



# Heavy metal pollution through hand loom–dyeing effluents and its effect on the community health

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## Abstract

Kumarkhali upazila in Kushtia district of western Bangladesh has become especially vulnerable to dye-effluent pollution over the last two decades. Twenty dyeing effluent samples were obtained at random from various dyeing units and used to determine the heavy metal concentration. The effluent pH, electrical conductivity and total dissolved solids ranged from 3.69 to 13.68, 627 to 7160 mS cm<sup>-1</sup> and 4140 to 19800 mg L<sup>-1</sup>, respectively. In dyeing effluents, the average concentrations of Zn, Cu, Pb, Mn, Fe and Cr ions were 5.50, 82.75, 6.80, 14.27, 66.03 and 65.28 µg mL<sup>-1</sup>, respectively, while the amount of Cd was barely detectable. Total annual discharges of Cu, Zn, Pb, Mn, Fe and Cr were found to be 21.52, 1.43, 1.77, 3.71, 17.12 and 16.98 kg year<sup>-1</sup>, respectively, which were high enough to pollute the local environment. According to the survey report, only a minority were aware of public safety measures and proper disposal procedures, though many respondents were conscious of the dangers associated with dyes and chemical substances. Most interviewees (58.33%) used synthetic dyes and other dangerous chemicals throughout the dyeing process, despite the fact that 43.33% did not use hand gloves. A remarkable 80% of respondents were improperly disposing of unused dyes and chemicals. Overall, there was a lack of awareness, right attitude and appropriate behavioural patterns about using dyeing chemicals. To prevent the negative effects of dyeing effluents on the community in the research area, environmental conservation rules should be appropriately implemented.

**Keywords** Hand-loom · Dyeing effluents · Kumarkhali upazila of Kushita, Heavy metals · Western Bangladesh

## Introduction

Water and soil contamination has a detrimental influence on the ecosystem, wildlife, and human health. Contaminations occur as a result of a variety of pollution-promoting activities carried out by both point and non-point sources, including industrial effluents, factory solid waste discharge,

automobile exhaust, dissolvable salts, agrochemical use, and the disposal of mechanical and metropolitan wastes in the biological system (Zakir et al. 2008; McGrath et al. 2001; Nriagu and Pacyna 1988; Schalscha and Ahumada 1998). It is a significant concern associated with dumping heavy metal-containing industrial effluents into waterbodies and soils because of the metals' environmental persistence and carcinogenic characteristics (Garbisu and Alkorta 2001; Gisbert et al. 2003). Heavy metals such as Cr, Pb, Cd, and As exhibit outrageous toxicity even at trace levels, and they are shown to harm the water-biological system and soil-plant ecosystem (Rahim et al. 2016; Akter et al. 2010; Türkmen et al. 2009). It is well-known that biologically destroying metal elements is likewise challenging due to their affinity for altering their oxidation state (Gisbert et al. 2003; Garbisu and Alkorta 2001). The most well-known aquatic poisons are heavy metals, and their presence in waterways and biota implies their natural or human origins (Ali et al. 2019). Their aggregation and distribution in soil, water, and other biological compartments continue to accelerate, resulting in

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sedimentation and deposition in water bodies, threatening sea-going species (Hobbelen et al. 2004; Koukal et al. 2004).

The textile and loom-dyeing industries of Bangladesh have expanded rapidly in recent years. These industries effluents are released unpredictably, either directly or after mixing with domestic wastewater. The widespread usage of these wastewaters on agricultural fields in distant areas of Bangladesh has resulted in the bioaccumulation of metals in cereals and vegetables (Saha et al. 2021; Sharma et al. 2007). When industrial waste-effluents are incorrectly managed and disposed of, they may constitute a severe threat to human health and the environment (Khan et al. 2001). The textile and dyeing industry is a significant environmental concern due to the large quantity of water and dyes needed throughout the production process (Rahman et al. 2020). The effluent dyes reduced from these industries are composed chiefly of many synthetic compounds. Copper, Zn, Cr, and Cd are the most significant metal pollutants created by metal-dye complexes and by Cr salt, an oxidising agent used in sulphur dyeing (Chavan 2001). Prolonged exposure to these hazardous heavy metals may cause serious health issues in humans (Yusuff and Sonibare 2004). The indiscriminate discharge of industrial dye wastewater also incorporates harmful metals into several environmental compartments, degrading the suitability of surface water (Ouali et al. 2018; Khan et al. 2008). On the other hand, health risks related to dyes' exposure depend on the employers' proper attitude towards the significant influence of dye effluents on humans and the environment (Rahman et al. 2020; Paramasivam et al. 2010). Many dyeing employees come into regular contact with chemical dyes due to their lack of information and negative attitudes to their detrimental consequences (Rahman et al. 2020; Paramasivam et al. 2010; Halidiya et al. 2005). As a result of dyeing chemical exposure frequently, several common ailments such as respiratory problems, skin allergies, and musculoskeletal disorders have appeared (Upadhyay and Pandey 2016). Thus, in the present world, one of the most significant challenges is to protect industrial employers' health and safety (Ghiasi and Ghiasi 2017).

Kumarkhali in the Kushtia district is a significant hub for the Bangladesh Handloom Board, with about 5020 handloom factories and 11,288 loom units situated here, but 20% of loom units are unproductive (BBS 2020). The majority of handloom factories and loom units in Kumarkhali are lack of adequate dyeing facilities. Each year, the dyeing industries in this region generate many effluents deposited straight into the neighbouring soil, farmland, and surface water, eventually ending up in the Garai river stream, a major waterway of this area. As a result, a huge number of villagers are now at risk due to pollution. Contamination of water and soils by different metallic and non-metallic chemicals is quite widespread in the country's dyeing industrial zones. Metallic salts and basic and acidic chemicals

are the most common inorganic contaminants. In the land and river, these inorganic components interact chemically and biochemically, degrading the water and soil quality of the surrounding area. As a result of this environmental contamination, the population of Kumarkhali upazila is now going to be threatened. Because of the above, this study was planned to fulfil two major objectives: (i) to determine the concentration of different heavy metals and to estimate their annual discharge load of hand-loom dyeing effluents of the study area, and (ii) to assess the impact of handloom dyeing industries on local community by studying their knowledge, attitudes and behavioural patterns regarding dyeing chemical usage. This study will contribute to the scientific community in two ways: (i) by giving information on pollution levels in the study region as well as their community health impacts and (ii) by establishing a clear perspective on future awareness for good policy-making that would protect the environment. As this research is the pioneer in this area, the authorities may soon propose a new level of environmental safeguards for dyeing industry contamination.

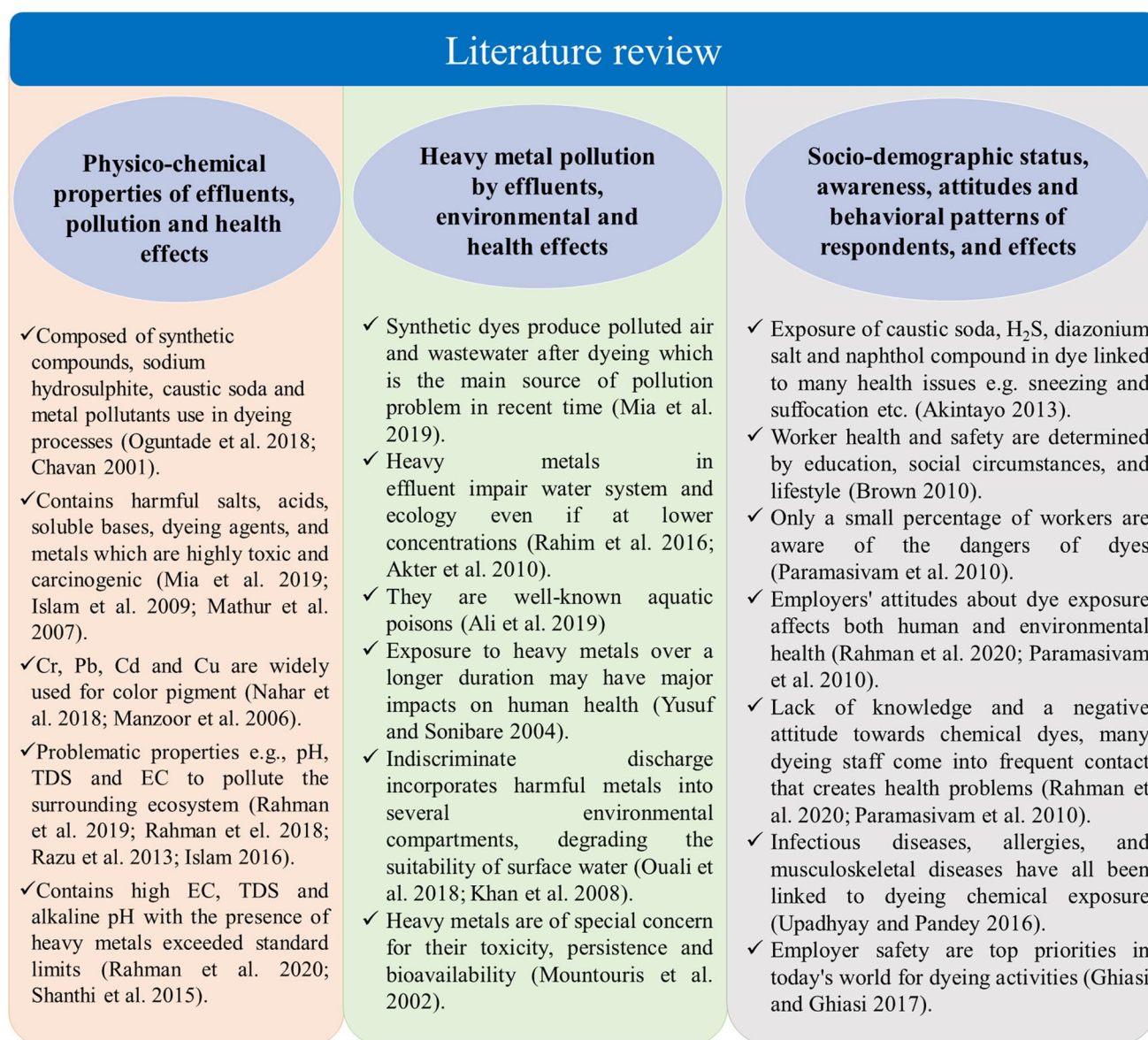
## Literature review

Our research is very first in the study area. Some literatures on health impacts on dyeing effluent pollution are available to support our study. Massive amounts of natural resources are wasted in deforestation and agriculture, causing environmental damage (Muhammad et al. 2021). Generally, the textile industries use a variety of potentially hazardous substances. Some of these compounds have been shown to accumulate in the body and are even carcinogenic (Azeez 2001). Azo dyes and reactive dyes are two examples of commonly used dyes in the textile industry that have been or are currently in use (Christie 2001). Sodium hydroxide, NaClO, Na<sub>2</sub>S, HCl and reactive dyes are some of the most essential chemicals in the dyeing and bleaching industries (Oguntade et al. 2018). A significant portion of dyeing chemicals is discarded as liquid, solid and gaseous waste, resulting in contamination of the water, land and air (Prabakaran and Thangavel 2002). Rahman et al. (2020) and Akter et al. (2010) found Pb concentrations as more than DoE wastewater standard levels, but some trace elements were found to be below the allowed range. Lead, Cd, Cu and Cr are often utilized in the manufacture of colour pigments for textile dyes and are hence frequent pollutants (Manzoor et al. 2006).

The liver glycogen and blood glucose levels of fish show that the water in the dam is more hazardous to them than the water downstream (MSE 2002). The most prevalent concern associated with reactive dyes is respiratory problems caused by dye particle inhalation. Occasionally, they might impair a person's immune system, which can result in a strong reaction when the individual inhales the

dye repeatedly. This is referred to as respiratory sensitisation, and itching, watery eyes, sneezing and asthmatic symptoms such as coughing and wheezing are common symptoms (Ahmed et al. 1998). Substances that are harmful when moist, such as  $\text{Na}_2\text{S}_2\text{O}_4$ , may induce violent reactions (Hydros). Hot liquids may result in scorching injuries (Ahmed et al. 1998). Dye and metal compounds cause both direct and indirect toxicity in the form of cancer, allergies and inhibition of development at various trophic levels (Kant 2012). Some of the dyeing effluents of textile industries act as irritant to the mucous membrane of the respiratory tract, and they may cause anything from slight bronchial irritation to a fatal pulmonary oedema (DoE 2008). Discharge of dye-containing effluents into the water

environment is undesirable not only for their colour, but also because many of the dyes released and their breakdown products are toxic, carcinogenic, or mutagenic to living organisms, primarily due to carcinogens such as benzidine, naphthalene and other aromatic compounds (Suteu et al. 2009; Zaharia et al. 2009). Apart from dyes, the principal sources of heavy metals in waste water include different salts and chemicals. Sediments, suspended particles and dissolved solids all act as reservoirs for harmful heavy metals and dyes, rapidly depleting dissolved oxygen and resulting in oxygen sag in the receiving water (Alihameed and Ahmed 2008). Alongside these above literatures, we found some related studies which are presented below (Fig. 1).



**Fig. 1** Literature review of the study

## Materials and methods

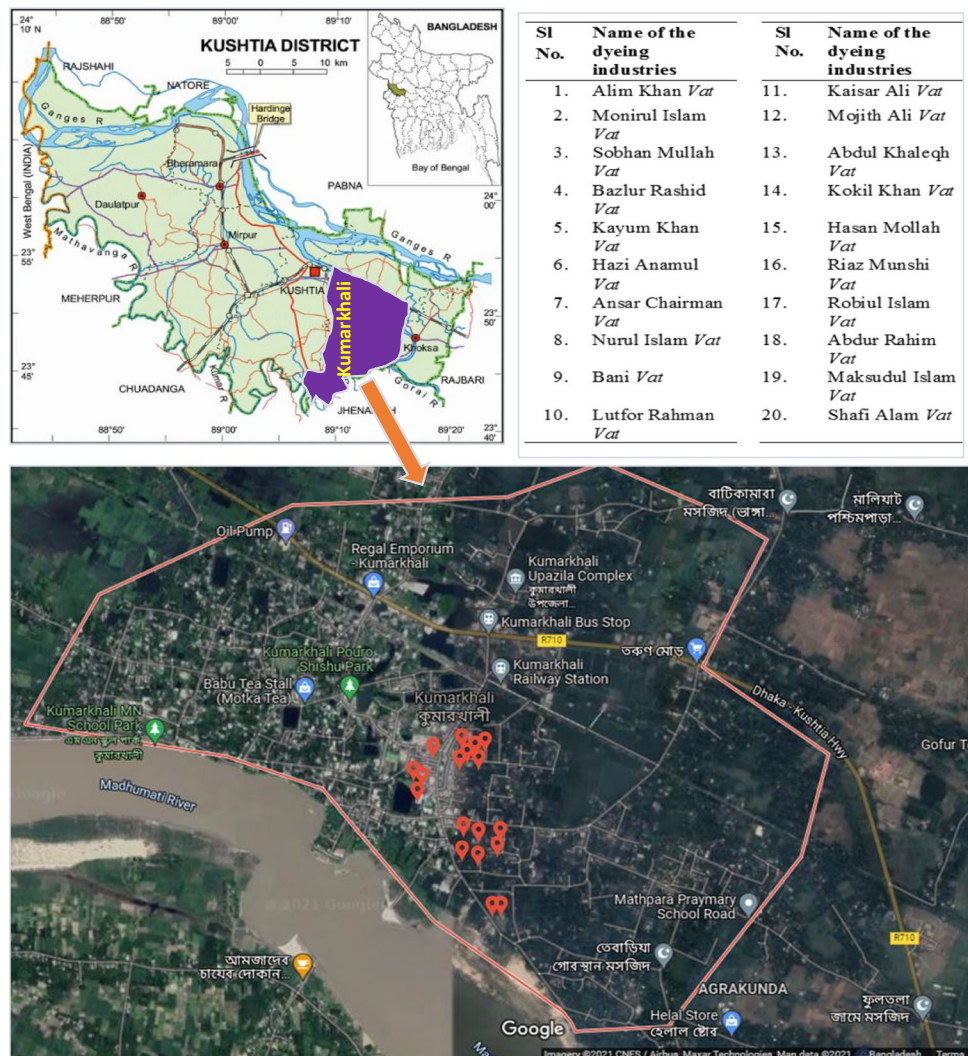
### Geographical information of study area

Kumarkhali is an upazila of Kushtia district in the division of Khulna, Bangladesh. Kumarkhali is located at 23.8542° N 89.2417° E having the total area of 286.77 km<sup>2</sup> (BNIW 2022). Among the total area, 10.5 km<sup>2</sup> is municipality area (BBS 2020). This upazila is bordered on the east by Kushtia’s Khoksa upazila, on the west by Kushtia Sadar upazila, on the north by Pabna Sadar upazila and on the south by Jhenaidah’s Shaikupa upazila. According to Bangladesh National Information Window (BNIW 2022), Kumarkhali had a population of 3,41,255 having a literacy rate of 82.07%. There are two rivers, i.e. Garai and Padma, in this area. Major crops in this area are paddy, jute, sugarcane and wheat.

### Sampling

Twenty locations were selected for sampling of dye effluents. Three samples were collected from each location of various loom-dyeing industries in Kumarkhali, Kushtia, as seen in Fig. 2. Because of personal dyeing protection of the industry’s owner, their precise global positioning system (GPS) cannot be specified here. Dyeing-effluent samples of about 500 mL were collected from each location in plastic bottles rinsed previously (APHA 2012). It was winter of the year 2016 for sampling because of ensuring dry weather to avoid rainy water. To avoid air exposure of the samples, the bottles were immediately sealed and brought to the laboratory. Then, HNO<sub>3</sub> (3–4 drops) was added to stay away from any growth of microbes. The chemical analyses of the samples were performed at the post-graduate laboratory of the Department of Agricultural Chemistry, Bangladesh Agricultural University, Mymensingh.

**Fig. 2** Collection sites for dyeing effluent samples in Kumarkhali upazila, Kushtia, Bangladesh



## Analytical methods used for dyeing effluents

The temperature, pH, total dissolved solids (TDS), and electrical conductivity (EC) of the effluent samples were measured by the electrode of thermometer, pH, EC, and TDS meter (Model-HACH sensION™ + EC5, USA), respectively (Singh and Parwana 1999; Ghosh et al. 1983). An atomic absorption spectrophotometer (AAS) (SHIMADZU, AA-7000; Japan) was used to estimate the trace metals' concentration with a standard set-up (Supplementary Table 1). For chemical analyses, precisely 10 mL of the effluent sample was digested with 10 mL of the tri-acid mixture ( $\text{HNO}_3$  :  $\text{H}_2\text{SO}_4$  :  $\text{HClO}_4 = 10 : 1 : 4$ ) in digestion tube using standard methods. The digest was then filtered using filter paper (Whatman no. 42), and 100 mL of the filtrate was rendered using purified water (Rahman et al. 2020). Quality assurance (QA) or quality control (QC) statement was maintained properly to avoid sample contamination throughout the analytical process (USEPA 1995).

## The estimation of THMD

For estimating the total discharge of heavy metal from dyeing effluents, some key points were kept in mind as follows:

1. The number of dyeing industries in the concerned area
2. The volume of effluent discharge per dyeing industry
3. The average amount of different heavy metals in the effluent

Heavy metal discharge from the loom dyeing industries of Kumarkhali, Kushtia, is being measured easily using these points. In Kumarkhali, Kushtia, approximately 100 loom-dyeing small units are open 5 days a week. Each loom dyeing industry can produce about 10 L of effluent per day based on the interview of the respondents. For calculating, the total discharge of each heavy metal, the following formula was used (Islam 2016):

$$\text{Total heavy metal discharge (THMDN)} = \text{Number of dyeing industries} \times \text{Volume of effluent discharge per day per dyeing industry (L)} \\ \times \text{Average amount of that metal in the effluent (mg L}^{-1}\text{)} \times \text{number of opening days per year}$$

## Respondents' awareness, attitudes and behaviour patterns

During January and February 2016, sixty people participating in various dyeing and weaving activities were asked to respond to the survey. This survey was performed with the help of a research assistant. A three-time pilot test was done using a specially designed questionnaire to determine the amount of time taken to complete the questionnaire

at the respondent stage. Individual data including age, education, occupation, training, and working experience were additionally gathered. We collected data on the socio-demographic status of the respondents and their awareness, attitude and behavioural patterns on dyeing activities. The denoted signs for awareness, attitudes and behavioural patterns of the respondents are AWAR, ATTI and BHP, respectively, for their short-expression in the "Results and discussion" section.

## Statistical analysis

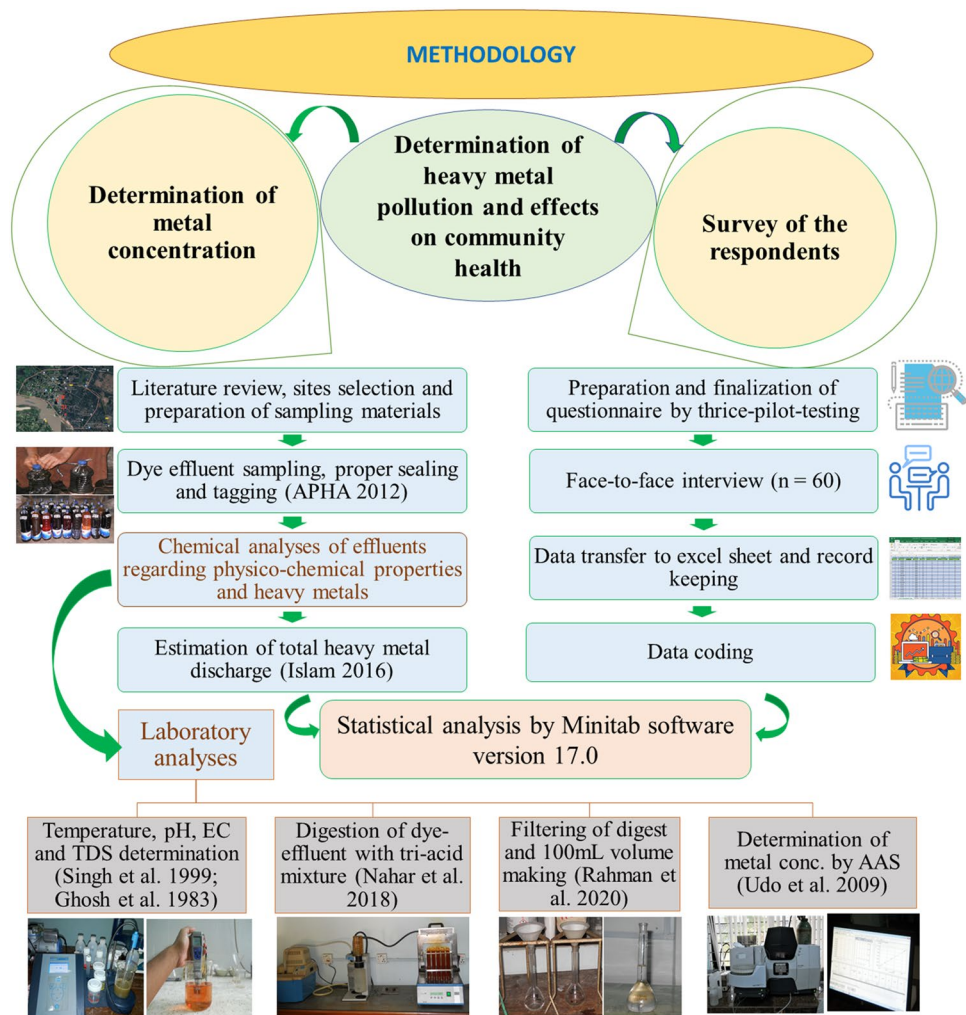
Data analysis for effluent samples and survey studies was conducted by using Minitab version 17.0 software tool (Minitab Inc., Pennsylvania, USA). The Kolmogorov-Smirnov goodness of fit test was used to check the data for normality, and the modified Levene's test was used to check for equality of variances. The survey data on the respondents' awareness, attitudes and behaviour patterns were analyzed using proper coding of the data.

The detail methodology can be presented in a graphical format as the following Fig. 3.

## Benefits of the study

Because of the high population density, fast industrialization and urbanization that have occurred in Kumarkhali during the past two decades, the area is very vulnerable to environmental degradation. A major source of pollution is believed to be the dyeing industry, which is one of the most significant sources of pollution. As a result, the soil and water bodies in this area are becoming increasingly polluted. It is essential to conduct a chemical analysis of dyeing industrial effluent in order to determine the concentration by heavy metals present in it. The current investigation will look at the current state of physico-chemical qualities and the amount of contamination of

heavy metals, especially Cu, Zn, Pb, Cr, Fe, Mn and Cd, in dyeing effluent samples collected from different places. The research will also provide light on the health effects of dyeing effluent, a significant contaminant, on the local population. To improve the health and well-being of the regional environment, researchers will be more inclined to focus on this subject area. Government policymakers and environmental protection agencies will become more careful in taking appropriate steps and financing to preserve

**Fig. 3** Outline of the research methodology of the study

the environment and human health and creating awareness among stakeholders. The authority will take on the task of establishing an effluent treatment plant (ETP) as quickly as possible.

## Results

In our study, we focused on assessing the pollution of heavy metals present in hand-loom–dyeing effluents and their impacts on local community by studying the respondents’ knowledge, attitudes and behavioural patterns. Actually, it was initially observed that a huge number of effluents from dyeing operations in the area are dumped directly into nearby soil, crops and surface waters, eventually ending up in the Garai river. For this reason, it was assumed that the heavy metal pollution thorough this dye-effluent would be a problematic situation and thus would harm the community health. The findings of this study will be useful to policy-makers and the general public as well as workers to become

more aware and protective. These reports will also serve the scientific community by giving information on pollution levels in the study area and their consequences on human health. A roadmap to resolve this problem will be probably implemented by the authority easily. In summary, the results of this study consist mainly in the following sections: (1) “Characteristics of hand-loom dye effluents in terms of physicochemical properties”; (2) “Heavy metals in hand-loom dyeing effluents”; (3) “The estimation of the total discharge of heavy metals”; (4) “Principal component and cluster analyses” and (5) “Awareness, attitudes and behavioural patterns of the respondents on loom-dyeing practices”.

### Characteristics of hand-loom dye effluents in terms of physicochemical properties

Physicochemical properties, i.e. temperature, pH, EC and TDS of loam dye effluents, are presented in Table 1. Temperature was ranged between 34.7 and 44.8 °C with an average value of  $39.3 \pm 2.86$  °C (Table 1). The estimated pH of

**Table 1** Physicochemical characteristics of dye-effluents of hand-loom industries of Kumarkhali, Kushtia, Bangladesh

Parameters	Range	Mean $\pm$ SD	Level of significance	ISWS	IWGV
Temperature ( $^{\circ}$ C)	34.7–44.8	39.3 $\pm$ 2.86	NS	40 (summer) 45 (winter) <sup>a</sup>	-
pH	3.69–13.68	12.05 $\pm$ 2.92	**	6.0–9.0 <sup>a</sup>	6.0–8.4 <sup>b</sup>
EC (mS cm <sup>-1</sup> )	627–7160	4238.65 $\pm$ 2180.63	**	1200 <sup>a</sup>	750 <sup>c</sup>
TDS (mg L <sup>-1</sup> )	4140–19800	8032 $\pm$ 3680.63	**	2100 <sup>a</sup>	-

ISWS inland surface water standards, IWGV irrigation water guideline value, NS non-significant

\*\*Significance at 5% level

<sup>a</sup>ECR (1997)

<sup>b</sup>Ayers and Westcot (1985)

<sup>c</sup>ADB (1994).

the effluent samples differed from 3.69 to 13.68 with a mean of 12.05 (Table 1). Out of 20 samples, 17 were strongly basic (pH 11.16–13.68), and the rest of the three samples were acidic to neutral (pH 3.69–7.85) (Supplementary Table 2). The EC value of the samples ranging between 627 and 7160  $\mu$ S cm<sup>-1</sup> with a mean value of 4238.65  $\mu$ S cm<sup>-1</sup> (Table 1). However, the average amount of total dissolved solids was 8032 mg L<sup>-1</sup>, ranging from 4140 to 19800 mg L<sup>-1</sup> (Table 1).

### Heavy metals in hand-loom–dyeing effluents

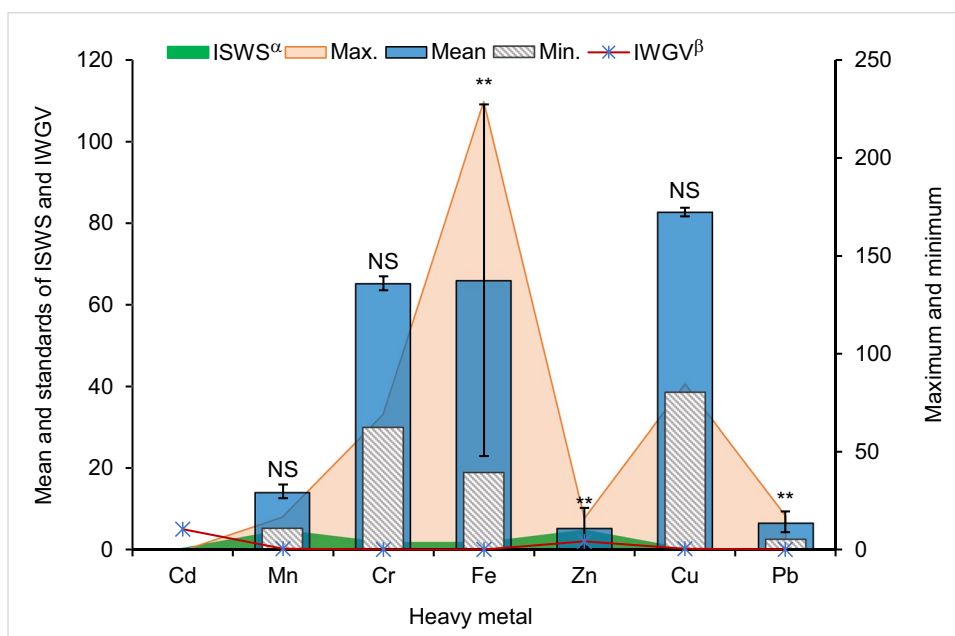
The concentrations of various trace metals (Cr, Pb, Cd, Fe, Cu, Zn, and Mn) have been analysed and presented in Fig. 4 and Supplementary Table 3. All of the dye-effluent samples obtained from various loom units of Kumarkhali, Kushtia, contained less than the detectable level (below detectable limit, BDL) of Cd (Table 3). We found a very high amount

of Fe ranging between 39.97 and 228.64  $\mu$ g mL<sup>-1</sup> with the mean concentration of 66.03  $\mu$ g mL<sup>-1</sup> (Fig. 4). The effluent samples showed a disproportionately high quantity of Mn, ranging from 11.55 to 17.24 g mL<sup>-1</sup>, with a mean value of 14.27 g mL<sup>-1</sup>. About 50% of samples had less than the mean value, and the rest 50% of samples contained higher than the mean value (Supplementary Table 3). The dye-effluent samples represented a very high Cr ranging from 62.76 to 69.42  $\mu$ g mL<sup>-1</sup> with a mean of 65.28  $\mu$ g mL<sup>-1</sup>. Zinc contents ranged from 0.15 to 16.72  $\mu$ g mL<sup>-1</sup> with a mean value of 5.50  $\mu$ g mL<sup>-1</sup> in the effluent samples (Fig. 4). Among 20 samples, 14 samples had less than the average value, and the rest of the six samples contained higher than the average value (Supplementary Table 3). The average concentration of Cu was 82.74  $\mu$ g mL<sup>-1</sup> (Fig. 4). A comparatively very high amount of Pb ranging from 5.99 to 17.72  $\mu$ g mL<sup>-1</sup> with a mean value of 6.80  $\mu$ g mL<sup>-1</sup> was estimated from the collected effluents (Fig. 4).

**Table 2** PCA of temperature, pH, EC, TDS, Mn, Cr, Fe, Zn, Cu and Pb of collected loom-dyeing effluent samples of Kumarkhali, Kushtia, Bangladesh

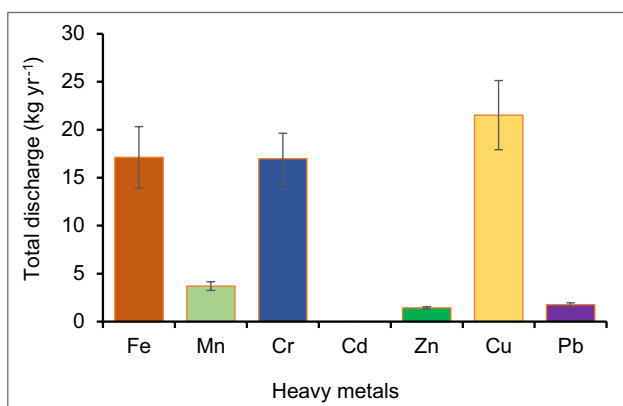
Parameters	PC <sub>1</sub>	PC <sub>2</sub>	PC <sub>3</sub>	PC <sub>4</sub>	PC <sub>5</sub>	PC <sub>6</sub>	PC <sub>7</sub>	PC <sub>8</sub>	PC <sub>9</sub>	PC <sub>10</sub>
Temperature	- 0.455	0.000	0.013	0.036	- 0.224	0.215	0.635	- 0.445	- 0.276	0.134
pH	0.295	- 0.426	- 0.186	- 0.351	0.123	0.433	0.093	- 0.125	0.343	0.478
EC	0.214	- 0.467	0.150	- 0.242	- 0.455	0.111	- 0.301	- 0.210	- 0.437	- 0.332
TDS	0.144	0.568	- 0.155	- 0.081	- 0.308	0.186	- 0.324	- 0.003	- 0.348	0.520
Mn	0.451	0.039	0.058	0.166	- 0.179	0.278	0.514	0.586	- 0.178	- 0.125
Cr	- 0.375	0.068	0.442	0.142	- 0.078	0.667	- 0.286	0.168	0.260	- 0.103
Fe	0.309	0.453	- 0.222	- 0.142	0.150	0.311	0.066	- 0.431	0.165	- 0.542
Zn	- 0.314	- 0.155	- 0.554	- 0.042	0.423	0.289	- 0.136	0.264	- 0.443	- 0.148
Cu	- 0.301	0.051	- 0.434	- 0.363	- 0.567	- 0.100	0.048	0.283	0.378	- 0.174
Pb	0.107	- 0.200	- 0.419	0.780	- 0.268	0.083	- 0.145	- 0.189	0.168	0.018
Eigenvalue	3.4923	2.2598	1.1365	0.9529	0.9157	0.4637	0.3656	0.2616	0.1206	0.0314
Proportion	0.349	0.226	0.114	0.095	0.092	0.046	0.037	0.026	0.012	0.003
Cumulative	0.349	0.575	0.689	0.784	0.876	0.922	0.959	0.985	0.997	1.000

**Fig. 4** Level of trace metal in the hand-loom dye-effluent of Kumarkhali, Kushtia, Bangladesh. BDL below detectable limit; NS non-significant, \*\*significance at 5% level; ISWS<sup>α</sup>: inland surface water standards of Bangladesh (ECR 1997); IWGV<sup>β</sup>: irrigation water guideline value proposed by: Cd and Mn — Ayers and Westcot (1985); Cr and Fe — USEPA (1999); Pb — DoE (2005)



**Table 3** Behavioural patterns on using toxic chemical substances and synthetic dyes in the dyeing practices (n = 60)

Items	Variables of behavioural patterns	Response (%)		
		Yes	No	Unknown
BHP 1	In the dyeing process, artificial dyes and chemicals are used.	58.33	8.33	33.33
BHP 2	Gloves are worn during the dyeing process.	48.33	43.33	8.33
BHP 3	Working with artificial dyes causes itchiness and inflammation in the body.	38.33	55.00	6.67
BHP 4	After finishing the dyeing work and before feeding, wash your hands.	61.67	38.33	0.00
BHP 5	Having skin problems or other chronic illnesses.	20.00	75.00	5.00
BHP 6	Admitted to the hospital within 6 months due to illness.	20.00	75.00	5.00
BHP 7	Disposing of unused dyes, additives and effluents in an environmentally responsible manner.	11.67	81.67	6.67
BHP 8	Over the last 6 months, noticed dead fish or animals in local water bodies.	20.00	51.67	28.33
BHP 9	In the last 6 months, observed destroyed crops in nearby fields.	15.00	36.67	48.33
BHP 10	Domestic animals have died in the surrounding region in the last 6 months.	3.33	13.33	83.33



**Fig. 5** Estimated total discharge of each heavy metal from dyeing effluents of Kumarkhali, Kushtia, Bangladesh

### The estimation of the total discharge of heavy metals

The dyeing effluent samples of the study contained a trace amount of Cd and a comparatively very high Fe. The calculated total annual discharge of Fe from dyeings of Kumarkhali was about 17.12 kg year<sup>-1</sup> (Fig. 5). A comparatively high Mn (3.71 kg year<sup>-1</sup>) was also present in the effluent samples. A significant amount of Cr was found in the effluent with total discharge (16.98 kg Cr year<sup>-1</sup>) (Fig. 5). On the other hand, the calculated total annual discharge of Zn was about 1.43 kg year<sup>-1</sup> whereas Cu was about 21.52 kg year<sup>-1</sup>. The effluents contained a higher Pb as discharged 1.77 kg year<sup>-1</sup> (Fig. 5).

### Principal component and cluster analyses

Principal component analysis (PCA) is a method to reduce dataset dimensionality, enhance interpretability, and at the same time reduce information loss (Jolliffe and Cadima 2016). The findings of Table 2 show that the first three main components have a value higher than 1.00. These three components account for 68.9% of the data variance. From the PCA value table, Table 2 can be observed that over 35% of the pattern variance is described by the first three PCs, 34.9% by PC1, 57.5% by PC2, and 68.9% by PC3. In the PCA analysis, the first main component is associated to a significant negative temperature connection and a positive combination of Mn. The second component has huge negative associations with pH and EC, while TDS and Fe have larger positive PC2 loads. The third component is associated with Cr, whereas Zn, Cu and Pb were very negative, which mainly gauges the presence of heavy metals in loom-dye effluents. Mn and Cr are essential to understand PC1 based on the loading diagram (Fig. 6). The loading of the Cr, Zn, Cu and Pb (PC3) compared to that of the other elements in the group (Fig. 6; Table 2) is seen; thus, this may mean a nearly independent behaviour in the group.

By showing the clusters created by grouping observations at different stages, a dendrogram may show how similar or dissimilar groups are to each other. The degree of resemblance between the two things is represented by the vertical axis. A total of 10 observations were used for this cluster analysis. To begin, two clusters (Cu and Mn in the worksheet) are connected together to create a new cluster with an 87.42 similarity level and a 0.252 distance level (Fig. 7). Despite the high levels of similarity and distance, there are simply too many clusters to be useful. As additional clusters are formed, the similarity level drops and the distance level rises. A single cluster is created by

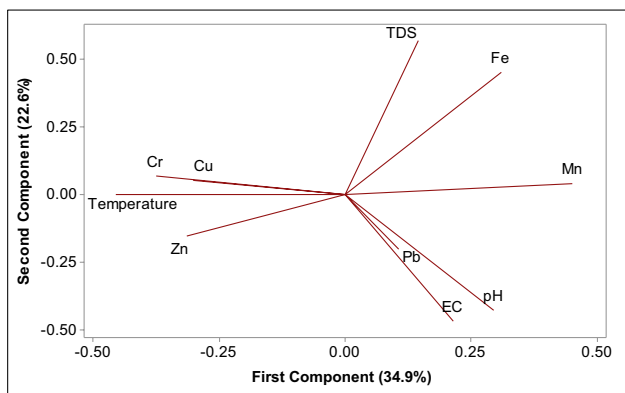


Fig. 6 Loading plot of major PCA of temperature, pH, EC, TDS, Mn, Cr, Fe, Zn, Cu and Pb of collected loom-dyeing effluent samples of Kumarkhali, Kushtia, Bangladesh

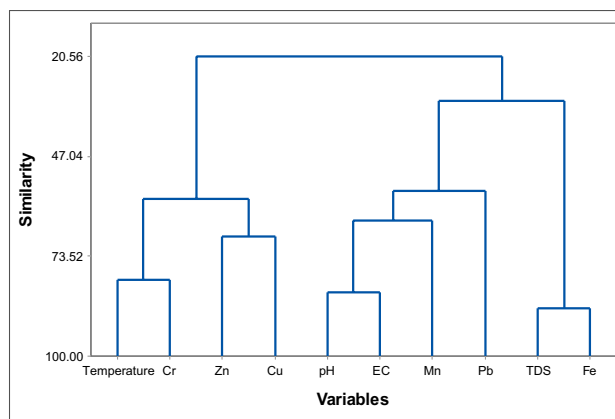


Fig. 7 Cluster analysis of temperature, pH, EC, TDS, Mn, Cr, Fe, Zn, Cu, Pb having single linkage and correlation coefficient distance

adding all of the observations together at the end. Fig. 7 indicates that reducing the number of clusters from four to three causes the similarity between Cr and Fe to decrease even more, suggesting that three clusters may be sufficient for the final partition (similarity 56.28).

### Awareness, attitudes and behavioural patterns of the respondents on loom-dyeing practices

#### Characteristics of the respondents

A total of 60 individuals were interviewed to assess the awareness, attitudes and behaviour patterns regarding dyeing activities. The age range of the studied population was from < 20 to > 60 years (Fig. 8). The educational characteristics of the study population were also assessed, and the majority of respondents (79%) had none or primary education; 21% had above secondary education (Fig. 9A). Categories of individuals included 23% hand-loom worker, 13% owner, and 3% cloth weaving labour, and most of the

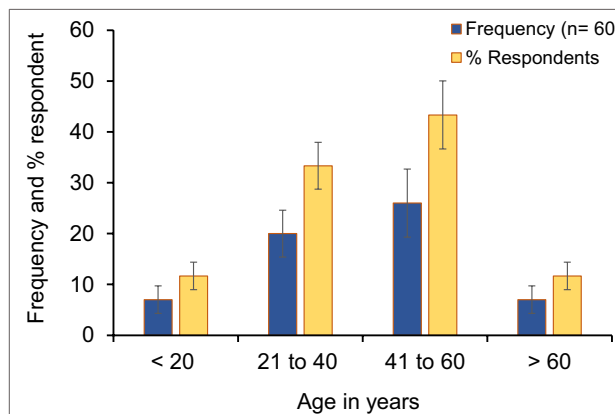
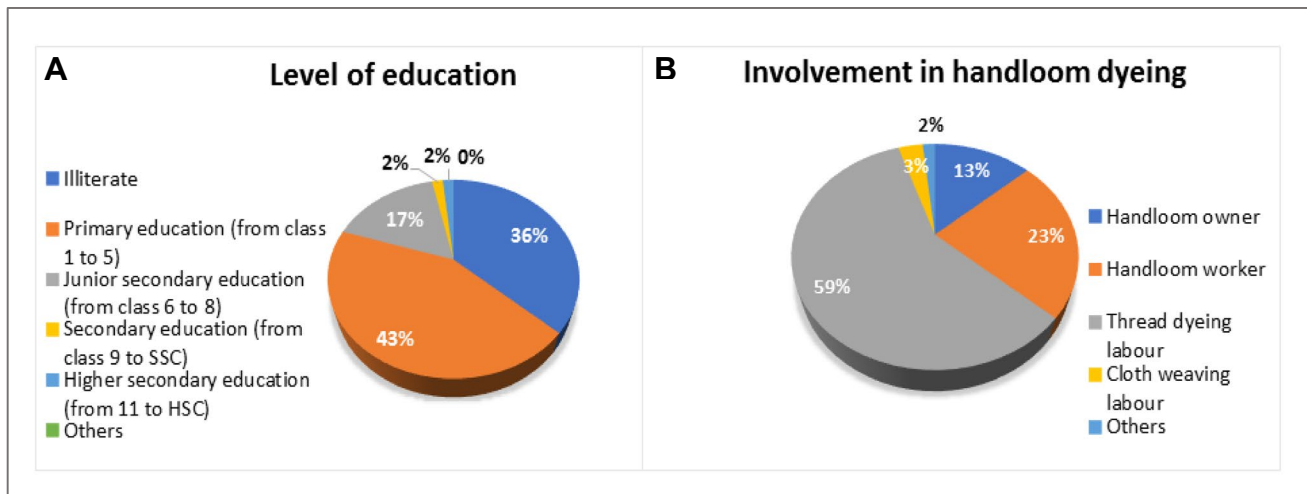


Fig. 8 Age distribution of the respondents



**Fig. 9** Level of education (A) and loom dyeing involvement (B) of the studied population

population (59%) was thread dyeing labourers, and 2% others or the merchants (Fig. 9B).

#### Awareness regarding the loom dyeing practices

The respondents' awareness of the use of chemical dyes was assessed using a questionnaire, and the result is presented in Fig. 10. The findings revealed that approximately one-third of the population was aware of the use of synthetic dyes, while the other half were unaware (Fig. 10). However, 65% of the general public was conscious of the dangers of synthetic dyes. Around 70% of respondents were aware of the environmental contamination caused by the direct dumping of dye effluents, while half were aware of the dyeing effluent disposal technique and treatment methods. Around 40% of the population blamed toxic synthetic dyes for skin issues, but 60% were conscious of the importance of wearing hand gloves to protect their bodies.

A collection of questions about attitudes of risks and effluents control was used to determine the respondents' attitudes on using poisonous artificial dyes and chemical substances and their effects on the environment and human health. Almost half of those interviewed, toxic synthetic dyes are unsafe for human wellbeing and the environment. Almost 60% of those polled agreed that wearing hand gloves for personal safety when dyeing was a good idea. Approximately two-thirds of the population agreed that direct disposal of dyeing effluents is dangerous and that dyeing effluents must be managed or treated before being disposed of in the setting (Fig. 11).

#### Observed behavioural patterns of the population responses to loom-dyeing practices

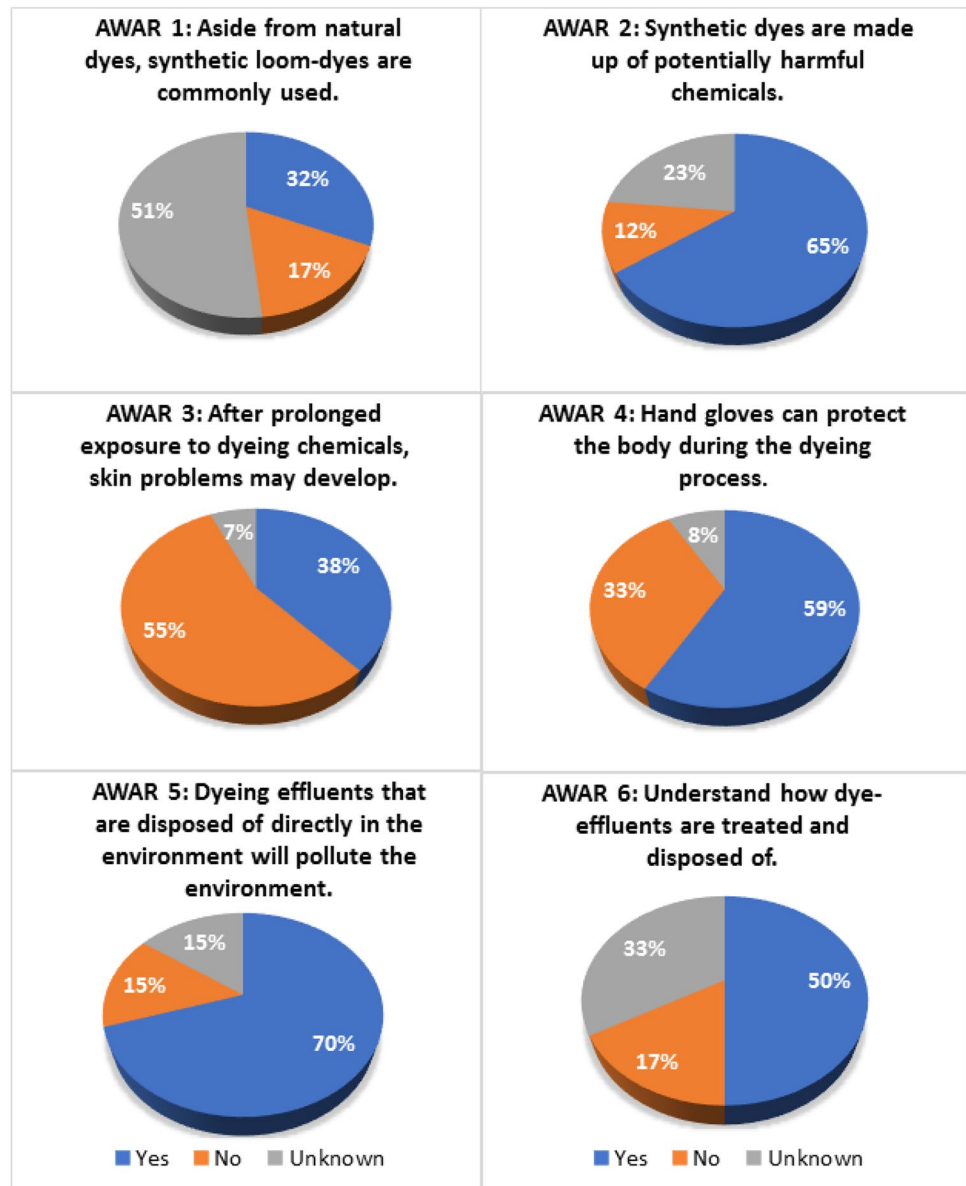
The questionnaire's segment included questions about workers', weavers' and owners' current behavioural patterns on chemicals and synthetic dyes used in dyeing practices along with their health and environmental consequences. In the dyeing phase, most respondents (58.33%) used artificial dyes and other harmful chemicals, even though 43.33% of respondents did not wear hand gloves while working with synthetic dyes (Table 3). Only 38.33% reported itchiness and pain in their bodies. However, after finishing the dyeing and before eating, most studied populations (61.67%) wash their hands. These attributes may be the reason for a slower response to illness (only 20%). More than 80% of respondents were not properly discharging unwanted dye effluents and chemicals. A significant response (15–20%) was found in the observation of certain environmental impacts associated with inappropriate disposal of unused dyes and chemicals and effluents (Table 3).

## Discussion

#### Physicochemical properties and heavy metal contents in dyeing-effluents

Among different physicochemical properties, range of effluent temperature was lower than the suggested value (ECR 1997), whereas pH was higher than the recommended values (ECR 1997; DoE 2008) (Table 1). Most of the samples

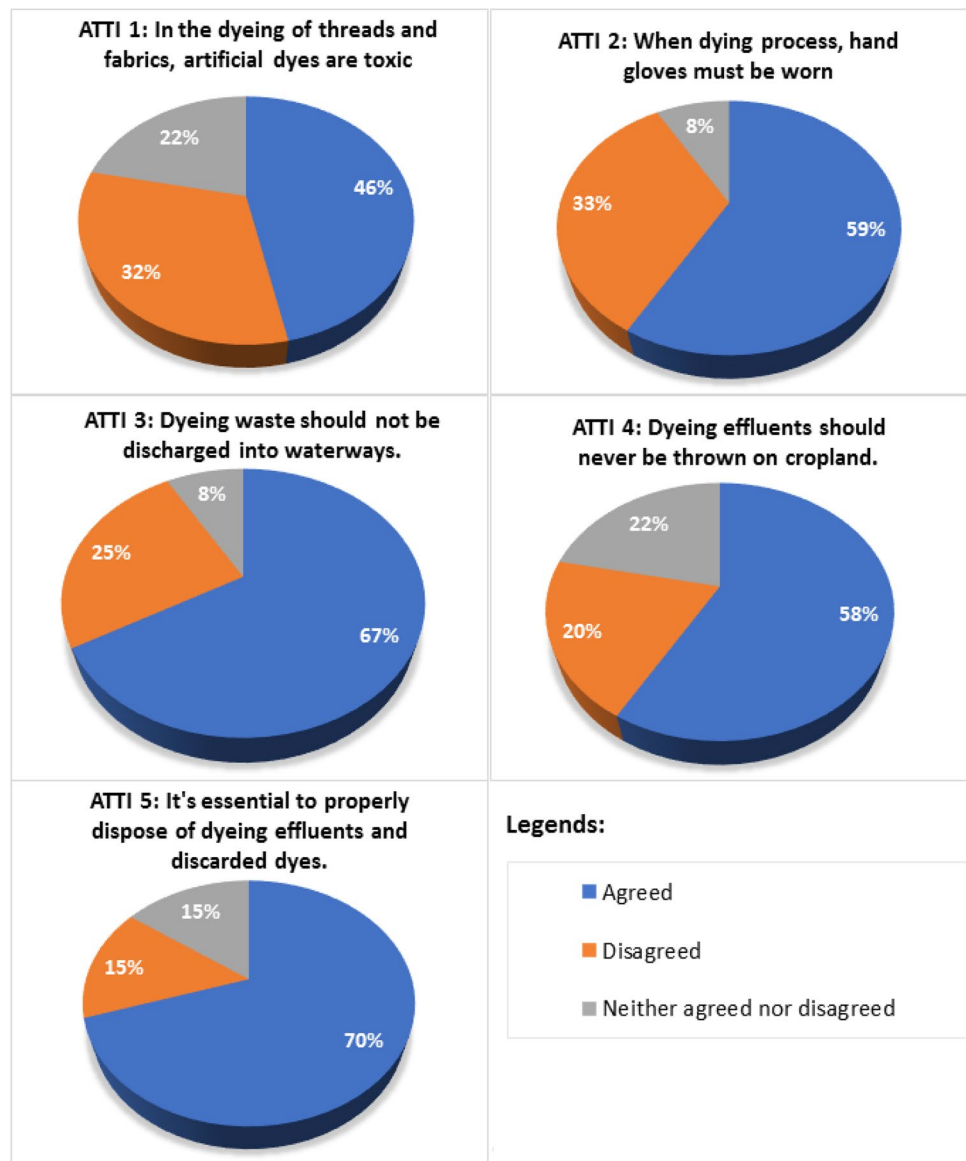
**Fig. 10** Respondents' awareness on loom-dyes and their effects on the environment and human health ( $n = 60$ ). The attitudes of the interviewees on used chemicals and loom dyes



were strongly basic. The recommended permissible pH ranged from 6.5 to 9.0 for irrigation water (Ayers and Westcot 1985). Our findings surpass the standard value. The pH of the current research was higher than the previous observations of Razu et al. (2013). The obtained pH value was the most diversified range of the value recorded in earlier researches (Rahman et al. 2020; Nahar et al. 2018; Kaur et al. 2010; Prasad and Rao 2010; Ranganathan et al. 2007). In the textile industry of Rawalpindi, a slightly higher pH has been noticed (Ali et al. 2009). The EC value of the samples was higher than the proposed inland surface water standards of Bangladesh (ECR 1997) (Table 1). The EC values remaining in the range of textile effluent of Bangladesh (250–63750)  $\mu\text{S cm}^{-1}$  as reported by Dey and Islam (2015). However, our outcome was lower than Tamil Nadu's textile-industry

effluents (Ranganathan et al. 2007). In addition to that Nahar et al. (2018) and Rahman et al. (2020), estimated EC value are two times higher in loom-dyeing effluents of Narsingdi and Sirajganj of Bangladesh, respectively. According to ECR (1997), standard TDS limit is  $2100 \text{ mg L}^{-1}$  in textile effluent. However, the average amount of total dissolved solids of our study was higher than this standard (Table 1). TDS levels for irrigation usually ranged of 450 to  $2000 \text{ mg L}^{-1}$  (Ayers & Wescot 1985). The obtained result exceeds both standards. The current study's TDS value is almost identical to the findings of Nahar et al. (2018) and Rahman et al. (2020). The average value of TDS was more significant than the values recorded by Rahman et al. (2019), Prasad and Rao (2010), Ali et al. (2009) and Ranganathan et al. (2007). The effluent test results of  $\text{TDS} > 2000 \text{ mgL}^{-1}$  are

**Fig. 11** Respondents' attitudes on the use of toxic synthetic dyes and chemicals along with environmental and health consequences



considered “unsuitable” for watering purposes which might be ultimately harmful to soil health and crop production. The obtained mean pH, EC and TDS values were higher than the standard irrigation limits that might cause deleterious effects on agricultural crop production and human health (Rahman et al. 2020; Rahman et al. 2019). According to earlier research, higher pH may be observed as a consequence of the use of different dyes, salts and solvents (Wood and Kellogg 1988) that settle down as toxic mixtures of organic and inorganic substances (Rahman et al. 2020; Nahar et al. 2018; Rahman et al. 2018). Electrical conductivity indicates the overall intensity of dissolved salts in the collected samples; it confirms water system salinity and is an essential aspect of water system use (Tchobanoglous et al. 2013). Significant concentrations of  $\text{HCO}_3^-$ ,  $\text{SO}_4^{2-}$  and  $\text{Cl}^-$  of Ca, Mg and Na also indicate high TDS level (Karanth 1994).

In general, Fe, Cu, Zn and Mn are heavy metals needed in low concentrations for the proper growth and advancement of living creatures, but when they surpass the acceptable limits, they negatively affect the ecology and health of human being. Results revealed that Cd in dye-effluent samples in the study area, contained less than the detectable level (below detectable limit, BDL) (Table 3) indicating that all of the effluent samples could be used safely for various purposes. The recommended concentration of Fe for inland surface water is about  $2.0 \text{ mg L}^{-1}$  (ECR 1997; DoE 2005) and for irrigation is  $5.00 \text{ mg L}^{-1}$  (Ayers and Westcott 1985). This data is concomitant with the earlier findings of Rahman et al. (2020), Ohioma et al. (2009) and Nahar et al. (2018). All of the samples had higher Fe contents and that was far more than the recommended levels. The concentration of Fe in this study exceeded the values reported

by Nahar et al. (2018), Rahman et al. (2020), Sivakumar et al. (2011), Akter et al. (2010), Tariq et al. (2006), Kaushik (2003) and Yusuff and Sonibare (2004) in the effluents of textile, dyeing, bleaching and tannery industries. Das and Borah (1983) reported that the higher Fe content might create unwanted effects like the astringent taste, staining, turbidity, deposits and development of microbes in pipes influencing the acceptability of water for home-grown usage. Mn is known as the least toxic heavy metals when swallowed (USEPA 1988). However, it can reach the brain in two ways when breathed in / by olfactory (nasal aviation route) that gives a direct path to cerebrum tissue and lung take-up that may provide a wellspring of progressing with exposure (Weiss 2006). The effluent samples showed a disproportionately high quantity of Mn, where about 50% of samples had less than the mean value, and the rest 50% of samples contained higher than the mean value (Supplementary Table 3). According to ECR (1997) and DoE (2005), for inland surface runoff, the standard value for Mn content is  $5.0 \text{ mg L}^{-1}$ . In contrast, the appropriate limit for agriculture is  $0.20 \text{ mg L}^{-1}$ , as reported by Ayers and Westcot (1985). All of the samples had Mn concentrations far higher than the irrigation and industrial effluent normal limits. The concentration of Mn of dyeing effluents was a few folds higher than in some previous studies (Rahman et al. 2020; Rahman et al. 2019; Prasad and Rao 2010; Akter et al. 2010; Ali et al. 2009; Ohioma et al. 2009). On the other hand, Sivakumar et al. (2011) noticed a higher Mn concentration ( $13.20 \text{ mg L}^{-1}$ ) in the effluent of Tamil Nadu's dyeing and tanning industry segments.

Chromium is generally found as the hexavalent and trivalent form in plants, soils, animals and rocks. They might enter into the environmental compartments from different industrial production system like metal plating, steelmaking, corrosion inhibitors, leather tanning, dyes, paints and wood additives (Huang et al. 2004). Chromium concentration highly exceeded the values reported earlier in different effluent samples (Rahman et al. 2020; Nahar et al. 2018; Razu et al. 2013; Sivakumar et al. 2011; Akter et al. 2010). Inland surface water should have a Cr content of  $2.0 \text{ mg L}^{-1}$ , according to ECR (1997). On the other hand, the standard limit of Cr for irrigation usage is  $0.011 \text{ mg L}^{-1}$ , as reported by USEPA (1999). About 97% and 100% of the samples contained higher Cr contents than that of the industrial effluent and irrigation standard limit, respectively. The standard content of Zn for inland surface water is about  $5.0 \text{ mg L}^{-1}$  (ECR 1997). Considering this limit, 13 samples of our analyses remained below the range. The legally allowable limit of Zn in irrigation water is  $2.00 \text{ mg L}^{-1}$  (Ayers and Westcot 1985). Only three samples were found to be acceptable for irrigation compared to the prescribed level, whilst the others were found to be unsuitable. Our study's Zn concentration was higher than those recorded by Rahman et al. (2020),

Rahman et al. (2019) and Nahar et al. (2018), but lower than the value of  $8.7 \text{ mg L}^{-1}$  reported by Sivakumar et al. (2011).

Adverse health effects can be raised with high-level exposure to Cu (Bremner 1998). According to ECR (1997), inland surface water's standard level of Cu content is about  $5.0 \text{ mg L}^{-1}$ , whereas  $0.20 \text{ mg L}^{-1}$  is the prescribed threshold for agricultural irrigation (Ayers and Westcot 1985). All the effluent samples contained Cu as higher than the recommended limit for inland water use and irrigation (Fig. 4). Several studies have previously recorded lower Cu concentrations than ours (Nahar et al. 2018; Rahman et al. 2020; Sivakumar et al. 2011; Yusuff and Sonibare 2004; Akter et al. 2010; Aslam et al. 2004), which expressed a fall of more than 90%, in comparison to the value mentioned above of the present study. About 64% higher Pb concentration ( $19.0 \text{ mg L}^{-1}$ ) in textile wastewater was reported previously (Sivakumar et al. 2011) compared to the present study. The standard value of Pb for fishing, industrial, agricultural irrigation and livestock water is  $0.05 \text{ mg L}^{-1}$ ,  $0.01 \text{ mg L}^{-1}$ ,  $0.05 \text{ mg L}^{-1}$  and  $0.05 \text{ mg L}^{-1}$ , respectively (ADB 1994). According to DoE (2005), irrigation water can contain  $0.01 \text{ mg L}^{-1}$  Pb. According to the findings of this report, dye-effluent samples can be harmful to the atmosphere, biodiversity and human health due to their high Pb content (Rahman et al. 2020). The standard limit for inland surface water for Pb is about  $0.1 \text{ mg L}^{-1}$  (ECR 1997; DoE 2005). The mean Pb concentration exceeds the values reported by Rahman et al. (2020), Akter et al. (2010), Rahman et al. (2018), Prasad and Rao (2010), Ali et al. (2009), Ohioma et al. (2009) and Mountassir et al. (2013). These effluents are often discharged indiscriminately into surrounding waters and then combined with irrigation water for field irrigation, resulting in soil accumulation (Nahar et al. 2018). Heavy metals impair the activity of microbes and other biological processes, so their deposition in soil and water bodies over time may affect soil biology and texture (Babich and Stotzky 1985). From the loading plot, it is seen that the pH, EC and TDS of the effluent samples were positive for Pb, Fe and Mn, while the concentration of Cr, Cu and Zn is negative (Fig. 6). It is clear from this finding that greater pH and EC may be causing more Pb and higher TDS for a larger concentration of Cr and may eventually lead to pollution of the food chain that may cause damage for human health. By showing the clusters created by grouping observations at different stages, a dendrogram may show how similar or dissimilar groups are each other. Despite the high levels of similarity and distance, there are simply too many clusters to be useful. As additional clusters are formed, the similarity level drops, and the distance level rises. A single cluster is created by adding all of the observations together at the end. With regard to temperature and other factors such as EC and TDS as well as Pb, it is apparent from the clusters that Cr and Zn may have had a strong connection with them (Fig. 7).

## Awareness, attitudes and behavioural patterns of the respondents on loom-dyeing practices

Awareness, attitudes and behaviour patterns regarding dyeing activities differed from person to person of the respondents. In our study, around quarter of the respondents had secondary or above education level. Previously, Rahman et al. (2020) surveyed in Belkuchi, Sirajganj loom-dyeing area and found that 35% respondents of that area had secondary education whereas 43.33% had primary education. Our study found approximately 33.3% of the population is aware of synthetic dye use, whereas nearly two-thirds was conscious of health dangers of synthetic dyes. According to the combined scoring of the awareness portion, approximately one-thirds of the respondents had sufficient awareness on ecology and human health. A survey of printing staff in Hong Kong showed a clear understanding of the harmful effects of chemical dyes (62%). According to a previous study (Rahman et al. 2020), most respondents in Belkuchi, Sirajganj had medium to high awareness and low to medium consciousness on agro-environmental adverse effects of synthetic dyes. Our findings are consistent with those of the survey. Akintayo (2013) discovered that the majority of the studied population was mindful of the harmful effects of dyes, caustic soda and hydrogen sulphite; however, only 26.80% were aware that dyes were poisonous to animals' respiratory system and other body parts.

Almost 60% of the studied people agreed on the importance of wearing hand gloves for personal safety, and harmful effects of direct disposal of dyeing effluents are dangerous and that dyeing effluents (Fig. 11). Previously, Rahman et al. (2020) observed that about half of the sample populations acknowledged that toxic loom dyes cause harm and that most respondents believed that safety precautions are expected. Human health can be harmed by a lack of awareness and attitudes towards various loom-dyeing practices (Haladiya et al. 2005). According to Akintayo (2013), the awareness and beliefs about the adverse effects of dye exposure may affect human health. Our findings are consistent with Rahman et al. (2020), who reported that more than 58.33% of dyeing staff were unaware of the proper discharge of discarded dyes, effluents and chemical substances.

## Policy Suggestions

Loom dyeing's broad adoption is contingent on public demand, feasibility, economics and governmental policies. To avoid any kinds of pollution, consciousness is the best policy. Awareness build up is important among the industrialists about the pollution problem and their legal responsibility to prevent it. In the earlier, several governments supported the dyeing sector after the advent of synthetic loom dyes and their ease of application. There were

no restrictions on dye testing or dye effluent discharge in the past. In the 1990s, the textile dye industry expressed concerns about synthetic dyes' environmental impact. All dyeing industry leaders have a responsibility to manage the textile fabric supply chain responsibly. If we want to retain proper dyeing facilities for future generations, we need to simplify our approach for the industries. First of all, dyeing effluents must be treated before dumping which should be imposed by making law. For this purpose, effluent treatment plant (ETP) establishment should be more emphasized. The personnel involved in handloom dyeing industries should also be trained regarding safety measures and appropriate disposal techniques. Generally, the dyeing workers discharge their effluents without considering any environmental issues, which is a traditional technique. Government and no-government organisations should come forward to ban this traditional methods with introducing the modern techniques. Secondly, national and community level bodies should be formed and validated to monitor soils and water sources near the industries, and remediation measure should be taken. To strengthen policy suggestions, future study might disaggregate globalization and trade components where ecological footprint might be a good comprehensive indicator (Alvarado et al. 2021). One of the other distinctive and essential policy recommendations that come out of this research is to improve worker understanding of efficient technical attitudes and behaviours with sustainable production together with increased industrial revenue. Since economic growth, industrial production and overall reserve contribute to environmental degradation in many countries, renewable energy and natural resources may help to reduce the environmental pollution issue (Dagar et al. 2021). The policy suggestions may assist policymakers in the research area as well as nations experiencing comparable difficulties with environmental contamination; this requires a comprehensive structural and technological change in order to improve the country's loom-dyeing system.

## Managerial implications

The significant consequences on environmental compartments happened as a result of industrialization and the continued use of ancient effluent disposal practices. Thus, the necessary knowledge for improving attitudes and behavioural patterns related to dyeing activities should be achieved through various types of training and workshops organized by GOs and NGOs or other environmental agencies, as well as through social media platforms such as Facebook, Twitter and YouTube. Another significant managerial implication is to recommend a second-best alternative dyeing method in which the effluent is treated and utilized as irrigation water. Government funding should be used to develop ETP-facilitated loom-dyeing, since the garment industry contributed

significantly to the national GDP (gross domestic product). Successful execution of government policies is crucial for improving the technical efficiency of dyeing personnel. These policies will also assist workers involved in dyeing processes in selecting the most environmentally friendly alternatives. Additionally, loom-dyeing facilities may be enhanced with the aid of subsidies provided via different government programs aimed at managing the sustainable garment sector.

## Conclusions

Metal contaminants are of concern worldwide and are mainly associated with increasing urbanization and anthropogenic activities, besides the other natural geogenic sources. Discharge and loading of untreated effluent disposes, containing toxic non-essential elements, into the soil, water and ambient air, have well known and documented health effects on exposed humans and other organisms. The overall picture of heavy metal concentration in dyeing effluents of Kumarkhali Kushtia's hand loom-dyeing industries was a matter of concern. In dyeing effluents, toxic metals such as Pb, Cr, Cu, Zn, Fe and Mn were found at significant levels. Furthermore, it is apparent that the effluent exceeds the recommended limits and is poisonous and needs treatment before being disposed of on land or water. The findings of the annual discharge load of metals predict that there might be high levels of contaminants in Kumarkhali, Kushtia's waterways and soil, sediment. The adverse effect of many chemicals and dye intermediates used in the clothing industry is severe, as their effects on the environment and public health take time to manifest. Since the respondents are regularly exposed to dyes with little or no control over the duration or extent of exposure, it is also crucial that the loom-dye workers become mindful of the harmful consequences of dyes when they are not appropriately treated. The improper discharge of dye-effluent should also be banned at all costs. Therefore, inventories on metal sources are of relevance in understanding exposure risks, developing alternative control strategies and efficient and environmentally friendly treatment technologies. The limitations of this research might be the inconsideration for the study of contamination of agricultural crops through dye-effluents. Another problem was found to be that the respondents did not agree to give their personal and health-related information easily. This limitation restricts us to increase our survey respondents. To know the actual public health problem, it is also wise to study health status of the respondents by day to day medical check-up. It was also a vital point that would be considered. So, we can do further deep research in this area including heavy metal accumulation in crops and regular health diagnosis of the respondents as vital recommendations.

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**Author contribution** Md. Shafiqul Islam conducted the research and prepared the initial manuscript; Md. Arifur Rahman analysed the data with graphical presentation, manuscript writing and improving the draft, English editing and critical revising; Kamrun Nahar helped in manuscript writing and corrections; Md. Saljar Rahman Chowdhury helped in manuscript formatting and revised the manuscript; Istiaq Ahmed revised the manuscript and improved with English corrections; K. M. Mohiuddin planned and supervised the research work.

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## Declarations

**Ethics approval and consent to participate** Not Applicable

**Consent for publication** Not applicable.

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