 0.92±0.86 | 2.12 | 0 | 93.28 | 0.21 | -2.01 | | 1.07±1.02 | 2.52 | 0 | 95.65 | 0.32 | -2.14 |
| **COD (mg/l)** | 193.11±149.19 | 516 | 52 | 77.26 | 1.38 | 1.79 | | 216.56±124.22 | 425 | 90 | 57.36 | 0.6 | -1.27 |
| **NH4+ (mg/l)** | 6.23±3.36 | 11.2 | 2.1 | 53.93 | 0.17 | -1.68 | | 5.81±3.17 | 10.4 | 2.2 | 54.63 | 0.19 | -1.88 |
| **NO3- (mg/l)** | 17.57±6.12 | 25.8 | 9.8 | 34.83 | 0.28 | -1.74 | | 31.67±10.03 | 44.5 | 18.4 | 31.68 | -0.33 | -1.6 |
| **PO43-(mg/l)** | 4.54±1.63 | 6.8 | 2.1 | 35.77 | 0.09 | -1.2 | | 3.34±1.75 | 7.33 | 1.51 | 52.43 | 1.66 | 3.21 |
| **SO₄²- (mg/l)** | 11.91±3.63 | 18.7 | 8.59 | 30.46 | 1.22 | 0.24 | | 84.81±16.96 | 107.8 | 54.2 | 20 | -0.47 | -0.32 |
| **K (mg/l)** | 31.93±10.78 | 48.7 | 18.5 | 33.74 | 0.08 | -1.32 | | 34.54±12.36 | 59.2 | 18.9 | 35.77 | 0.99 | 0.8 |
| **Ca (mg/l)** | 82.31±28.95 | 132.6 | 32.9 | 35.17 | 0.04 | 0.51 | | 77.4±29.18 | 130.2 | 30.9 | 37.7 | 0.37 | 0.36 |
| **Mg (mg/l)** | 44.61±21.30 | 83.6 | 11.9 | 47.74 | 0.58 | 0.46 | | 41.91±26.09 | 95.1 | 16.5 | 62.25 | 1.43 | 1.16 |
| **Cl- (mg/l)** | 36.47±16.10 | 70.4 | 16.5 | 44.14 | 1.07 | 1.66 | | 173.75±2.94 | 178.25 | 170.05 | 1.69 | 0.32 | -0.9 |
| **B (mg/l)** | 1.81±0.85 | 3.29 | 0.87 | 46.92 | 1.18 | 0.17 | | 0.53±0.16 | 0.79 | 0.32 | 29.78 | 0.19 | -0.99 |
| **Cd (mg/l)** | 0.29±0.72 | 2.21 | 0 | 251.57 | 2.97 | 8.85 | | 0.22±0.56 | 1.7 | 0 | 246.95 | 2.96 | 8.8 |
| **Cr (mg/l)** | 0.4±0.52 | 1.42 | 0.03 | 131.72 | 1.37 | 0.57 | | 0.28±0.47 | 1.31 | 0.02 | 167.55 | 1.88 | 2.57 |
| **Ni (mg/l)** | 0.35±0.40 | 1.25 | 0.06 | 113.66 | 1.83 | 3.04 | | 0.27±0.36 | 1.02 | 0.03 | 133.47 | 1.71 | 1.7 |
| **Cu (mg/l)** | 0.81±0.57 | 1.83 | 0.07 | 70.16 | 0.5 | -0.2 | | 0.86±0.73 | 2.1 | 0.04 | 85.16 | 0.38 | -0.95 |
| **Zn (mg/l)** | 0.48±0.22 | 0.75 | 0.12 | 45.65 | -0.41 | -1.35 | | 0.31±0.21 | 0.76 | 0.09 | 68.6 | 1.19 | 1.63 |

Table 4: Table portraying the water quality standards and studied parameters in both season (winter- summer).

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Parameters** | **WHO limits (2017)** | **DPHE limits (2020)** | **Irrigation standards** | **Sampling Stations (Winter- Summer)** | | | | | | | | |
| **GD** | **GT** | **SC** | **HS** | **RB** | **KB** | **ZI** | **ST** | **PB** |
| Temperature (◦C) | 20-30 | 25 - 30 | -- | 20.8–27.4 | 21.7 –28.5 | 21.9–29.3 | 22.1–27.6 | 19.4–27.3 | 20.8–27.4 | 19.3–27.1 | 21.6–28.8 | 22.8–27.7 |
| pH | 6.5 - 8.5 | 6.5 - 8.5 | 6.5- 8.4 | 7.86–7.22 | 7.96–7.59 | 6.12–6.83 | 7.45–7.80 | 7.3–702 | 8.1–7.81 | 5.8–6.75 | 5.55–5.28 | 8.82–7.20 |
| EC (μS/cm) | -- | <300 | 2500 | 1170–1375 | 1293–1453 | 1356–1072 | 1560–1823 | 488–692 | 1172–1596 | 367–538 | 1236–1380 | 2302–1412 |
| TSS (mg/l) | -- | 10 | -- | 280–464 | 320–387 | 350–434 | 160–302 | 95–178 | 196–296 | 210–461 | 465–461 | 300–322 |
| Turbidity (NTU) | -- | 10 | -- | 59.6–274 | 78.6–223 | 85.3–208 | 39.9–175 | 28.8–122 | 42.5–176 | 48.9–262 | 97.4–162 | 75.5–203 |
| Salinity (mg/l) | 200 | 200 | -- | 585–709 | 606–702 | 542–606 | 860–1332 | 270–360 | 612–942 | 162–244 | 108–720 | 1280–630 |
| TDS (mg/l) | 600 | 1000 | 2000 | 578–852 | 712–867 | 786-590 | 955–1155 | 202–208 | 586–1037 | 195–327 | 835–1040 | 1350-936 |
| DO (mg/l) | 6 | 6 | -- | 1.82–1.96 | 1.37–1.87 | 0.14-0.12 | 1.72–2.12 | 2.12–2.52 | 0.85-0.5 | 0.1–0.15 | 0.0–0.0 | 0.13–0.37 |
| COD (mg/l) | 4 | 4 | 150 | 95–130 | 90–133 | 220–320 | 83.0–93 | 52–152 | 120-90 | 282-256 | 516-425 | 280–350 |
| NH4+  (mg/l) | 1 |  | 5 | 2.6–2.9 | 3.2-2.8 | 8.0-7.6 | 4.6-2.2 | 2.1–3.0 | 5.6–5.9 | 9.4-8.2 | 11.2-10.4 | 9.4–9.3 |
| NO3 (mg/l) | 50 | 50 | 10 | 13.1–33 | 12.4–32.3 | 17.3–37.2 | 12.4–18.4 | 9.8–19.8 | 18.2–38.2 | 24.6–41.9 | 24.5–44.5 | 25.8-19.7 |
| PO43-(mg/l) | 1 | 6 | 2 | 3.5-2.15 | 4.2-3.46 | 6.0–7.33 | 3.0-2.27 | 3.9-3.21 | 4.9-2.29 | 6.51-1.51 | 2.1–3.24 | 6.8-4.57 |
| SO42-(mg/l) | 250 | 400 | 960 | 12.4–92.5 | 11.4–74.2 | 18.7–107.8 | 10–70.8 | 10.8–89.2 | 8.59–54.2 | 17.1–94.7 | 9.3–77.7 | 8.9–102.1 |
| K (mg/l) | 12 | 12 | 2 | 39.2–59.2 | 36.8–46.8 | 42.2-32.5 | 48.7-40.1 | 19.4–23.8 | 33.1-29.4 | 18.5–18.9 | 28.2–31.2 | 21.3–29 |
| Ca (mg/l) | 75 | 75 | 400.8 | 95.6–102.5 | 86.4-72.3 | 108.2-98.6 | 132.6-130.2 | 32.9-30.9 | 83.1-72.5 | 56.2-54.3 | 75.5-69.8 | 70.2-65.5 |
| Mg (mg/l) | 50 | 35 | 60.8 | 52.6–75.4 | 37.4–39.6 | 68.9-38.9 | 83.6–95.1 | 11.9–16.5 | 38.5-30.4 | 29.8-28.8 | 42.6-21.8 | 36.1-30.7 |
| Cl- (mg/l) | 250 | 150-600 | 1065 | 44.8–175.3 | 21.6–178.2 | 70.4–174.3 | 34.8–170.1 | 32.5–173.2 | 16.5–172.8 | 25.3–171.9 | 36.4–177.6 | 45.9–170.1 |
| B (mg/l) | 2.4 | 1 | -- | 1.25-0.32 | 1.74-0.45 | 1.62-0.68 | 0.87-0.79 | 3.29-0.63 | 3.15-0.42 | 1.72-  -0.6 | 1.30-0.54 | 1.31-0.35 |
| Cd (mg/l) | 0.003 | 0.005 | 0.01 | 0.007-0.003 | 0.008–0.012 | 0.015–0.018 | 0.092–0.152 | 0.003–0.002 | 0.005–0.003 | 2.210  -  1.700 | 0.082-0.065 | 0.165-0.069 |
| Cr (mg/l) | 0.05 | 0.05 | 0.1 | 0.049-0.021 | 0.089-0.062 | 0.296-0.082 | 0.045-0.024 | 0.031-0.015 | 0.025–0.045 | 1.10-0.825 | 1.42-1.31 | 0.51-0.11 |
| Ni (mg/l) | 0.07 | 0.1 | 0.2 | 0.058-0.025 | 1.250-0.736 | 0.062-0.062 | 0.102-0.065 | 0.128-0.089 | 0.207-0.207 | 0.721-1.023 | 0.256-0.112 | 0.356-0.092 |
| Cu (mg/l) | 2 | 1 | 0.2 | 0.388–0.458 | 0.965–1.230 | 0.065-0.035 | 0.926–0.989 | 0.195-0.114 | 0.850–2.100 | 1.830-1.580 | 0.652-0.096 | 1.420-1.100 |
| Zn(mg/l) | 3 | 5 | 2 | 0.119-0.087 | 0.612-0.302 | 0.669-0.349 | 0.286–0.186 | 0.307-0.127 | 0.335-0.131 | 0.623–0.759 | 0.753-0.442 | 0.598-0.392 |

*3.1. Physico-chemical properties of water*

The descriptive statistics of the measured physicochemical characteristics, ionic status, and metal concentration, i.e., Temperature, pH, EC, TSS, TDS, DO, COD, Turbidity, Salinity, Ca2+, Mg2+, K+, B(OH)3-, NH4+, NO3-, PO43-, SO43-, Cl-, Cd, Cr, Ni, Cu, Zn of nine sampling stations in both winter and summer season of Buriganga river water are presented in Table 3, including the summary statistics, standard deviation (SD), coefficient of variance (CV%), skewness, and kurtosis of the data-set. Most of the studied metals displayed a wide range of individual elemental concentrations, which is eventually reflected through the large standard deviation and high value of CV%. The presence of extreme outliers might have significantly affected the mean concentrations of metals. The normality of the dataset was confirmed through the analysis of its absolute kurtosis and skewness value, where generally absolute values of the skewness coefficient as < 3.000 and the kurtosis coefficient as <8.000 was considered normally distributed (Wei et al., 2018). The coefficients of the skewness ranged from (−0.56 to 2.97 in winter and -1.63 to 2.96 in summer) and kurtosis (−2.01 to 8.85 in winter and -2.14 to 8.8 in summer), where except of Cd on both seasons due to its high kurtosis value, rest of the parameters were normally distributed.

All the studied water quality parameters, their respective standards according to WHO, 2017, DPHE, 2020, and irrigation standards (Ayers & Westcot, 1985); are portrayed in the Table 4. The temperature of river Buriganga was observed ranging from 19.3 to 22.8°C in winter and 27.1 to 29.3°C in summer with a mean of 21.16°C in winter and 27.9°C in summer, respectively. The pH values of water samples varied from 5.57 to 8.82 during winter and 5.28 to 7.81 in summer and the average value was 7.12 which indicates that the river water was more or less neutral. The average physical characteristics TDS (688.78 mg/l in winter, 779.11 mg/l in summer), TSS( 264 mg/l in winter, 350.33 in summer), Turbidity(61.83 NTU in winter, 200.56 NTU in summer) and chemical characteristics EC (1216 μS/cm in winter and 1260.11 μS/cm), Salinity (558.33 mg/l in winter and 693.89 mg/l in summer), DO (0.92 mg/l in winter and 1.07 mg/l in summer), and COD (193.11 mg/l in winter and 216.56 mg/l in summer) of the studied samples from Buriganga showed higher mean concentration in summer, compared to winter (figure 3a). The ranges of physicochemical characteristics (in mg/l) were TDS: 195-1350 winter and 208 to 1155 in summer; TSS : 95-465 in winter and 178-464 in summer; Turbidity (NTU): 28.8- 97.4 in winter and 122- 274 in summer; EC(μS/cm): 367- 2302 in winter and 538- 1823 in summer; Salinity: 108- 1280 in winter and 244- 1332 in summer; DO: 0- 2.12 in winter and 0- 2.52 in summer and COD: 52- 516 in winter and 90- 425 in summer. Except for mean pH, all the physicochemical characteristics were excessively higher than the WHO (2017) and DPHE (2020) standards for drinking (Table 4). However, only pH, EC, and TDS value of Buriganga at all the sampling stations met the criteria for irrigation (Ayers & Westcot, 1985) (Table 4).



Fig: Box plot of physico chemical characteristics of water of river Buriganga in contrast to the recommended standards for drinking and irrigation.

Mean content of common cations Ca2+, Mg2+ and NH4+ (in mg/l) were 82.31, 44.6, and 6.23 in winter and 77.4, 41.91, and 5.81in summer respectively, where the concentrations were higher in winter than summer; except for K+ (31.93 mg/l, in winter, 34.54 mg/l in summer) (Fig 5). A comparative high mean concentration of Cl- (173.75 mg/l in summer, 36.47 mg/l in winter), SO42- (84.81 in summer, 11.91 mg/l in winter), and NO3 (31.67 mg/l in summer, 17.57 mg/l in winter) is observed in summer, on the contrary, PO43- (4.54 mg/l in winter, 3.34 mg/l in summer) and B (1.81 mg/l in winter, 0.53 mg/l in summer) is abundant in winter (Fig 3b). Ionic concentration of Buriganga river water ranges (in mg/l) were K+, 18.5- 48.7 in winter and 18.9- 59.2 in summer; Ca2+, 32.9- 132.6 in winter and 30.9- 130.2 in summer; Mg2+, 11.9- 83.6 in winter and 16.5- 95.1 in summer; NH4+, 2.1- 11.2 in winter and 2.2- 10.4 in summer; NO3-, 9.8- 25.8 in winter and 18.4- 44.5 in summer; PO43-, 2.1- 6.8 in winter and 1.51- 7.33 in summer; SO43-, 8.59- 18.7 in winter and 54.2- 107.8 in summer; Cl-, 16.5- 70.4 in winter and 170.05- 178.25 in summer; and B, 0.87- 3.29 in winter and 0.32- 0.79 in summer. All the cations studied surplus the permissible limit for drinking (DPHE, 2020, WHO, 2011). Cl-, SO42-, and PO43- concentration in water were within the desirable range, whereas, NO3 and B had exceeded the permissible limit according to standards for potable water (DPHE, 2020). Though Ca2+, NH4+, SO43-, and Cl- concentration of the river water met the irrigation water quality, concentration of K+, NO3-, PO43- far exceeded the limit (Ayers & Westcot, 1985).



Fig: Box plot of metal concentration of water of river Buriganga in contrast to the recommended standards for drinking and irrigation.

The average concentrations of heavy metals, Cd, Cr, Ni, Cu and Zn were 0.29 mg/l, 0.40 mg/l, 0.35 mg/l, 0.81 mg/l, 0.48 mg/l in winter and 0.22 mg/l, 0.28 mg/l, 0.27 mg/l, 0.86 mg/l, 0.31 mg/l in summer in the water of Buriganga river, where, the mean Cr, Cd, Ni, and Zn content showed slightly lower concentration in summer than winter (Fig 3c). The ranges of total metal concentrations (in mg/l) were Cd, 0- 2.21 in winter and 0- 1.7 in summer; Cr, 0.03- 1.42 in winter and 0.02- 1.31in summer; Ni, 0.06- 1.25 in winter and 0.03- 1.02 in summer, Cu, 0.07- 1.83 in winter and 0.04- 2.1 in summer; and Zn, 0.12- 0.75 in winter and 0.09- 0.76 in summer. Cd, Cr, and Ni concentrations of Buriganga river exceeded the standard limit for drinking (DPHE, 2020, WHO, 2017), while only Zn concentration falls within the irrigation water criteria () (Table 4).

*3.2. Watershed distribution of Heavy metals*

The spatial distribution of trace metal concentrations in water portrayed some likeliness and differences among metals. Cr, Cd, and Zn exhibited a similar pattern of highest concentration in the downstream of Buriganga, making the sampling stations ZI, HB, PB, and ST a major ‘hotspot’ of heavy metal pollution. Ni and Cu also have a higher concentration in the downstream, however, the upstream point GT presented a high concentration of these two metals, which may be due to the metal industries at both ends of the Buriganga river. Moreover, there might be a noteworthy contribution of the inflow of another urban river Turag to Buriganga around the confluence point to the rise of metal concentration. Therefore, the station GT appeared as a solitary hotspot in the Buriganga river. The middle part of Buriganga has a slightly lower concentration compared to other stations due to its location in the urban city center. The sample point ZI is the most vulnerable of all, having the highest amount of all individual heavy metals. Cd has the highest concentration in ZI in both season and Lowest in RB in winter and ST in summer. In both sampling season, ST station has the highest Cr concentration whirs, KB and RB have the lowest concentration of Cr in Winter and summer, respectively. The peak concentration of Ni was found in GT station in dry winter and ZI station in wet summer. Minimum Ni was traced to the GD station in both seasons. The highest content of Cu was observed in ZI and KB station, and the lowest was observed in SC station in winter and summer, respectively. Zn concentration was maximum in ZI and KB stations in winter and summer consecutively, and minimum in GD station in both seasons.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Name of water body** | **Cd (mg/L)** | **Cr (mg/L)** | **Ni (mg/L)** | **Cu (mg/L)** | **Zn (mg/L)** | **References** |
| Buriganga, 2010 | 0.0093 | 0.5872 | 0.00880 | 0.163090 | - | Ahmad et al., 2010 |
| Buriganga, 2015 | 0.0123 | 1.640 | 0.1669 | 0.0191 | 0.1972 | Sarkar et al., 2015 |
| Buriganga, 2019 | 0.0040–0.0720 | 0.000570-0.003170 | 0.001210–0.0031770 | 0.0009470–0.0090530 | 0.0031480–0.0199160 | Whitehead et al., 2019 |
| Buriganga, 2018 this study | 0.2560 | 0.3370 | 0.3090 | 0.8330 | 0.3930 | This study |
| Mahananda River, India | .00010 - 0.00050 | 0.000320- 0.002310 | 0.000340 - 0.001430 | 0.001180 - 0.004640 | 0.001950 - 0.018320 | Shil and Singh, 2019 |
| Catalan River, Spain | 0.00120 | 0.00240 | 0.00270 | 0.00130 | 0.00190 | Carafa et al., 2011 |
| Chinese Loess Plateau rivers | 0.000050 - 0.000310 | 0.00040- 0.1060 | 0.001440 - 0.044710 | 0.000480 - 0.05280 | 0.0020 -0.08330 | Xiao et al., 2019 |
| Tigris River, Turkey | 0.004370 | 0.0050 | 0.0450 | 0.1650 | 0.0370 | Varol and Sen, 2012 |
| Huai River, China | 0.61740 | 0.023080 | 0.04620 | 0.052320 | 110 | Wang et al., 2017 |
| Chinese Loess Plateau well waters | 0.0000050 - 0.000090 | 0.000090- 0.2440 | 0.000870 - 0.5160 | 0.001510 - 0.99660 | 0.00230 - 0.8950 | Xiao et al., 2019 |
| Xiangjiang River, China | 0.01340 | 0.006610 | 0.001470 | 0.20330 | 0.08460 | Zeng et al., 2015 |
| Dan River, China | 0.00070 | 0.00010 | 1.680 | 0.00120 | 0.007830 | Meng et al., 2016 |
| World average | 0.000080 | 0.00070 | 0.00080 | 0.001480 | 0.00060 | Gaillardet et al., 2003 |

*3.3. Water Type*

Using ionic properties of water, a piper plot was drawn and water was classified based on the plot (Figure 3).

In Figure 3 diamond shape consists (i) Calcium\_chloride type, (ii) Magnesium\_bicarbonate type, (iii) Sodium\_bicarbonate type, (iv) Sodium\_chloride type, (v) and (vi) Mixed type water and two trilinear shape consist (A) Magnesium type, (B) Calcium type, (C) Potassium type, (E) Sulphate type, (F) Bicarbonate type, (G) Chloride type, (D) and (H) No dominant type water. In winter, approximately 89% of the samples were Magnesium\_bicarbonate type and others were Mixed type. Approximately 78% of the samples were Calcium\_chloride type in summer. Both winter and summer almost half of the samples were calcium type and others were in no dominant type. For anions, approximately 89% in winter and 67% in summer of the samples were bicarbonate type and chloride type, respectively.

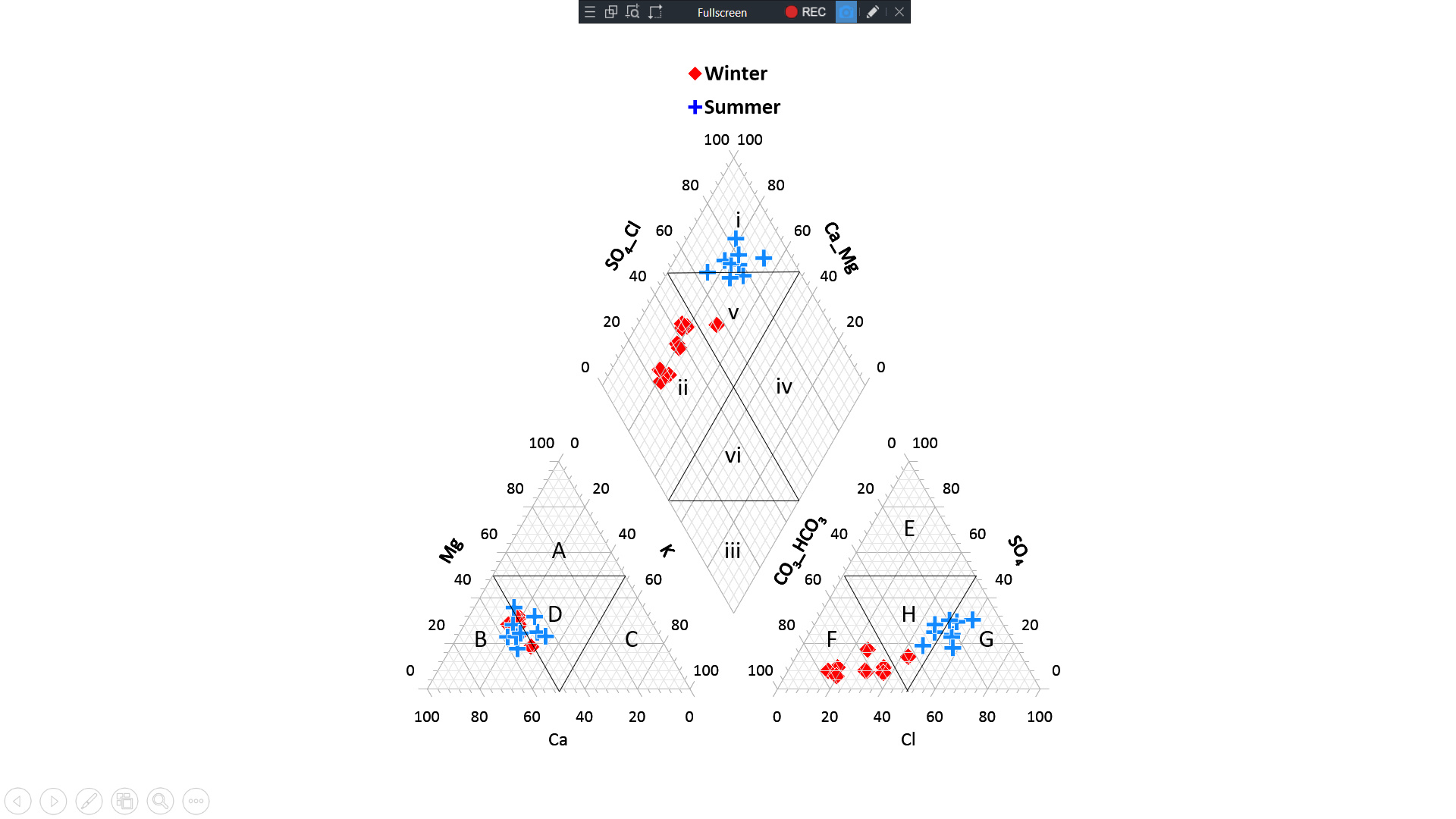


Fig. . Piper diagram of the river water samples for both winter and summer season.

***3.6. Source apportionment***

In order to facilitate consistent evaluation of the dataset of multiple variables monitored during various periods at different sampling stations, multivariate analyses were performed through Pearson's correlation, principle component analysis and cluster analysis. It classified the concentration of metals to their possible origin.

3.6.1. Correlation Analysis

Correlativity among the selected parameters was tested using Pearson’s coefficient with statistical significance set at p<0.05 and p<0.01.

Table 5: Pearson’s Correlation matrix of heavy metals in winter and summer season water of the Buriganga river.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | pH | DO | COD | Cd | Cr | Ni | Cu | Zn |
| **Winter** | | | | | | | | |
| **pH** | 1 |  |  |  |  |  |  |  |
| **DO** | 0.47 | 1 |  |  |  |  |  |  |
| **COD** | -.694\* | -.830\*\* | 1 |  |  |  |  |  |
| **Cd** | -0.356 | -0.391 | 0.261 | 1 |  |  |  |  |
| **Cr** | -.768\* | -.750\* | .937\*\* | 0.536 | 1 |  |  |  |
| **Ni** | 0.077 | -0.114 | 0 | 0.345 | 0.145 | 1 |  |  |
| **Cu** | 0.102 | -0.398 | 0.249 | .711\* | 0.408 | 0.541 | 1 |  |
| **Zn** | -0.54 | -.822\*\* | .746\* | 0.274 | .708\* | 0.441 | 0.287 | 1 |
| **Summer** | | | | | | | | |
| **pH** | 1 |  |  |  |  |  |  |  |
| **DO** | 0.503 | 1 |  |  |  |  |  |  |
| **COD** | -.823\*\* | -.735\* | 1 |  |  |  |  |  |
| **Cd** | -0.148 | -0.335 | 0.129 | 1 |  |  |  |  |
| **Cr** | -.869\*\* | -0.585 | .677\* | 0.455 | 1 |  |  |  |
| **Ni** | 0.039 | -0.167 | -0.06 | .775\* | 0.297 | 1 |  |  |
| **Cu** | 0.567 | -0.159 | -0.421 | 0.374 | -0.138 | 0.524 | 1 |  |
| **Zn** | -0.483 | -0.664 | 0.618 | .810\*\* | .688\* | .686\* | 0.158 | 1 |

\*\* Correlation is significant at the 0.01 level (2-tailed). \* Correlation is significant at the 0.05 level (2-tailed).

Correlation analysis among pH, DO, COD, and heavy metals in surface sediments showed significant positive correlations between Cr, Zn; and Cu, Cd in winter; whereas among Zn, Cd, Cr, and Ni in summer, indicating the potential for a closely related pollution source (Table 5). pH has a distinct negative relationship with COD and Cr in both seasons, suggesting that water acidity amplifies organic pollution and metal availability, though pH has no significant relationship with NI, Cu and Zn in any part of the year. Dissolved oxygen (DO) in water also exhibited this antagonistic relation with COD (<0.01) and Cr (<0.05) in both seasons, additionally with Zn (<0.01) in winter, meaning DO decreases with the increase of chemical oxygen demand and metal concentrations. COD, Cr, and Zn have a significant strong positive relationship with each other in winter meanwhile, COD is significantly correlated with Cr in summer, declaring the fact that Cr and Zn have a strong complexation with organics, on top of that, these elements may have a similar point source in Buriganga. Cd is significantly correlated with Cu in winter; and with Ni and Zn in summer, which may be due to the seasonal variation in industrial activities, wherein winter Cd and Cu has a similar source; on the contrary, Cd, Cr, Ni, Zn has a similar source and similar transport pathways in summer. Ni has no significant relationship with other metals in winter, moreover it has a r value of 0 with COD, meaning Ni is completely unrelated to COD of water, and it’s source is different from other metals in summer. Cu concentration in summer exhibited no significant relationship with other metals and properties, pronouncing different source.

3.6.2. Factor Analysis

Table 6: Results of factor analysis of water quality parameters in summer and winter after varimax rotation.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Parameters | **Winter** | | | | **Summer** | | | |
| 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| pH | -0.71 |  | 0.63 |  | -0.79 |  |  | 0.55 |
| EC |  |  | 0.95 |  |  | 0.70 | -0.53 |  |
| TDS |  |  | 0.89 |  |  | 0.71 |  |  |
| DO | -0.92 |  |  |  | -0.88 |  |  |  |
| COD | 0.97 |  |  |  | 0.87 |  |  |  |
| NH4 | 0.98 |  |  |  | 0.93 |  |  |  |
| NO3 | 0.88 |  |  |  | 0.64 |  |  |  |
| K |  | 0.91 |  |  |  | 0.77 |  |  |
| Ca |  | 0.96 |  |  |  | 0.91 |  |  |
| Mg |  | 0.96 |  |  |  | 0.86 |  |  |
| Cd |  |  |  | 0.67 |  |  | 0.91 |  |
| Cr | 0.92 |  |  |  | 0.82 |  |  |  |
| Ni |  |  |  | 0.78 |  |  | 0.88 |  |
| Cu |  |  |  | 0.88 |  |  |  | 0.92 |
| Zn | 0.80 |  |  |  | 0.62 |  | 0.67 |  |
| Total | 6.43 | 3.84 | 1.94 | 1.42 | 6.62 | 2.96 | 2.26 | 1.31 |
| % of Variance | 42.84 | 25.62 | 12.90 | 9.44 | 44.13 | 19.71 | 15.09 | 8.71 |
| Cumulative % | 42.84 | 68.45 | 81.35 | 90.80 | 44.13 | 63.84 | 78.93 | 87.64 |

A multivariate Factor analysis (FA) was performed to identify the parameters that control metal distribution as well as to recognize possible sources of elements and heavy metals in Buriganga river. FA is a powerful tool since it reduces the dimensions of multivariate data to understand the interrelation between the elements and their controlling factors. Factor loadings are generally classified depending on their absolute loading values, absolute loading values > 0.75 is as ‘strong’, 0.75–0.50 as ‘moderate’, and 0.50–0.30 as ‘weak’ (Liu et al., 2003; Shil and Singh, 2019). The varimax rotation results of 15 major pollution inducing parameters (pH, EC, TDS, DO, COD, NH4, NO3, K, Ca, Mg, Cd, Cr, Ni, Cu, and Zn) ignoring the weak relations along with the percentages of variance and cumulative variance are summarized in Table 6. Four factors explain 87.64% of the total variance in summer and 90.80% of total variance in winter season. All extracted components had the eigenvalues more than 1. In winter, factor 1 was accounted for 42.84% of the total variations observed with an eigenvalue 6.43, showing strong negative loading of pH and moderate negative loading of DO, strong positive loading of COD, NH4, NO3, and Cr, and Zn. Factor 2 embodied strong positive loading of major cations: Ca, Mg, K, describing 25.62% of the total variance. Factor 3 explained 12.90% of total variance with strong positive loading of EC, TDS, moderate loading of pH. Factor 4 having the lowest eigenvalue (1.42) described only 9.44% of the total variation with strong positive loading of Ni, Cu, and moderate positive loading of Cd. Summer FA also produced 4 distinct factors, where factor 1 explains 44.13% of the total variance and consists of components very similar to factor 1 in winter season. In winter factor 1 showed strong negative loading of pH and DO, strong positive loading of COD, NH4, and Cr, and a moderate positive loading of NO3, and Zn. Factors 2, 3, and 4 account for 19.71%, 15.09%, and 8.71%, respectively, having strong positive loadings for K, Ca, Mg and a moderate loading of EC and TDS; strong positive loadings of Cd, Ni, moderate positive loading of Zn, and a moderate negative loading of EC; strong positive loading of Cu, and a moderate loading of pH respectively.

3.6.3. Cluster Analysis

Cluster analysis or clustering is a process of identifying similarity between groups of datasets. Clustering is an unsupervised classification that is useful in solving classification problems. The hierarchical cluster analysis (HCA) was applied to identify the similarity between different sampling stations in the river during winter and summer. The dendrogram (Figure 4) produced for winter and summer using Ward’s linkage method and square Euclidean distance showed three statistically significant clusters at (𝐷link/𝐷max) \* 25>5. Buriganga being a highly heavy metal polluted urban river in close vicinity of all kinds of industries ranging from tanneries to shipbreaking industries, with a ubiquitous high concentration of metals in more or less every station, cluster analysis of the studied stations was mainly based on the salinity properties of water.

The first cluster consists of the sampling station of GD, KB, GT, SC, HS, and ST for winter and GD, GT, KB, ST, PB, and SC for summer. All these stations have a moderate level of EC, TDS, Salinity compared to the remaining two clusters; and a range of concentrations of trace elements. Buriganga is an urban river, meaning thousands of industries and manufacturing companies have established on the bank of the river using Buriganga as a potential source of water and their subsequent discharge arena. Municipal solid and liquid waste along with the industrial effluents and agricultural run-off gets discharged in the river water without considerable regulation procedures. Cluster 1 in both seasons also contains two major river port of Dhaka city, GT, and ST sampling stations, which also contribute to a large amount of pollution of organics and heavy metals in this cluster. Overall it can be said that, cluster 1 is mostly dominated by urban land-use together with industrial and agricultural activity of the city center. The second cluster consists of PB for winter and HS for summer. These stations are separated from others in the respective season due to their overly high concentration of dissolved ionic constituents. PB station in winter receives highly concentrated industrial effluents from nearby jute mills and other factories. HZ station has a cluster of tanneries in that area, even though tannery industries are relocating to Savar, some industries are still in operation. Moreover, the previous influence of tannery industries is also present in HS station. Therefore, PB in winter and HZ in summer falls under a separate cluster of their own for the maximum value of EC, TDS, Salinity than the other stations of Buriganga river and can be classified as industrial region. High content metal concentration is also observed in these stations. The third and final cluster comprises of the sampling station of RB and ZI both for winter and summer. Cluster 3 also comprises of urban land, with considerable amount of electronics industries along the periphery of city center. In those sampling points comparatively minimum value of EC, TDS, Salinity is found. An exceptionally high concentration of Ni in ZI station due to battery factories and factories reusing electronic waste discharge heavily nickel-containing effluents, which may be another reason for clustering ZI into this separate cluster with RB in both seasons.

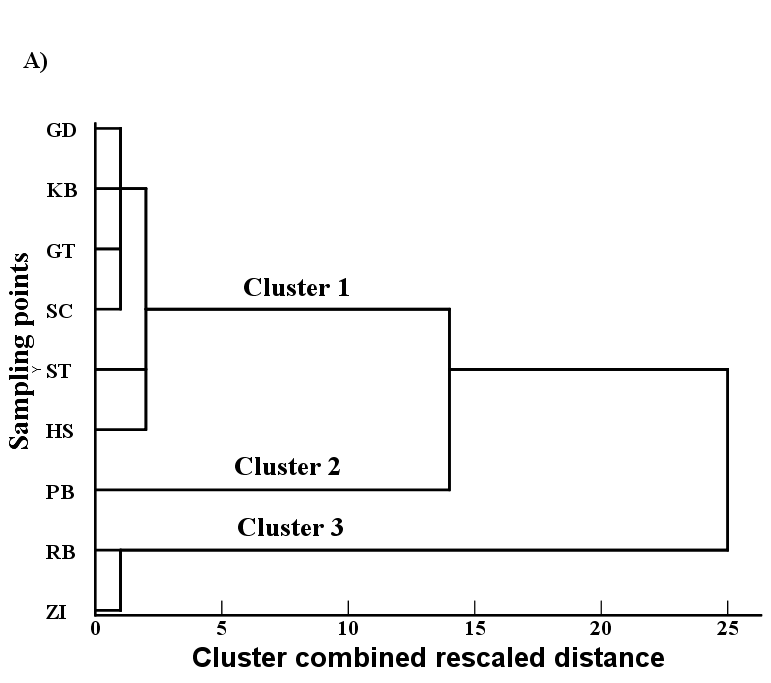
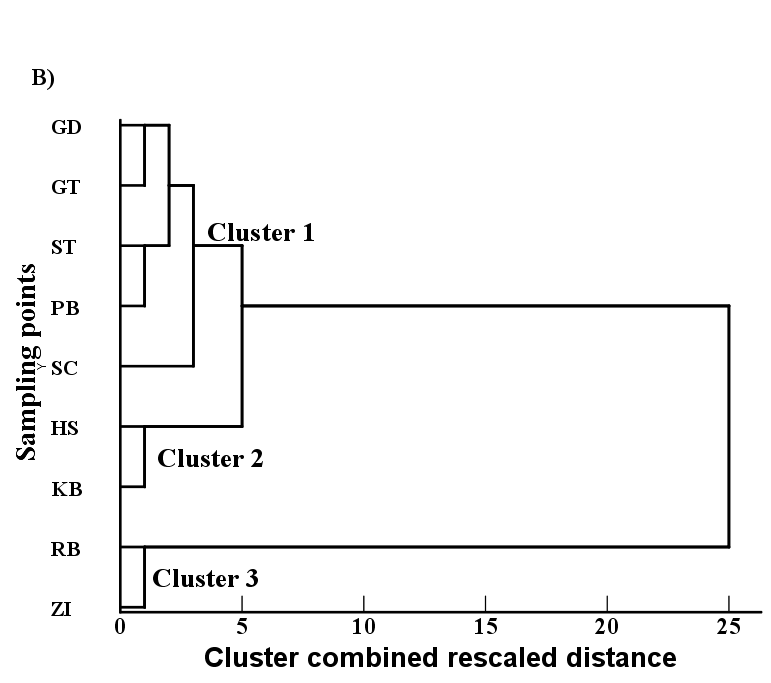
 

Fig: Dendrogram showing relation of the nine sampling stations of river Buriganga in A)winter, B)Summer.

*3.7. Water quality assessment*

3.7.1. Water Quality index

Water quality in the river systems around Dhaka are driven by effluent discharges from the thousands of factories discharging into the rivers as well as largely untreated domestic waste (Islam et al., 2016). Water quality index (WQI) for the river Buriganga is evaluated using the weighted arithmetic index method and sixteen water quality parameters (pH, Turbidity, TDS, DO, NO3-, PO43-, SO42- , Ca2+, Mg2+, Cl-, B, Cd, Cr, Cu, Zn, Ni) of nine sampling stations in two different seasons for drinking purposes. Furthermore, the water quality parameters Bangladesh standards according to Department of Public Health Engineering (DPHE) were utilized for calculations. The WQI values in Buriganga ranged from 79.79 to 4565 with an average of 701.93 which indicates the unsuitability for drinking purpose (Table 7)

Table 7: WQI values and water types of the samples

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Sampling Point | Winter | | Summer | |
| WQI | Quality | WQI | Quality |
| ST | 548.52 | Water unsuitable for drinking | 544.689 | Water unsuitable for drinking |
| GT | 156.67 | Poor Water | 248.286 | Very Poor Water |
| GD | 109.87 | Poor Water | 239.910 | Very Poor Water |
| SC | 195.13 | Poor Water | 243.401 | Very Poor Water |
| RB | 79.79 | Good Water | 124.691 | Poor Water |
| KB | 109.70 | Poor Water | 195.976 | Poor Water |
| ZI | 4565.45 | Water unsuitable for drinking | 3669.387 | Water unsuitable for drinking |
| HS | 268.31 | Very Poor Water | 467.849 | Water unsuitable for drinking |
| PB | 538.39 | Water unsuitable for drinking | 328.746 | Water unsuitable for drinking |
| Average | 730.21 | Water unsuitable for drinking | 673.660 | Water unsuitable for drinking |

In Buriganga river 40% of the sample belongs to “unsuitable for drinking” class, 20% is “very poor water”, 35% is “poor water” (Table 7, Figure 5). Only a sampling station in RB in winter shows good water 50 ≤ WQI ≤100 in winter (Xiao et al., 2019). The highest WQI is observed in ZI station in both seasons, which may be for the excess heavy metal contamination from the electronic industries located there. There is a tremendous variation among the measured parameter values in this study for the nine stations because of diverse industrial facilities and purpose of use of the river water yet all of them shows the decaying condition of one of the major rivers of Bangladesh. Seasonal variation also worsens the shape.

3.7.2. Nemerow Index

The DPHE standard values of water quality parameters to use water for drinking or irrigation are considered for determining the Nemerow Pollution Index values (Figure 6). Almost all the sampling stations of Buriganga in winter sampling delineated heavily contaminated water Pn value exceeded 1. Only one sampling station (RB) exhibits the water is under the threat of contamination 0.7 ≤ Pn ≤ 1, with Pn value 0.986. In the summer two sampling sites, GD and RB reported uncontaminated water with a Pn value less than 0.7 (Liu et al., 2015; Zhang et al.2017). All the other values in the summer season are heavily contaminated indicating the seriousness of the heavy metal pollution (Zhang et al., 2017). Nemerow index (Pn) documented a maximum value of 319.63 in winter and 245.99 in summer at the ZI sampling station indicating ‘heavy’ metal pollution (Pn≥1) (Mazurek et al., 2016; Zhang et al., 2017; Shil and Singh, 2019). The outcome of Pn indicates that anthropogenic activity gravely affects and obliterates the aquatic environment of river Buriganga. Furthermore, heavy metal pollution seen in the Buriganga river far outreaches the water quality requirements of natural surface water. Thus, the influx of pollution needs to be rigorously controlled immediately (Shil and Singh, 2019).

3.7.3. Heavy metal pollution index

The heavy pollution index (HPI) calculated with mean values of all sampling stations comes out to be 5059.879 in winter and 3952.602 in summer, which is way higher than the permissible index value (100). The value of the HPI indicates the water is completely unsafe for drinking purpose and intensely polluted with heavy metals due to anthropogenic activities such as urban industrial and municipal discharge and agricultural runoff. Heavy metal pollution index is calculated for all the sampling stations and two seasons separately (Table 8).

Table 8: Calculation of a Heavy Metal Pollution Index (HPI).

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Seasons | Elements (ppm) | Mi | Si | Ii | Wi | Qi | Wi.Qi | HPI |
| Winter | Cd | 0.287 | 0.005 | 0 | 200 | 5748.889 | 1149778 | 5060 |
|  | Cr | 0.396 | 0.05 | 0 | 20 | 793.555 | 15871.11 |  |
|  | Ni | 0.349 | 0.1 | 0.02 | 10 | 411.388 | 4113.889 |  |
|  | Cu | 0.810 | 1 | 0.05 | 1 | 80.070 | 80.070 |  |
|  | Zn | 0.478 | 5 | 0.2 | 0.2 | 5.791 | 1.158 |  |
|  | Sum |  |  |  | 231.2 |  | 1169844 |  |
| Summer | Cd | 0.224 | 0.005 | 0 | 200 | 4497.778 | 899555.6 | 3953 |
|  | Cr | 0.277 | 0.05 | 0 | 20 | 555.111 | 11102.22 |  |
|  | Ni | 0.267 | 0.1 | 0.02 | 10 | 309.861 | 3098.611 |  |
|  | Cu | 0.855 | 1 | 0.05 | 1 | 84.818 | 84.818 |  |
|  | Zn | 0.308 | 5 | 0.2 | 0.2 | 2.256 | 0.451 |  |
|  | Sum |  |  |  | 231.2 |  | 913841.7 |  |

*3.8. Human Health Risk Assessment*

**Non-carcinogenic**: According to USEPA (2005), Cd and Cr was considered for both carcinogenic and non-carcinogenic risks, while Ni, Cu and Zn were only included in the non-carcinogenic risk assessment. Non- carcinogenic health risks of Buriganga river pertaining individual hazard quotient, HQ of five heavy metals (Cd, Cr, Ni, Cu, and Zn) and combined hazard index, HI through ingestion and dermal pathways in winter and summer season was showed in table 9. The large standard deviations (SD) in the HQ and HI values observed, portrayed considerable variation in the site-wise metal concentration. The value of HQ, HI exceeding the threshold, i.e., > 1 represents the existence of heavy metal pollution and health risk of serious concern, and HI<1 indicates existence of heavy metal pollution without health risk (Xiao et al., 2019, Shil and Singh, 2019). The hazard quotient (HQ) through ingestion pathway showed in both seasons and age group, adult and children consumed Cd (adults 0.88; children 0.92) > Cu (adults 0.36; children 0.37) >Cr (adults 0.15; children 0.16) > Ni (adults 0.02; children 0.02) > Zn (adults 0.0098; children 0.0102) in winter, and Cd (adults 0.69; children 0.72) > Cu (adults 0.32; children 0.33) >Cr (adults 0.18; children 0.19) > Ni (adults 0.02; children 0.02) > Zn (adults 0.0063; children 0.0066) in summer. The HQ value for Cd in winter was very close to 1, ranged from 0.01 to 6.08 for adults and 0.01-7.07 for children, posed the highest health risk on the Buriganga river water. Individual HQ values for five heavy metals through ingestion were considerably < 1; however, their combined effects (HI) were beyond threshold limit > 1, which demonstrated that, Buriganga river water was a severe threat to the locals for chronic health issues. The High value of mean HI for ingestion was recorded in winter (adults 1.43; children 1.49) compared to that of summer (adults 1.22; children 1.26). HQ through dermal absorption in Buriganga river was excessively higher and followed a different order of severety than the ingestion pathway, Cr (adults 2.55; children 5.24) > Cd (adults 1.85; children 3.79) >Ni (adults 0.28; children 0.58) > Cu (adults 0.01; children 0.02) > Zn (adults 0.0008; children 0.0016) in winter and Cr (adults 1.78; children 3.66) > Cd (adults 1.44; children 2.97) >Ni (adults 0.22; children 0.44) > Cu (adults 0.01; children 0.02) > Zn (adults 0.0005; children 0.001) in summer. The HQ dermal for Cr and Cd far exceeded the threshold unite value, indicating serious potential adverse dermal health hazards for local community. High value of mean HI>1 for dermal contact was recorded in winter (adults 3.31; children 6.80) compared to that of summer (adults 2.44; children 5.02).

**Carcinogenic**: Incremental lifetime cancer risk (ILCR) values have been quantified based on available slope factor CSFIngestion values (in [mg kg−1 day−1]−1) for metals Cd (0.38) and Cr (0.5). According to the USEPA guidelines for both age groups of the population, when ILCR < 1.0E−06, there is no risk; if the ILCR values are in between 1.0E−06 and 1.0E−04 the carcinogenic risk is acceptable and if ILCR values > 1.0E−4, the risk is not acceptable (USEPA, 2004; Cao et al., 2017; Shil and Singh; 2019). The mean ILCR values in this study (Table 9) for Cd ((1.68E-04 for adult< 1.75E-04 for children) in winter> (1.31E-04 for adult< 1.37E-04 for children) in summer) and Cr ((3.06E-04 for adult< 3.18E-04 for children) in winter> (1.62E-04 for adult< 1.69E-04 for children) in summer) concentration reported for Buriganga river exceeded the acceptable limit > 1.0E−04, rendering the overall Buriganga river water was Carcinogenic. Except for ZI in both seasons station, all the value for ILCR for Cd for both age group was within the acceptable range of cancer risk. Unacceptable value (> 1.0E−4) of ILCR for Cr was observed in the sampling station SC in upstream in summer, and all the downstream region, ZI, ST, and PB in both seasons. However, none of the value was seen to be of cancer risk free. Thus, water in the river Buriganga should never be considered for a drinking purpose in its present condition.

Table 9: Hazard quotient (HQ) , hazard index (HI), Incremental lifetime cancer risk (ILCR) values for adults and children in ingestion and dermal pathways in Buriganga river.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Elements** | **Non- carcinogenic risk** | | | | | | | | **Carcinogenic risk** | | | |
| **Winter** | | | | **Summer** | | | | **Winter** | | **Summer** | |
| **Ingestion** | | **Dermal** | | **Ingestion** | | **Dermal** | | ILCR | | | |
| **Mean** | **Range** | **Mean** | **Range** | **Mean** | **Range** | **Mean** | **Range** | **Mean** | **Range** | **Mean** | **Range** |
| HQ Adult | Cd | 0.88 | 0.01- 6.08 | 1.85 | 0.02-14.2 | 0.69 | 0.01- 5.23 | 1.44 | 0.01-10.92 | 1.68E-04 | 1.75E-06 to 1.29E-03 | 1.31E-04 | 1.17E-06  to 9.94E-04 |
| Cr | 0.15 | 0.01-0.55 | 2.55 | 0.16-9.14 | 0.11 | 0.01-0.51 | 1.78 | 0.10-8.42 | 3.06E-04 | 1.46E-05 to 8.32E-04 | 1.62E-04 | 8.77E-06  to 7.66E-04 |
| Ni | 0.02 | 0.00-0.08 | 0.28 | 0.05-1.01 | 0.02 | 0.00-0.06 | 0.22 | 0.02- 0.82 |  |  |  |  |
| Cu | 0.36 | 0.03-0.80 | 0.01 | 0.00-0.02 | 0.38 | 0.02-0.92 | 0.01 | 0.00-0.03 |  |  |  |  |
| Zn | 0.0098 | 0.002-0.015 | 0.0008 | 0.0002-0.0012 | 0.0063 | 0.0018-0.0156 | 0.0005 | 0.0001-0.0012 |  |  |  |  |
| **HI Adult** | | 1.43 | 0.12-8.09 | 3.31 | 0.32-21.88 | 1.22 | 0.07-6.32 | 2.44 | 0.18-17.07 |  |  |  |  |
| HQ Children | Cd | 0.92 | 0.01-7.07 | 3.79 | 0.04-29.17 | 0.72 | 0.01-5.55 | 2.97 | 0.03-22.44 | 1.75E-04 | 1.82E-06 to 1.34E-03 | 1.37E-04 | 1.22E-06 to 1.03E-03 |
| Cr | 0.16 | 0.01-0.58 | 5.24 | 0.33-18.78 | 0.11 | 0.01-0.53 | 3.66 | 0.20-17.29 | 3.18E-04 | 1.52E-05 to 8.65E-04 | 1.69E-04 | 9.12E-06 to 7.96E-04 |
| Ni | 0.02 | 0.00-0.08 | 0.58 | 0.10-2.07 | 0.02 | 0.00- 0.07 | 0.44 | 0.04- 1.69 |  |  |  |  |
| Cu | 0.37 | 0.03-0.84 | 0.02 | 0.00-0.05 | 0.39 | 0.02-0.96 | 0.02 | 0.00-0.60 |  |  |  |  |
| Zn | 0.0102 | 0.0025-0.0161 | 0.0016 | 0.0004-0.0025 | 0.0066 | 0.0019-0.0162 | 0.001 | 0.0003-0.0025 |  |  |  |  |
| **HI children** | | 1.49 | 0.13-8.41 | 6.80 | 0.67-44.96 | 1.26 | 0.07-6.58 | 5.02 | 0.37-35.06 |  |  |  |  |

**4. Disscussion**

*4.1 Pollution status of the river*

4.1.1. Physico-chemical properties

The rates of biological and chemical processes depend on temperature. pH determines the corrosive nature of water (Bhateria and Jain, 2016). The studied river water was more or less neutral with a hint of strong acidity in sampling station ST. pH values are relatively low during the summer season. Excessive organic pollution by sewage water and different industrial waste might be the reason for low pH in the lower part of the river, as they increase decomposition in water which in turn lower the pH. The average studied EC in river water was 1234.06 μS/cm where the DoE standard for drinking water is <300 μS/cm and for irrigation <1200 μS/cm, and for industrial effluent not beyond 1200 μS/cm and hence river water at the sampling points were not suitable for drinking, irrigation, and industrial purpose. EC values of the water are gradually increasing with time which can be because of high total dissolved solids from received wastewater (industrial and sewage effluent) and agricultural runoff due to the additional chloride, phosphate and nitrate ions (Wetzel, 2001). The river water is so dark black that it looks like burned engine gasoline (Uddin and Jeong, 2021). The average turbidity value in winter was 61.83 NTU and in summer where the average value was 200.56 NTU Where, the drinking water standard of turbidity should not exceed 1 NTU and 10 NTU respectively (WHO, 2011; DPHE, 2020). High turbidity is linked to low DO and thus low photosynthesis that adds oxygen to the water.

Dissolved oxygen concentration in Buriganga was alarmingly low (0 mg/l in ST and ZI point) in both seasons with a mean of 0.99 mg/l in cpmarison with DoE drinking water standard of 6 mg/l. ST point showed the lowest value of DO (0 mg/l) during winter because of higher micro-organisms grown in lower level stagnant water during this dry season. ST sampling station is also a BIWTA launch terminal discharging an extensive amount of untreated oil and passenger wastes which declining DO values of water. Considering the DO values, some suggest that the Buriganga river water is biologically dead and not suitable for fishing as well as stressful for most of the aquatic organisms (WRC, 2016). The pollutants are severely harming the quantum of dissolved oxygen (DO) in this river, making it impossible for fish and other aquatic organisms to live in them. At present, the Buriganga river is considered almost no presence of fish among some of the major polluted rivers around the world. High TDS influences the changing of natural taste and demonstrates the existence of toxic minerals (Whelton et al., 2007). According to WHO standard, the maximum limit of TDS is 600 mg/l and according to USEPA, the maximum limit is 500 mg/1, on the contrary, the mean Buriganga river concentration of TDS was 733.94 mg/l making water more turbid and saline that has an inverse effect on aquatic lives and crops as well as unsuitable for drinking (WHO, 2011). However, according to DoE and DPHE, the value is 1000 mg/1, which implies that some samples were within the limit (DPHE, 2020). With increasing EC and TDS value, DO value decreases probably due to the increase of ionic constituent as well as organic matter in the water body. The mean COD of Buriganga river was 204.83 mg/l which refers to the higher organic pollutants (Sarkar et al, 2015), which was responsible for the total increase the microbial decomposition which in turns might cause oxygen depletion to a level detrimental to aquatic life (Ravindra and Kaushik, 2003). The standard value for COD is 4 mg/l (DoE, 1997; Islam et al., 2016). Thus, the water of the river Buriganga is not suitable for domestic use, let alone drinking (Uddin et al., 2016). The household and industrial wastages are drained into the River which stimulates the growth of micro-organisms and thereby increasing the COD value in the river water body.

The mean salinity was 626.11 mg/l. Salinity increases with the increase of pH in water. Total suspended solids (TSS) are a total quantity measurement of solid material (all suspended solids, organic and inorganic, by mass) per volume of water. Suspended solids can work as porters of toxins, which readily adhere to suspended elements. The average TSS was 264 mg/l in winter and 350.33 mg/l in summer. Suspended particles can come from soil erosion, runoff, discharges, stirred bottom sediments, or algal blooms. Excessive suspended sediment can impair water quality for aquatic and human life, impede navigation, and increase flooding risks (Wood, 2014). DPHE standards for TSS to maintain the aquatic ecosystem are 10 mg/l and hence all the samples exceeded the standard value suggested by DPHE (DPHE, 2020).

4.1.2. Ionic status of water

Biologically available forms of Nitrogen, includes nitrate, or ammonium in water reservoir can cause eutrophication which can prevent oxygen from entering into the water, generating it hypoxic and forming a dead zone for fish (Murshed et al., 2020). Ammonium Ion (NH4+) is not toxic to fish biota like unionized dissolved ammonia gas (Downing and Merkens 1955), however the NH4+ concentration of river water in both seasons ranging from 2.1 to 11.2 mg/L; exceeded the admissible limit of 1mg/L in both seasons (WHO, 2017). The concentration of nitrate (NO3-) in the Buriganga was found to be within the standard limit of 50 mg/L in all the sampling stations. The concentration of K+, Ca2+, and Mg2+ was high during the winter season. On the other hand, concentrations of these cations were comparatively low in water during the summer season. However, all the values of major cations were inflated than the standard for drinking water of Bangladesh. In a previous study, Jolly et al., (2012) observed comparatively lower K+, Ca2+, and Mg2+, values in an unpolluted area of the Buriganga river. The DPHE standard for K+, Ca2+, Mg2+, and NH4+ are 12 mg/l, 75 mg/l, 30-35 mg/l and 0.5 mg/l, respectively. All the anions were within the safe limit except nitrate (NO3-), chloride (Cl-), and boron B(OH)3-. Jolly et al. (2012) found the concentration of nitrate (NO3-), chloride (Cl-), phosphate (PO43-), and sulfate (SO42-) on an unpolluted site of Buriganga was 5.68 mg/l, 15.6 mg/l, 0.019 mg/l, 0.057 mg/l respectively. The augmented values in this study show the increased pollution in the investigated area. Except at station RB in winter nitrate concentrations were higher and in all station’s chloride concentrations were lower than the admissible limit of DPHE throughout the year of Buriganga river. So, the water of the Buriganga river has nitrate pollution identical to the findings reported by Moniruzzaman et al., (2009).

4.1.3. Status of heavy metals in the water samples

Cr, Cd, and Ni showed slightly lower concentration in summer than winter, which might be because of the dilution of river water by precipitation and river influx. Drinking water standard for Cr, Cd, Ni, Cu, and Zn are 0.05, 0.005, 0.1, 1, and 5 mg/L according to DPHE and 0.05, 0.003, 0.07, 2, and 5 mg/L according to WHO (WHO, 2017). Except for Cu and Zn, all other values exceed the standard limit for both seasons. A similar study was conducted in Buriganga river by Sarkar et al. (2015) and the metal concentration of Cr, Cd, Ni, Cu, and Zn were ranging 0.0306-0.2163 mg/l, 0.0018-0.0162 mg/l, 0.0663-0.2486 mg/l, 0.0112-0.0238 mg/l, and 0.0878-0.2948 mg/l, respectively, almost throughout the year. Whitehead et al. (2019) found a high amount of Cr, Cd, Cu, and Pb pollution in the several sampling points of the Buriganga river system. In the present study, except for Cu, all the metals showed greater concentration in Winter. In comparison to the standard value and the mean studied heavy metals are tremendously inflated, i.e., Cd ̴ 57× in winter and Cd ̴ 49× in summer; Cr ̴7× in winter and Cr ̴5× in summer; and Ni ̴3× in both seasons. Table 11 displayed a relative comparison of trace metal concentration among some major rivers of the world. The mean concentration of heavy metal in Buriganga in comparison to the world average river metal concentration displays the magnitude and amplification of metal pollution in the studied sites; Cd ̴ 3202×, Cr ̴481×, Ni ̴385×, Cu ̴562×, and Zn ̴655× (Gaillardet et al., 2003).

Table 10: Comparison of heavy metal status.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Name of water body** | **Cd (mg/L)** | **Cr (mg/L)** | **Ni (mg/L)** | **Cu (mg/L)** | **Zn (mg/L)** | **References** |
| Buriganga, 2010 | 0.00934×10−3 | 0.5872×10−3 | 0.0088×10−3 | 0.16309×10−3 | - | Ahmad et al., 2010 |
| Buriganga, 2015 (mg/l) | 0.01232×10−3 | 1.6401×10−3 | 0.16694×10−3 | 0.01912×10−3 | 0.19724×10−3 | Sarkar et al., 2015 |
| Buriganga, 2019 | 0.004×10−3 –0.072×10−3 | 0.00057×10−3-0.00317×10−3 | 0.00121×10−3–0.003177×10−3 | 0.000947×10−3–0.009053×10−3 | 0.003148×10−3–0.019916×10−3 | Whitehead et al., 2019 |
| Buriganga, 2018 this study | 0.256×10−3 | 0.337×10−3 | 0.309×10−3 | 0.833×10−3 | 0.393×10−3 | This study |
| Mahananda River, India | 0.0001×10−3 - 0.0005×10−3 | 0.00032×10−3- 0.00231×10−3 | 0.00034×10−3 - 0.00143×10−3 | 0.00118×10−3 - 0.00464×10−3 | 0.00195×10−3 - 0.01832×10−3 | Shil and Singh, 2019 |
| Catalan River, Spain | 0.0012×10−3 | 0.0024×10−3 | 0.0027×10−3 | 0.0013×10−3 | 0.0019×10−3 | Carafa et al., 2011 |
| Chinese Loess Plateau rivers | 0.00005×10−3 - 0.00031×10−3 | 0.0004×10−3- 0.106×10−3 | 0.00144×10−3 - 0.04471×10−3 | 0.00048×10−3 - 0.0528×10−3 | 0.002×10−3 -0.0833×10−3 | Xiao et al., 2019 |
| Tigris River, Turkey | 0.00437×10−3 | 0.005×10−3 | 0.045×10−3 | 0.165×10−3 | 0.037×10−3 | Varol and Sen, 2012 |
| Huai River, China | 0.6174×10−3 | 0.02308×10−3 | 0.0462×10−3 | 0.05232×10−3 | 11×10−3 | Wang et al., 2017 |
| Chinese Loess Plateau well waters | 0.000005×10−3 - 0.00009×10−3 | 0.00009×10−3- 0.244×10−3 | 0.00087×10−3 - 0.516×10−3 | 0.00151×10−3 - 0.9966×10−3 | 0.0023×10−3 - 0.895×10−3 | Xiao et al., 2019 |
| Xiangjiang River, China | 0.0134×10−3 | 0.00661×10−3 | 0.00147×10−3 | 0.2033×10−3 | 0.0846×10−3 | Zeng et al., 2015 |
| Dan River, China | 0.0007×10−3 | 0.0001×10−3 | 1.68×10−3 | 0.0012×10−3 | 0.00783×10−3 | Meng et al., 2016 |
| World average | 0.00008×10−3 | 0.0007×10−3 | 0.0008×10−3 | 0.00148×10−3 | 0.0006×10−3 | Gaillardet et al., 2003 |

The results of water quality index showed on RB station in winter falls under the category of ‘good water’ for drinking purpose. All the southern part of Buriganga river sampling points exhibited a water quality ‘unsuitable for drinking’, which point to the overly unregulated urban industrial activities in the periphery of the river. The middle part of the river water quality is poor to very poor, according to WQI. Similarly, the Nemerow index identified Buriganga river is heavily contaminated (Pn≥1) with soluble salts, organics, and heavy metals in both seasons. The peak polluting element among all is Cd. In line with the results of WQI, the nemerow index also had a high Pn value in the downstream of the river where industrial activities are maximum, with the highest value in ZI station throughout the year. Even the only station RB with a lower value of Pn is under threat (0.7 ≤ Pn ≤ 1) of metal pollution. According to HPI results in this study, the overall water quality of the river is at its nadir. The spatial interpolation (fig 6) of index results identified a similar pattern with a ‘hot spot’ in the southern portion of the river basin, which is the location of the urban industrial zone. From the results of index analysis, Buriganga river water should never be considered for domestic use, let alone drinking, especially in the southern part, in its present condition.

The results of water quality index showed only RB station in winter falls under the category of ‘good water’ for drinking purpose. All the southern part of Buriganga river sampling points exhibited a water quality ‘unsuitable for drinking’, which point to the overly unregulated urban industrial activities in the periphery of the river. The middle part of the river water quality is poor to very poor, according to WQI. Similarly, the Nemerow index identified Buriganga river is heavily contaminated (Pn≥1) with soluble salts, organics, and heavy metals in both seasons. The peak polluting element among all is Cd. In line with the results of WQI, the nemerow index also had a high Pn value in the downstream of the river where industrial activities are maximum, with the highest value in ZI station throughout the year. Even the only station RB with a lower value of Pn is under threat (0.7 ≤ Pn ≤ 1) of metal pollution. According to HPI results in this study, the overall water quality of the river is at its nadir. The spatial interpolation (fig 6) of index results identified a similar pattern with a ‘hot spot’ in the southern portion of the river basin, which is the location of the urban industrial zone. From the results of index analysis, Buriganga river water should never be considered for domestic use, let alone drinking, especially in the southern part, in its present condition.



Figure 6: Indices explaining variations of Water Quality Index and Nemerow Pollution Index.

*4.2. Pollution sources*

Pollution sources of Cr and Zn followed a similar pattern in this study. The high Cr value confirms that the pollution originating from tannery waste is crucial. Numerous tannery industries had been established on the bank of Buriganga and been operating without any proper effluent treatment plants for years, which in turn was responsible for Cr pollution in Buriganga. Although only recently, to reduce the pollution load, tannery industries have been relocated to Savar, few industries are still in operation near HB. Other sources of chromium and zinc may be electroplating, cement paint, rubber, etc. manufacturing industry located around the river Buriganga. Zinc (Zn) is an essential micronutrient for the plants and plays a vital role in the catalytic activities of several enzymes.. However, a higher concentration of Zn than the regulatory standard in potable water could result in toxicity. Cr and Zn are significantly correlated to each other (<0.05), and their interrelation was confirmed in the PC1, meaning these two metals have a similar source of origin and distribution pathways.

The administration of agricultural byproducts such as fertilizers, pesticides, and biosolids (sewage sludge), the dumping of industrial wastes or the deposition of atmospheric contaminants escalate the total concentration of Cd in water According to principal component analysis, the source of Cd in the Buriganga river is different from other metals and is an element of the second component, PC2.

Nickel in Buriganga is generated from an isolated source in winter, based on the inference made by correlation analysis. In the winter PCA, Ni is the only component of PC6 and unrelated to the source of other metals. Dockyards in the river-bank and a launch terminal at ST and GT point may be a source of high concentration of nickel in these stations (Sarkar et al., 2015). Major anthropogenic sources of Ni around Buriganga river are nickel alloys, including stainless steel, electroplating, catalysts, discarded batteries, electronics, chemical, petroleum, metal product, ceramics, and paints industries (Massoura et al., 2006; Shil et al., 2019). The concentration of Ni in this study exceeds the standard value and indicates extreme Ni pollution in river Buriganga. Copper (Cu) have a geogenic source of origin, through processes like hydro-chemical reactions of soil weathering of rocks and geological metamorphosis. Cu in drinking water comes from Cu pipes, pesticide production, chemical industry, metal piping, as well as from additives designed to control algal growth (Xia, 2018). The source of Cu is similar to the source of Ni in the summer season; seasonal variation in industrial activity might play an influencing role.

***4.3. Human Health Risk***

Table 7 shows the average daily dose (ADD) value of each heavy metal studied in winter and summer season. The table 8 represents the HQ and HI values for river water samples, where value ≥1 represents the existence of heavy metal pollution and health risk, and HI<1 indicates existence of heavy metal pollution without health risk (Cao et al., 2017; Singh et al., 2018). The risk analysis shows that both age groups, adults and children, consume and absorb heavy metals in a different order, although both groups exhibited high risk from dermal contact than direct ingestion and children are in escalated risk of metal exposure than the adults, however regardless of age groups peoples are at a very high risk of metal pollution from the water of river Buriganga. Hazard index followed the order of health risk, i.e. Ni> Cu> Cr> Cd> Zn for children and Ni> Cu> Cd> Cr for adults. Only health risk of Zn for adults showed a value HI<1 indicates existence of heavy metal pollution without health risk. Using geospatial maps, the spatial distribution along the sampling stations have been shown in Figure 7. Variations of HI values at different sampling stations are geospatially shown in the map (Figure 7).



Figure 7: Indices explaining variations of HI for adult and child in winter and summer.

Results from table 9 showed that Ni has the highest average value of health hazard. HI for Ni in all the stations exhibited a value way higher than the baseline value 1. Dermal hazard poses the dominant risk similar to other metals and contributed most in hazard index count. GT and ZI have health risk through ingestion for children and all the sampling stations has dermal hazard via Ni. Cu has an existence of metal pollution and risk of health injuries in all the stations except for SC. Cr has the next highest mean value of HI for children in ST, GT, SC, ZI, and PB in winter and ST, SC, ZI, and PB in summer. It is recognized as a potential carcinogen for human beings worldwide (AWWA, 2013). For adults ST, SC, ZI, and PB in winter and ST and ZI had a value HI≥1. Adults are more susceptible to Cd pollution than the children, though only sampling stations ST in winter and ST, ZI, HB, and PB displayed High Cd health risk. Though most of the sampling stations in both showed seasons exhibited hazard index greater than baseline value 1, Zn has the minimum mean value for HI due to its consistency near 1. Carcinogenic risk due to Cd and Cr consumption from river water also proved to be not acceptable in some sampling area, whereas all the other sampling station have acceptable amount of risk present, which can further bioaccumulate and magnified toward cancer in human body. Aquatic organisms, especially fish, accumulate heavy metals such as Cr, Cd in their tissues and organs in higher quantities than those found in the ambient water (Turko˘glu and Parlak, 1999). So, this pollution causes various serious negative effects on some organisms such as fish and these are carried over to the human body through the web food (Yayıntas et al., 2007).

HQ ingestion, HQ dermal, HI, and ILCR values for children are higher than adults (Table 8), showing that children are more vulnerable than adults when exposed to the same environment. Therefore, residents especially sensitive children should pay special attention to Buriganga river water especially for bathing purposes as dermal injury risk from the studied metals are dominant. Low-level exposure of heavy metals can irritate the skin and cause ulceration. Long-term exposure can cause kidney, circulatory system, and liver damages. The health risk reduction of the river water can be incentivized by several cost and non-cost approaches for exterminating heavy metals or by reducing the dependency on the river water for household purposes.

**5. Conclusions**

The present study concludes that water samples collected from river Buriganga accumulate various ions and metals at concentrations more than the maximum permissible limits pointing unsuitability for any kind of use. A moderate concentration of most of the physical-chemical and ionic properties i.e. Temperature, EC, TSS, TDS, DO, COD, Turbidity, Salinity, K+, B(OH)3-, NO3-, SO43-, Cl- are observed to be leading in the summer season except for pH, NH4+, PO4-, Ca+, Mg+. Elevated temperature and rainless summer before sampling may be the reason behind this. However, heavy metals (Cd, Cr, Ni, and Zn) showed greater concentration in winter. Excessive metal pollution in Buriganga showed mean Cd, Cr and Ni concentrations in winter were 0.29 mg/l, 0.40 mg/l, and 0.35 mg/l respectively; which were more than 50 times, 5 times and 3 times respectively in comparison with the individual standard for provided by DPHE. Heavy metal pollution and their cumulative effect on the river and surrounding environment is assessed using water pollution index, Nemerow index method, heavy metal pollution index, the risk to human health is assessed with the USEPA model. A set of statistics including Pearson correlation, principal component analysis, cluster analysis methods are also used to classify the concentration of metals to their possible origin. Unimaginably high WQI, HPI, and Pn in the river are related to the tannery, metal, and other industrial and sewage inputs, as well as oil exploitation at both ends of the river. The outcome of all the indices indicates that the urban industrial activity gravely affects and obliterates the aquatic environment of river Buriganga. For the health risk assessment, as was the primary contaminant to human health, an order of Ni> Cu> Cr> Cd> Zn for children and Ni> Cu> Cd> Cr for adults are followed. Dermal hazard poses the dominant risk in all the metals and contributed most in hazard index count. Moreover, Children are more susceptible to metal pollution than adults. Cd and Cr possess high cancer risk, especially for children. Pearson’s correlation, PCA and cluster analysis reveal that Cr and Zn, and the organic pollution of the river have a similar source of origin. The main source of Cr pollution in river water is tannery industries. Buriganga River had received waste from numerous tanneries in Hazaribagh, until 2018. Despite the resettlement of all the tannery industries, Buriganga still flows as squalid as it did before; its oxygen level is still five times below the acceptable level. Cd remains in the most polluted concentration and has a similar source like dissolved salts. Ni showed no significant correlation with other trace elements in the winter season, indicating a completely different source in the river. Principal component analysis portrayed analogous result of correlation analysis, validating the source analysis result, the southern points of Buriganga sampling points exhibited the maximum metal pollution, due to the presence of all kinds of urban industries. Low level of water and shortage caused by insufficient rainfall, unceasing input of industrial effluents and sewage water, the poor planning with the old methods used in irrigation is the main obstacle behind rivers natural self-purification. The results of the analyzed physical, chemical parameters for index calculation supported the low water quality observed. We recommend long-term monitoring and contamination control management system as well as setting up central effluent treatment plants at the industrial clusters, including the export processing zones (EPZs) to recover this overly polluted aquatic ecosystem.

References