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Research article

Investigating the prospect of cleaner production in informal enterprises: A scientific assessment of environmental burdens and economic efficiency

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ABSTRACT

The present study aims to assess the prospects for cleaner production (CP) and sustainable development (SD) of informally operated small manufacturing enterprises, which are frequently blamed for uncontrolled waste disposal and causing pollution to the environment. The economic efficiency level of these firms has been explored to this end, and the metallic pollution loads in the surrounding environment have been scientifically analyzed to investigate the nexus between these two. DEA (Data Envelopment Analysis)-Tobit analysis has been employed, and a pollution load index (PLI) of heavy metal pollution comprising two environmental compartments (soil and water) has been constructed based on the concentration level of metalloid pollutants in the samples collected from the surrounding areas of the studied informal firms in Bangladesh. The study disproves CP practice in majority of the informal firms in Bangladesh by observing a positive relationship between firm-level efficiency and pollution load sourced from their production activities. Afterwards, this study estimates the eco-efficiency level of firms by considering pollution load as an undesirable output and minimizing its impact in an input-oriented DEA model. Applying the eco-efficiency scores in censored Tobit regression analysis, the outcome endorses the prospect of CP for informally operated enterprises in Bangladesh. However, the CP prospect can only materialize if and only if firms are provided with adequate technical, financial, and strategic support for achieving eco-efficiency in their production. The informal and marginal nature of the studied firms restricts them from getting access to the facilities and support services needed for implementing CP and moving towards sustainable manufacturing. Therefore, this study recommends green practices in informal manufacturing and limiting the informal firms by bringing them gradually under the coverage of formalization, which is in line with the achievement of the targets mentioned in Sustainable Development Goal 8.

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1. Background

Industrial pollution appears to be a global concern since it is not only associated with earth heating and environmental degradation but also imposes a significant impact on human health [1,2]. It generates health nuisance materials that affect people's health by causing various chronic diseases contributing to premature mortality, and lowering fertility rates that ultimately hinder the economic growth of a country [1,3,4]. Therefore, research on industrial pollution becomes crucial in the fight against global environmental degradation [5]. At the same time, a modification in industrial economic structure from unsustainable to sustainable has also become important as a target to make it more meaningful [6,7]. Cleaner production (CP) has emerged as a strategy to this end by promoting less polluting industrial processes that lower risks to humans and the environment. CP focuses on the implementation of waste and pollutants minimization by eliminating the use of toxic raw materials and reducing the quantity of toxic wastes and products through efficiency improvements in the production process [8–10]. CP is important for firm management as it enhances profit, reduces resource use and pollutant emissions, and ensures workplace safety [8], which attributes to the achievement of sustainable development (SD) [10]. Improvement in existing production efficiency through the implementation of clean technology is a way to develop CP [9,11] that aids efforts towards SD [12]. Therefore, more and more researchers are now advocating for efficiency improvement based on environmental judgments that hold an important role not only in CP but also in sustainability studies [7,13,14]. The present study has contributed to this by considering the industrial productions under the informal sector since they often become pollution-intensive, which fosters a number of environmental problems in some emerging and developing countries [15,16].

The informal sector, which captures three interlinked dimensions: informal units, informal activities, and informal employment [16], was officially recognized by the International Labor Organization (ILO) at the International Labor Conference in 2002. This study has considered the ILO definition of the informal sector, which takes account of all production activities taking place in the informal settlements [17]. These activities are imperfectly regulated and not subject to government scrutiny [18,19], but they become important from the perspective of employment generation and revenue earning [20–22]. Activities in this sector induce environmental degradation as they impose a serious challenge to the implementation of environmental regulations and weaken the regulatory effects on countries [15,16,23–25]. Moreover, they use low-cost modes of production and cheap labor-based technology that generate pollution and impose social costs see Refs. [26,27]. Informally operated manufacturing or metal finishing operations (such as galvanometry, electroplating, metal cleaning, leather and mining industries, dyes and pigment industries) often discharge untreated industrial wastes containing considerable amounts of heavy metal ions into nature that creates environmental pressure. Their continuous deposition in the soils and water bodies make them toxic due to high exposure duration and damage the relevant eco-system [28–30]. When informal production relocates formal sector production, augmented non-compliance with environmental regulations by informal enterprises increases pollution that needs to be addressed in the study on environmental degradation [27,31].

Under such a context, this study aims to explore the CP performance of informal manufacturing enterprises through efficiency analysis since efficiency in resource use is one of the main areas of CP, while inefficiency in the production process leads to many byproducts and wastes [32]. The study also investigates the metalloid pollution caused by informal firms in this regard, as metal-based industrial activities (in the face of rapid industrialization and urbanization), and the leaching of metals from different sources (due to various anthropogenic activities, such as landfills and waste dumps) have become a concern for the researchers. It creates environmental load and biological and physiological complications in humans along with toxicity in cases of high concentration [2,30,33]. The non-biodegradable and bio-accumulative nature of metallic pollutants has turned the research on minimizing their effects on the environment and avoiding their adverse effects on humans a top priority in these days [29,30]. The present study has contributed to this by constructing a composite Pollution Load Index (PLI) comprising two environmental compartments guided by the idea that heavy metal concentrations in water and soil sediment can be used to evaluate the anthropogenic and industrial impacts and risks caused by wastewater discharges in the soil and water bodies [34]. This study has also investigated its minimization effect by estimating eco-efficiency, which is an index of sustainability [35] and contributes to resolving the key problem in achieving SD [14].

National data on informal sector enterprises is not available. As a result, an interviewer-administered survey was conducted on informally operated firms, and soil and water samples were collected from the surrounding areas of the surveyed enterprises to identify pollution by heavy metals, specifically, lead (Pb), nickel (Ni), and chromium (Cr). Bangladesh was considered for this study because it is a densely populated country with increasing metalloid exposure and heavy metal poisoning case reports. Already, groundwater arsenic (As) contamination becomes a major public health problem in this country and causes the biggest disaster in the world [33]. Moreover, Bangladesh facilitates the indiscriminate installation of industrial units in its development process [36] that are mostly informally operated, employ 80% of the labor force, and contribute 30% of Gross Domestic Product (GDP) [37]. These micro, small, or medium-sized enterprises are found to be located in the surrounding areas of the capital city, Dhaka, and other major cities and become responsible for unplanned urbanizations and environmental crises in urban areas [36,38]. Besides, environmental regulations are routinely violated in Bangladesh due to a lack of enforcement by the relevant agencies, which appear to be corrupt, ineffective, and weak [39]. This provides an undue opportunity to firms in informal manufacturing sector, that account for two-thirds of the total informal contribution to Bangladesh's GDP [40], to cause serious heavy metal pollution through their uncontrolled waste disposal into nearby soil and water bodies [41]. This needs to be investigated for the sustainability prospects of urban development. However, there has been no formal research on the performance evaluation of informal enterprises that incorporates their link to worsening environmental crises. Overlooking this issue of the informal sector in the formulation and implementation measures of environmental policy may lead to misleading outcomes [42,43].

This study contributes to the literature in several ways. First, the economic efficiency assessment of three types of manufacturing enterprises operating in the informal sector will characterize the development of informal industrial enterprises in Bangladesh see Ref. [44]. Second, an assessment of the efficiency of informal production units and its relationship to pollution will inform policymakers about their role in achieving eco-efficiency and their potential contribution to sustainable production. This evaluation is significant in the prospect of achieving strategic objective 'green growth' in Bangladesh, as World Bank (2004) has recognized the informal sector as a source of alternative services for the poor and crucial for inclusive development [45]. Third, the efficiency and performance assessment of informal enterprises will provide directives for the formal sector's development, as these two are positively linked in Bangladesh's economy [46]. Fourth, estimation of the unaccounted load to the environment by the construction of PLI and its inclusion in the eco-efficiency analysis. This inclusion is relevant to socio-economic and safety concerns, which were integrated into the CP concept in 1998 b y the United Nations Environment Program (UNEP).

2. Literature review

There is not much literature on the advancement of knowledge about the adoption of cleaner production (CP) practices in informal sector industries and its contribution to the Sustainable Development Goals (SDGs) from a holistic perspective. Despite having a large volume of literature on SDG, a further understanding is required to link the adoption of CP principles in informal firms with the achievements in the economic, environmental, and social dimensions of SD. Recent research works are focusing to this end. Significance of CP as an aided effort to achieve SD by conservation of raw materials and energy, removal of toxic raw materials, and reduction of the amount and toxicity of all wastes was discussed in a study by Refs. [10,12]. Economic and environmental gains resulting from the implementation of CP in small enterprises in the metal and machine industries are evaluated by Ref. [10]. According to the findings of this study CP practice through the implementation of waste water treatment stations in the manufacturing process leads to l economic gains, promotes efficient use of raw materials and environmental improvements [47]. reviewed the cleaner production concepts in the electroplating industry. They opined on the efficient use of natural resources and energy and the reduction of risks for humans and the environment throughout the lifecycle of a product, which are the core principles of CP. In a similar review [8] has stated that CP can be implemented by reducing waste and pollutants, increasing production efficiency and lowering risks to humans and environment. Based on the lessons learned from the setbacks due to the occurred incidents [7] found it necessary to upgrade the efficiency models as the negative effects of industrialization on the environment, human survival, and further production improvement became more visible with the deepening of industrialization.

Efforts to increase efficiency in manufacturing process by adopting clean technologies, replacing hazardous raw materials, improving management, initiating intensive research and development are highlighted by Ref. [9]. Using eco-efficiency of the Data Envelopment Analysis (DEA) and comparing desirable output with undesirable output [14] showed that most efficient countries in EU member states had higher economic growth and per capita income [48]. first evaluated industrial eco-efficiency in Chinese provinces using DEA and then identified the determinants of the resulting eco-efficiency scores. Technological deficits and weak environmental policies were identified as the reasons for lower industrial eco-efficiency in this study. Eco-efficiency analysis was also conducted on coal industries in China by Ref. [13], on coal industry ecosystem in China by Ref. [49], on the heavy pollution industries of China by Ref. [5], on European Railways by Ref. [50] using a network DEA model. All these studies were based on secondary data and projected efficiency trends.

The potentiality of the informal sector as a key element in the struggle towards sustainability was explored by Ref. [51]. This study focused on how the informal economy could encourage the sustainable use of resources and could offer an alternative to the regulated market economy. However, a significant relationship between informal economies and higher level of pollution was evident in a number of studies [19,49,52–58]. The findings by Ref. [27] have revealed that the environmental regulations are not effective in the informal sector and it relies on conventional energy sources. The results also revealed a mixed picture for South Asian countries in terms of their contribution to emissions. The informal sector was shown to be a long-term driver of ecological footprint levels when it was linked to formal economies in an investigation by Ref. [58] on Turkey [59]. found the positive influence of the informal sector on emissions of local pollutants and no significant impact on global pollutants, i.e., CO_2. They pointed out that since the informal sector in developing countries mostly relied on labor-intensive production techniques and utilized less energy, it led to lower levels of emissions. An inverted U-shaped relationship between the informal sector and environmental pollution was also revealed by Ref. [19] for 152 countries and for China by Ref. [60]. [55] opined that the nexus between the informal sector and environmental management should be considered the bedrock for the sustenance of urban areas in low-income countries.

Considering the diverse impact of the informal sector on environmental pollution, which can be explained by their low productive efficiency, it appears critical to assess the potential of this sector in CP, which is a significant parameter in the SDG. However, no study has been found so far that captures the performance of informal firms in CP either by efficiency or by eco-efficiency analysis. In the African context, research towards generating quality information on assessing the informal SME's potential was stressed by Ref. [21] since urban precincts of the informal sector were considered to be the root cause of many problems. In urban areas of Bangladesh [57], conducted a study on the brick kiln industries under the informal sector, and those were found to be unprofitable after incorporating the health impact and other social costs of pollution associated with this industry.

Reviewing the available literature, this study has been convinced that there exists a lack of research on CP prospects and progress towards attaining SDG targets. Firms in the informal sector are neglected in this, particularly in environmental efficiency analysis to offer quantitative evidence in the CP prospect. To fill this gap the present study subscribes to the importance of CP for informally operated firms in different industries by assessing empirically their efficiency-pollution nexus. It can provide an important insight into policy measures for moving forward with the CP agenda, particularly in the face of informal sector growth and environmental degradation.

3. Material and methods

3.1. Data

This study is conducted for informal manufacturing firms, and primary data is collected at the enterprise level from three different areas of the capital city, Dhaka, Bangladesh. The enterprises were selected based on the criteria provided by ILO (2018): unincorporated private firms with no permanent premises, registered at the local level (not at the national industrial authority), not maintaining accounts (no formal bookkeeping), no social security contribution, and no tax on wages [61]. A structured questionnaire was used to collect information from 90 enterprises (in total) that were operating informally during the period between August and December 2021. Therefore, the used data set was cross-sectional. Three types of small manufacturing industries were chosen using a stratified sampling technique. The selected industries are: leather and leather products; plastic and small machinery; dyeing and clothing. Survey areas were selected based on the information of cluster setup of the particular type of firms in the area. Hemayetpur area was selected for interviewing firms in the leather and leather products industries, Lalbagh (including Islambagh) area for plastic and small machinery, and Keraniganj area for the dyeing and clothing industries. Each area was divided into small zones for the collection of environmental samples, and firms for the interview were selected from the zones in a nearly equi-proportional manner. A total of 30 firm owners/managers were interviewed from each area, and firms with no more than 10 full-time workers were qualified for the interview [following [62]]. Before the interview, the enumerators provided sufficient information to the respondents regarding the aims and objectives of the study to avoid any bias in answering questions. Each interview began after the respondents signed the consent forms that were supplied. During data collection, researchers as well as the enumerator follow all the ethical norms considered by the University of Southern Queensland (USQ), Australia (USQ HREC ID: H21REA014).

The survey questionnaire began with the demographic information of the respondents and then moved on to the questions about the average volume of total output per month, price per unit of output, number of workers (full-time and part-time), wage per workers, average cost of raw materials. The questionnaire also enquired about firms' engagement with emission control technology, subcontracting and its type, and access to and availability of loans for business purposes. Following [63,64], this study considers labor and raw material costs (yearly) needed for the production as input variables, while output variables are divided into desirable output and undesirable output. Revenue of firms (annual sales expressed in monetary units) is considered a desirable output, and the metallic pollution load generated by indiscriminate emissions discharge from the production units in the surrounding area is considered an undesirable output variable in this study. Cost and revenue data are calculated in BDT (One Bangladeshi Taka [BDT] = US$ 0.0099 approximately as of 13th November 2022). Econometric software packages STATA version 15, DEAP version 2.1 and EVIEWS version 10 have been used for the analysis of data.

For an understanding of how polluting these industries are, a Pollution Load Index (PLI) has been constructed in this study for two environmental compartments following [28,30,65]. Samples were collected for this from the soil and water of each area [based on the study by Refs. [34,38]]. The heavy metals Chromium (Cr), Nickel (Ni), and Lead (Pb), which have been identified as the most toxic elements in the environment by the US Environment Protection Agency (EPA) [28] and are claimed to discharge to the environment at different stages of industrial production due to the untreated nature of wastewater and dumping of solid waste, are considered for investigation.

3.1.1. Construction of pollution load index (PLI)

PLI is an integrated approach that assesses soil and water quality. This process aims to investigate the metal contaminants into the surrounding environment of the studied firms due to indiscriminate effluent discharge and solid waste dumping. PLI calculation procedure was adopted from Ref. [28]. Contamination of hazardous materials (Cr, Ni, and Pb) was investigated in the surface soils and water either released from firms or stored in nearby water bodies. PLI was calculated for soil and water sample using the following formula:

$$PLI = (CF_1 \times CF_2 \times \ldots\ldots \times CF_z)^{\frac{1}{z}}$$

Where, CF represents the Contamination Factor and z is the number of samples collected from each studies area. CF is an essential tool to monitor heavy metal contamination. It is individual for each heavy metal as it is the ratio between the concentration of heavy metal (C_{hm}) and the background value of that heavy metal (C_b).

$$CF = \frac{C_{hm}}{C_b}$$

The background value of the metals are mentioned in the Appendix. All the chemical diagnosis were done in a chemical laboratory for the determination of total concentration of selected heavy metals (Pb, Zn, Cu) in both soil and water. The Pollution Load Indices (PLIs) was derived from the obtained concentration level of heavy metals in soil and water for each sample and then combined together associating with an equal weight to find a composite PLI. All the instrumental and technical supports for this scientific analysis were provided by Dr. Wazed Mia Science Research Center (WMSRC), Bangladesh and the Department of Environmental Science, Jahangirnagar University, Dhaka, Bangladesh. The details of study area, sample collection and data processing methodology for PLI construction are presented in the Appendix.

4. Methods

Data Envelopment Analysis (DEA), a non-parametric approach, is applied in this study for empirical analysis. It is a mathematical optimization technique to measure the relative efficiency of each studied unit, named a decision-making unit (DMU), that converts the input into output under the conditions of multiple inputs and outputs [66–69]. DEA (BCC) model based on variable returns to scale (VRS) [70] has been applied to this study, which is a radial model, and is widely used to evaluate environmental issues [66]. This input-oriented DEA model is a cost-saving representation of the production process that serves as an explicit measure of efficiency change even when undesirable outputs are integrated into the analysis. The decision to choose this orientation is also influenced by the probable control of the managers over input quantities see [71], in the context of the present study. DEA perceives an efficiency frontier by accepting the most efficient DMU as a reference point and calculating the other DMUs' efficiencies in a relative sense based on their distances to this reference point [66,72].

This study assumes that there are *n* DMUs and m inputs are used by each of them to produce Q outputs. M is the (mxk) input matrix and Q is the (qxk) output matrix where $j \in I_N : I_N = \{1, 2, ..., n\}$, an index of set of firms. The inputs and output vectors of the firms are expressed as $x_j \in R^m$ and $y_j \in R^q$ respectively. Economic efficiency is obtained by ensuring maximum benefit from a given cost or minimizing the cost of a given benefit. In this study efficiency (allocative) describes the use of two inputs namely, labor and raw materials by DMUs in the proportion that minimizes the cost of production when input prices are given [73]. The model (model-1) can be stated as follows:

$$Min\ \vartheta_e$$

s.t.

$$\sum_j v_j y_{qj} - s_q^+ = y_{qe}, q = 1, 2, \ldots, Q$$

$$\sum_j v_j x_{mj} - \vartheta_e x_{me} + s_m^- = 0, m = 1, 2, \ldots, M$$

$$\sum_j v_j = 1$$

$$\mathrm{v_j} \geq 0, \mathrm{j} = 1, 2, \ldots, \mathrm{n}$$

$$\mathrm{s_q^+} \geq 0, \mathrm{s_m^-} \geq 0, \forall \mathrm{q, m}$$

Where, DMU e is the unit under evaluation and ϑ_e is the efficiency scores.

4.1. Tobit regression model

Tobit regression, a variable limited model, is used to investigate how environmental and production management factors affect firm efficiency level. In Tobit regression, the dependent variable is modelled as the censored data, where the observation of compliant drivers can be clustered at a threshold value of zero (left censored in Tobit literature). Non-compliant drivers are kept as continuous data for representing the magnitude of non-compliance [35,74]. Tobit regression can be expressed as

$$Y_i^* = \alpha + \beta X_i + \varepsilon_i i$$

$$Y_i = Y_i^*, if\ Y_i^* > 0$$

$$Y_i = 0, if\ Y_i^* \leq 0$$

Where, Y_i is the dependent variable calculated using a latent variable Y_i^* for positive values and censored otherwise. X_i is a vector of independent variables, α is the intercept vector and β is the coefficient vector. ε_i is the error term where $\varepsilon_i \sim (0, \sigma^2)$. Maximum likelihood (ML) method is more appropriate in this cases since the ordinary least squares (OLS) regression projects biased result where the dependent variable is partial continuous. Here the dependent variable is the efficiency index that is bound between 0 and 1 values and derived from DEA. The firm level efficiency function can be written as:

$$E_i = \alpha + \beta_{1i} PLI_i + \beta_{2i} Tech_i + \beta_{3i} Loan_i + \beta_{4i} Subcont_i + \varepsilon_i$$

Here, E_i represents DEA VRS efficiency scores, *i* indicates the number of DMUs, The independent variables considered in this model are pollution (*PLI*), use of pollution reducing technology (*Tech*), access to loan (*Loan*) and engagement of firms in subcontract arrangement (*Subcont*). Since it is difficult for informally operated production units to unveil the exact level of emissions and the pollution damage estimate values for each DMU, indexed values of metalloid pollution load (PLI) in soil and water are used as the main explanatory variable by allotting those to the relevant firms. Use of pollution reducing technology [64], access to loans, and engagement of firms in subcontract arrangements that may influence business strategy [mentioned by Ref. [75]] are also considered as influencing factor of economic efficiency along with PLI [35,64,76]. The selection of these explanatory variables is guided by a disregard for environmental practices, such as waste reduction and proper dumping, minimum resource use, and recycling [77,78], as well as limitations in capital and labor performance, firm management, and technology adoptions by informal SMEs [77,78] that provoke the assumption of the presence of undesirable outputs (i.e. pollution) in the production process of informal firms [7].

Since the solution of the ecological problems is the key to achieving sustainable economic, social, and ecological development, this study has applied DEA for environmental analysis and estimated eco-efficiency in the next stage, where undesirable (bad) outputs such as pollution or emissions also come into consideration apart from inputs and desirable (good) outputs [13,79–81] Production process improvement was the first of four basic approaches to eco-efficiency proposed in WBCSD (1992), and the present study attempts to focus on that through eco-efficiency assessment for the achievement of SD. Schaltegger and Sturm (1990) first proposed the concept of eco-efficiency in 1990 which involved the creation of more economic value with less environmental impact [7,82]. The current study adheres to Li and Luo's (2016) definition of environmental efficiency, where it is implied by a certain area that uses fewer environmental resources and produces less ecological impact to provide products and services targeting to meet human needs [5,11]. Eco-efficiency deals with the key problem in achieving SD by progressively working with the aim of obtaining more economic benefit with least environmental damage [14].

At this stage, $y_j = (y_j^g, y_j^b)$, which indicates the total output vector is separated into two sub-output vectors, where, $(y_j^g : q \in I_g : I_g = \{1, 2, \ldots, k\})$ is the k output vector of desirable outputs, and $y_j^b : q \in I_b : I_b = \{k+1, k+2, \ldots, Q\})$ is the remaining $(q-k)$ output vectors that are undesirable (bad) outputs i.e. environmental load (PLI) created by unaccounted pollutant discharge but remain unaccounted. Undesirable outputs can be treated as inputs, and the idea was proposed by Ref. [83]. [84,85] applied this to calculate environmental efficiency [16]. This method infers a negative effect of undesirable output levels on efficiency, and hence it is non-decreasing in desirable outputs and non-increasing in undesirable outputs. In this study, the eco-efficiency of firms is captured by reducing resource usage and decreasing environmental damage [84]. Taking insight from Refs. [67,80,86,87] the input oriented model (model-2) with undesirable output (as input) can be stated as,

$$Min\ \vartheta_e$$

s.t

$$\sum_j \nu_j y_{qj}^g - s_q{}^g = y_{qe}^g, q = 1, 2, \ldots, Q^g$$

$$\sum_j v_j y_{qj}^b - \vartheta_e y_{qe}^b + s_q{}^b = 0, q = 1, 2, \ldots, Q^b$$

$$\sum_j v_j x_{mj} - \vartheta_e x_{me} + s_m{}^- = 0, m = 1, 2, \ldots, M$$

$$\sum_j v_j = 1$$

$$v_j \geq 0, j = 1, \ldots\ldots., n$$

$$s_q^g \geq 0, s_q^b \geq 0, s_m^- \geq 0, \forall q, m$$

5. Results

5.1. The results from the estimation of PLI

The summary statistics of the concentration factor of selected heavy metals in soil and water samples collected from the studied areas are presented in Table 4 of the Appendix. Environmental samples were collected in the period August–December 2021 (a juncture of wet and dry seasons) and the scientific investigation found a base level of contamination for most of the studied metals in

Table 1
Results of Contamination Factor (CF) analysis and PLI.

Location	Soil					Water				
	Pb	Ni	Cr	Degree of Concentration	PLI	Pb	Ni	Cr	Degree of concentration	PLI
Hemayetpur	0.01	0.16	1.29	1.45	0.05	0.05	0.38	50.16	50.69	0.95
Lalbagh	2.34	0.53	0.12	2.98	0.52	0.45	0.22	0.01	0.67	0.02
Keraniganj	6.41	0.17	0.05	6.63	0.39	0.01	0.51	4.23	4.23	0.10

Note: Background value of the metals: Pb 20, Ni 49 and Cr 97 [Sources [28,98]].
PLI = 0 => Perfection, PLI<1 => Baseline Level Contaminants.
PLI> 1 => Progressive deterioration of soil due to metal.

the collected soil and water samples. Only a few samples of soil and water projected a high contamination factor score. The results of concentration factor analysis and area wise PLI scores are presented in Table 1. These results are also presented graphically in Figs. 1 and 2 for soil samples and in Figs. 3 and 4 for water samples. Flow diagram of environmental parameter analysis is presented in Fig. 6 of the Appendix. The applied procedures of water and soil samples digestion for metal detection are presented diagrammatically in Figs. 7 and 8 of the Appendix, respectively.

Table 1 projects that the levels of metal contamination in soil and water samples of all three studied areas are low (less than the first cutoff value 8), except for Cr in the water sample from Hemayetpur and for Pb in soil sample of Keraniganj. The contamination factor (CF) was the highest for Cr in water samples collected from Hemayetpur area. Its CF value for soil was 1.29, indicating a moderate level of contamination, and for water it was 50.16, indicating a very high level of contamination. Other heavy metals (Pb and Ni) were found to be at a low level in the areas. As leather tanning industries, where chrome tanning is used in the tanning process, are located in the Hemayetpur area, tannery industries can be identified as a possible source of Cr pollution. Workers, entrepreneurs, and residents of this area remain at high health risk due to Cr pollution in the area since Cr is mutagenic and carcinogenic to humans [88].

At Lalbagh, the CF value of Pb in soil was 2.34 and in water was 0.45, indicating moderate and low-levels of contamination, respectively. The CF values of Ni in soil and water samples of the Lalbagh area were 0.53 and 0.22 respectively, which indicated a low-level of contamination. Ni is commonly used as a major alloying element [89], so the likely sources of Ni in the studied samples were the machinery industries nearby. Pb stabilizers such as Pb sulfate, Pb stearate, etc., are used as common additives [90–92], and the probable sources of Pb in the samples are the nearby plastic industries. Dermal absorption of Pb and Ni into the human body may impose an important risk for developing cancer [60,93].

At Keraniganj, the CF value of Pb in the soil was 6.41, indicating a very high level of contamination, and the CF value of Cr in the water was 3.71, indicating a considerable level of contamination. As an individual metal, the CF value of Ni was highest in the water samples of Keraniganj (0.51), although it indicated a low-level contamination. Pb and Cr are widely used in the production of color pigments for textile dyes [94]. Hence, nearby textile dyeing industries were the probable sources of Pb and Cr discharge that are mutagenic and carcinogenic to humans [88,93].

5.2. *Result of efficiency analysis*

The summary of the utilized DEA model is presented in Table 5, and the summary of input and output variables used in efficiency estimation is presented in Table 6 of the Appendix. The relative efficiency scores of firms under each category of industries (the DMUs) are obtained from the estimation of an input oriented DEA model where pollution load has been ignored (model 1). The result (obtained from using econometric software DEAP version 2.1) is presented in Table 7 of the Appendix. Variable Returns to Scale (VRS) represents the measure of the amount by which all inputs can be reduced to produce the same output as the DMUs move from the variable returns to scale frontier to the constant returns to scale frontier. However, the VRS scores in the DEA outcome reveal a very low level of efficiency for all categories of informal enterprises, which is quite expected due to their informal organizational structure. Under the assumption of VRS, the average CRS efficiency score of selected firms in the leather industry is the lowest at 8.6%, and the average VRS efficiency score is 13.8%, which implies that on average, leather firms are highly inefficient in economic considerations. For scale efficiency, the average score is found to be 67.9%, which indicates that the actual scale of production has diverged by 32.1% on average from the most productive scale size in leather industries. The average CRS score for studied firms under plastic and small machinery is 33.9%, and the average VRS score is 44.2%, while their average scale efficiency is 77.5%. Selected firms in the dyeing and clothing industries project an average CRS score of 24.7% and a VRS score of 37.7%, although their scale efficiency score is 77.3%.

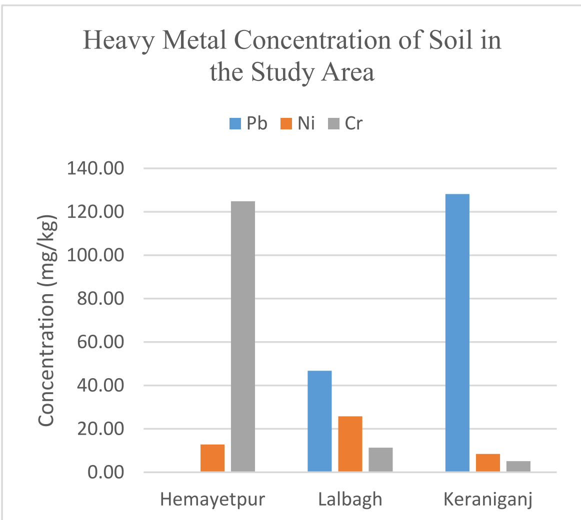

Fig. 1. Heavy metal (Pb, Ni, Cr) concentration in soil.

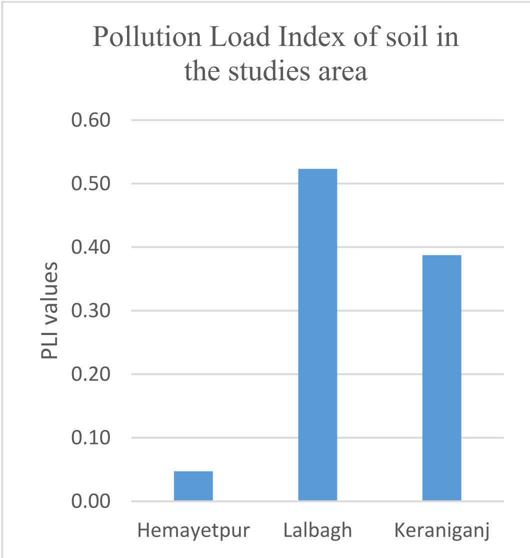

Fig. 2. PLI for soil sample in three studies area. Source: Author's own calculation.

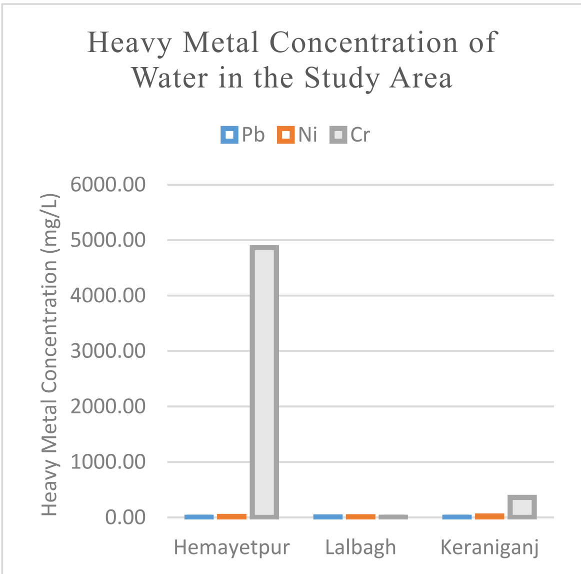

Fig. 3. Heavy metal (Pb, Ni, Cr) concentration in water.

5.3. *Result of tobit regression*

The Tobit regression result is presented in Table 2. The outcome reports that the economic efficiency levels of two out of the three categories of informal firms are significantly linked to the pollution generated by the firms.

The efficiency levels of firms in the leather, and dyeing and clothing industries are positively associated with the pollution level of the surrounding area, for which the firms themselves are responsible. The positive and significant correlation between these two variables reveals the fact that a high level of pollution is the inevitable cost of efficiency for informally operated firms in these two industries. This indicates, economic efficiency can be achieved or enhanced in these firms at the cost of the environment due to their dependency on low-cost environmentally harmful inputs and/or production technology, unskilled cheap labor, indecent work conditions, and poor waste disposal practice as the cost-minimizing strategy. The PLI Coefficient for firms in the plastic and small machinery industries has come up with a negative sign (which is expected in an ideal context), and projects no significant relationship with efficiency. The low level of pollution concentration in the surrounding area of the plastic and small machinery firms and the comparatively higher level of efficiency scores may contribute to this relationship. This result has confirmed that informal firms in the

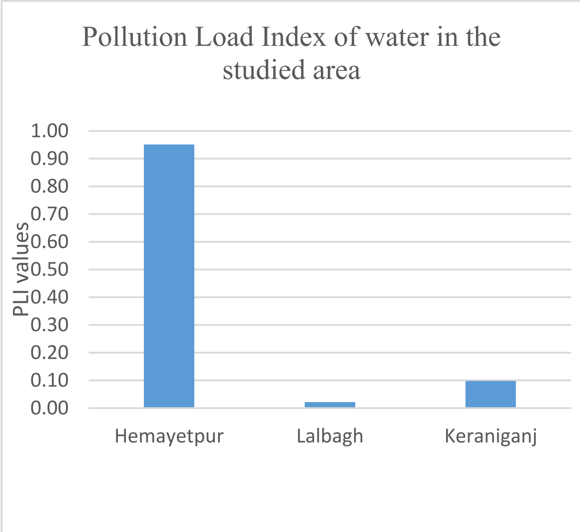

Fig. 4. PLI for water sample in three studies area. Source: Author's own calculation.

Table 2
Result of Tobit regression.

Explanatory variables	Leather industries			Plastic and small machinery industries			Dyeing and clothing industries		
	Coeff	SE	t-score	Coeff	SE	t-score	Coeff	SE	t-score
PLI	0.015***	0.005	3.02	−0.010	0.008	−1.16	0.025***	0.006	4.40
Tech	0.037	0.037	0.41	−0.097	0.149	−0.76	−0.161	0.102	−1.58
Loan	0.136	0.088	1.55	−0.109	0.144	−0.65	−0.038	0.098	−0.39
Subcont	−0.016	0.082	−0.20	0.051	0.133	0.38	−0.058	0.091	−0.63
Cons	−0.069	0.102	−0.68	0.574***	0.167	3.44	0.303	0.114	2.66

Note: *** represents statistical significance at 1% level, ** represents statistical significance at 5% level and * represents statistical significance at 10% level.

leather, and dyeing and clothing industries are polluting and operating far from CP practices in their production, whereas the firms in the plastic and small machinery industries pose no threat to CP.

5.4. Result of Eco-efficiency analysis

This study attempts to find the future CP prospects of informal firms by estimating efficiency scores after addressing environmental issues in the model, having confirmed the positive correlation between pollution and economic efficiency of informal firms in two industries. Fig. 5 depicts the average economic and environmental efficiency scores of informal firms operating in three industries.

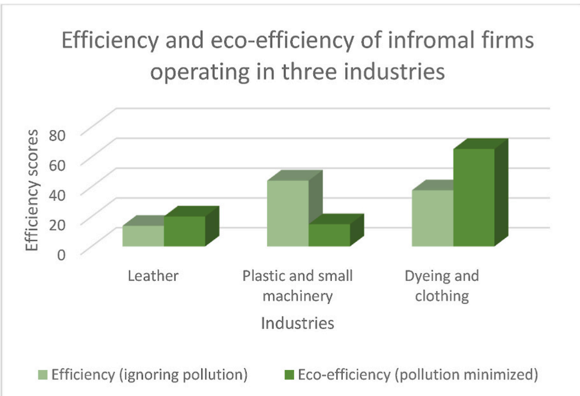

Fig. 5. Average economic and environmental efficiency of informal firms operating under three industries.

In the eco-DEA model, pollution load, which is an undesirable output of informal production, has been minimized with other inputs considered. The average VRS efficiency scores are found to be increasing in the eco-DEA model estimation outcome for two categories of industries that are polluting. Average efficiency increases by 6.3% for firms in the leather industry and by 27.6% for dyeing and clothing industries after minimizing the pollution load like other inputs. However, efficiency decreases by 29% for the plastic and small machinery industries, may be due to observed insignificant pollution load in the environmental components of the surrounding area of these firms. The scale efficiency of firms in all industries decreases after minimizing pollution load in production. This indicates the high cost of pollution abatement, which enhances the economic vulnerability of firms in the prevailing context and is the ultimate reason for not approaching towards eco-efficiency. The details of the eco-efficiency estimation outcomes (obtained from using econometric software DEAP version 2.1) are presented in Table 8 of the Appendix, while the results of Tobit analysis incorporating eco-efficiency outcomes with the same independent variables are presented in Table 3 below in order to confirm the pollution-eco-efficiency nexus.

The results in Table 3 show that the correlation between pollution and eco-efficiency becomes insignificant for the informal firms in most of the industries (Plastic and machinery, and dyeing and clothing) and it projects a significant negative relationship for the firms in leather industry, which is expected in general. Access to loans increases eco-efficiency for the firms in leather industry whereas access to loans and subcontract agreements both contribute to increase the eco-efficiency of firms in plastic and small machinery industries.

5. Discussion

In the prevailing scenario, metallic pollution, for which informal manufacturing firms are responsible, is significant in its relation to economic efficiency of informal firms for most of the categories under study (the leather and dyeing and clothing industries). The higher the level of pollution, which is sourced from their own production practices, the greater the economic efficiency for firms in these industries. However, this nexus can be altered along with efficiency improvement if firms move to achieve eco-efficiency by minimizing their pollution load. Only these practices and measures taken by informal firms for pollution reduction and control can help materialize the CP agenda in informal industrial units and lead to the achievement of SDG targets. However, a reduction in scale efficiency in an attempt to minimize pollution indicates that environmental considerations drag firms further away from the optimal operation since firms have to face technical and financial constraints to bear the expenses associated with minimizing pollution load. This will make firms less competitive unless they receive any external support.

The environmental efficiency estimated in this paper is relative. These efficiency results are in line with the findings of [95,96] for China. The increase in efficiency levels of polluting firms after their pollution minimization may be due to the fact that environmentally legitimate firms can attract customers and utilize labor and resources more successfully than poor performers [39]. Another reason may be that a less polluted work environment helps to promote sound health and increases the productivity of workers and entrepreneurs. The eco-efficiency outcome of this study finds the future prospect for CP in informal sector enterprises in the urban areas of Bangladesh if and only if enterprises and other stakeholders take adequate measures to address firm-level pollution issues. In the present scenario, achieving eco-efficiency in informal firms is a far-reaching goal since they are not financially and technologically capable enough to carry out CP practices in their production process. They needs considerable attention from policymakers, governments and non-governmental organizations for the realization of sustainable manufacturing, Otherwise, it will take a toll on the surrounding environment and people's health in the neighborhood of the informal firms. This result justifies Target 3 under SDG 8 for the productivity improvement and gradual transformation of informal firms towards formalization since they impose a threat to the environment and human health that should be prevented with proper attention.

6. Conclusion and policy suggestions

This study has estimated the economic efficiency level of firms operating in the informal sector of urban Bangladesh by adopting an input-oriented DEA method and has explored pollution as a plausible factor affecting the efficiency level of informal firms. With an ultimate aim of investigating the prospect of informal firms in SD through the achievement of CP, this study captures the metallic pollution load generated particularly by these firms. Cr contamination is found to be high in water samples around firms in the leather industry (in Hemayetpur area), and Pb contamination is found to be alarming in a soil samples around firms in dyeing and clothing

Table 3
Result of Tobit analysis for eco-efficiency outcome.

Explanatory variables	Leather industries			Plastic and small machinery industries			Dyeing and clothing industries		
	Coeff.	SE	z-score	Coeff.	SE	z-score	Coeff.	SE	z-score
PLI	−0.004**	0.002	−1.926	−0.038	0.039	0.958	0.001	0.006	0.146
Tech	−0.100	0.136	−0.737	−0.314***	0.121	−2.592	−0.045	0.125	−0.390
Loan	0.387**	0.164	2.369	0.289**	0.129	2.242	0.008	0.113	0.076
Subcont	−0.018	0.128	−0.144	0.378***	0.133	0.107	3.523	0.106	−0.409
Cons	0.221	0.156	1.409	0.005	0.141	0.036	0.841***	0.131	6.419

Note: *** represents statistical significance at 1% level, ** represents statistical significance at 5% level and * represents statistical significance at 10% level.

industry (in Keraniganj area), although the other metallic ingredients are seen at a tolerable level for rest of the collected samples. The empirical results obtained from Tobit regression analysis have revealed a significant positive correlation of pollution on firm-level efficiency for these two above mentioned industries, which evident the polluting nature of the informal firms operating in these two industries. This result reveals a lack of CP practice in these two categories of informal firms under the existing economic arrangements.

In this a context, the current study has investigated the CP prospects of these firms by minimizing undesirable output (pollution load) in the DEA model. Estimating the eco-DEA models, the result implies that firms can enhance their efficiency even after their pollution minimizing efforts, compared to the situation where pollution burdens are ignored. Thus, by taking care of pollution in production, informal enterprises can contribute to CP and sustainability and alter the positive pollution efficiency nexus. However, SMEs that are operated under informal arrangements, face constraints in accommodating pollution in their production process due to the high cost associated with it. Firms become less competitive in price if they take measures to minimize pollution or produce environment-friendly outputs. Therefore, the relevant authority should come forward to materialize CP arrangements in informal firms since the application of conservative command and control regulation to those small and medium firms seems to be difficult in its implementation, although very rational [26,56]. According to ILO (2010), if a decent environment is created in informal sector firms, it could be a part of greening the economy [97]. However, the present context of the informal manufacturing firms that has been revealed by this study is not impressive, although perceives future potential with the precondition of achieving technical, financial, and managerial improvements. Bringing the informal firms under formal coverage can be the first step in improving the scenario. Benefits provided under formal arrangements can address the inefficiency of most of the informal firms, which has been realized by the outcome of the DEA analysis of this study, and the impact of pollution, which has long-term disadvantages for humans and the ecology. This study also states the need for the substitution of raw materials, the improvement of the production technology, and the use of more efficient production methods that can be important initiatives for CP development in these enterprises.

The findings of this study will justify policy measures proposed by global bodies to limit the size of informal industrial enterprises in Bangladesh and other developing countries from both economic and environmental considerations. Meanwhile, the strategy of implementing indirect environmental regulations, adopting financial and/or technological support policies, utilizing social capital, and implementing information-based policy such as educational programs that publicize information about pollution to build awareness can put forward to uphold CP. Firms can also be encouraged to invest in innovative technologies to achieving this. Rigorous environmental stewardship campaigns to create inclusive and environment-friendly economic activities in urban areas can also be carried out. Due to the inapplicability of direct environmental regulatory instruments to informal sector enterprises, enterprise owners' awareness of adopting eco-efficient technology and using environmentally friendly products, as well as more efficient resource management, can help to achieve a decent work environment in informal sector firms and prevent pollution to the surrounding environment. Thus, the practice of corporate social responsibility (CSR), which is based on three pillars; economy, environment, and society, will be ensured and help in pursuing SD. Implementation of CSR by informal firms will make them socially and environmentally responsible [see Ref. [78]]. Simultaneously, at the national level, targeted policy measures on challenges faced by informal SMEs, such as access to credit and finance, proper location and networking, the legal and regulatory framework, and technological development, can be addressed to facilitate green development concepts in urban areas by ensuring CP in informal production and business. Since small-scale production in the informal sector continues to exist in the economy due to slower absorption mechanism into the modern, formal economy [see Ref. [17]], proper planning, motivation, and adequate support for informal production and business throughout the process of formalization will make them committed to meeting social and environmental needs, which underpin CP concepts. This will also ensure economic returns that will safeguard not only the quality of economic growth but also social welfare and environmental sustainability.

Author contribution statement

Nahid Sultana: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Mohammad Mafizur Rahman: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data.

Rasheda Khanam: Conceived and designed the experiments.

K.M.Zahidul Islam: Analyzed and interpreted the data.

Md. Rayhanul Islam Rayhan: Performed the experiments.

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Data availability statement

Data will be made available on request.

Declaration of interest's statement

The authors have no competing interest to declare.

Supplementary content related to this article has been published online at [URL].

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2023.e14583.

Appendix

Brief description of the studies areas

Hemayetpur area consists of several small-scale tanneries and leather product-producing firms. The tannery industry uses a lot of water for leather processing purposes. The wastewater is designed to disperse into a central treatment plant (CETP) and after treatment discharges into the nearby river Dhaleshwari. However, some untreated wastewater is seen to overflow from the drains before reaching CETP and logs onto the surface due to a poor drainage system. These untreated effluents impose a crucial public health concern. A total of 5 water samples were collected from the nearby areas of interviewed enterprises where they were found to overflow from the drainage water and transported to the environmental compartment either by logging or by surface runoffs. A total of 3 soil samples were also collected from the periphery area of interviewed firms. The Lalbagh (including Islambag) area is located on the bank of the river Buriganga. A large number of small-scale plastic and machinery firms are situated in this area. The ultimate destination of the effluent from these plastic and metallic industries is the nearby Buriganga river. There is a drainage channel through which industrial effluents are discharged into the river. A total of 5 water samples were collected from the effluent discharge of surveyed farms. A total of 3 soil samples were also collected. Keraniganj, another area on the river Buriganga where many dying, fabrics and clothing industries are located. Untreated effluents from these industries are also discharged into the Buriganga river stream through the poorly maintained drainage channel. A total of 4 water and 4 soil samples were collected from this area. All the samples were transported, preserved safely following due procedure and tested in a well-equipped and well-recognized laboratory to find the metallic concentration levels. The details of the PLI construction utilizing these concentration values are presented in the following sub-section.

Scientific Procedure for the assessment of metallic concentration in soil and water samples.

Flow Diagram of Environmental Parameters Analysis (Fig. 6).

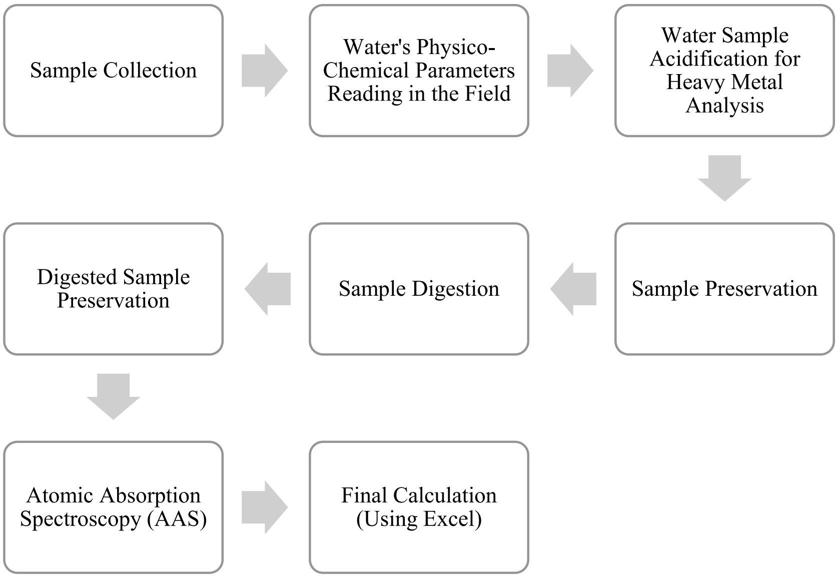

Fig. 6. Environmental Parameters Analysis.

Sample preservation

A gross total of 14 water and 10 soil samples were collected from the studied area. The water samples were collected in cleaned plastic bottles, pre-washed with 20% nitric acid (HNO_3) [99] and double-distilled water. Two 250 ml bottles were used in each sampling point. One is for physicochemical parameters analysis another is for heavy metal analysis. To measure the heavy metal concentration, 65% concentrated HNO_3 was added to each sample by dropper immediately after collection to keep the pH below 2 to minimize precipitation & adsorption onto container walls [100]. The physicochemical parameters (pH, EC) were measured at the field. The samples were then transported using an icebox to the laboratory of Environmental Sciences, Jahangirnagar University, Savar, Dhaka-1342. Samples were labeled correctly and preserved in the refrigerator at below 4 °C.

The soil samples were collected using an excavator to dig the soil at (0–40 cm) depth [101]. After digging up, almost 250 g m of soil was collected in the zipper polybag. The collected soil samples were transported to the abovementioned laboratory & preserved in the refrigerator at below 4 °C.

Sample Digestion Procedure

Samples are digested to reduce interference by organic matter and to convert metals associated with particulates to a form that can be determined by atomic absorption spectrophotometer (AAS).

Surface water sample digestion

Water samples were digested with concentrated HNO_3 acid for heavy metal determination as described by Ref. [100].
Apparatus:
The required apparatuses were.

1. Beaker
2. Hot plate (Model MS300 H s, MTOPO, Korea)
3. 100 ml volumetric flasks
4. Pipette
5. Glass rod

Reagent:
The required reagents were.

1. 65% conc. HNO_3 acid, analytical or trace-metals grade had been used
2. HCl acid

Procedure:
100 ml distilled water and 5 ml 65% concentrated HNO_3 acid was added for digestion. The solution was heated at 105^0c in a digital hot plate in a fume chamber. Then the solution was slowly boiled and evaporated on a hotplate to the lowest volume possible. Continue heating until digestion was completed as shown by a light-colored, clear solution. After cooling, beaker was washed down with distilled water and transferred solution into volumetric flask to make 50 ml. Then the solution was filtered by Whatman (0.41 μ m pore size) into the plastic bottle and finally taken the sample for analysis by AAS. Along with the water samples, a blank sample was digested. The total procedure is given in (Fig. 7).

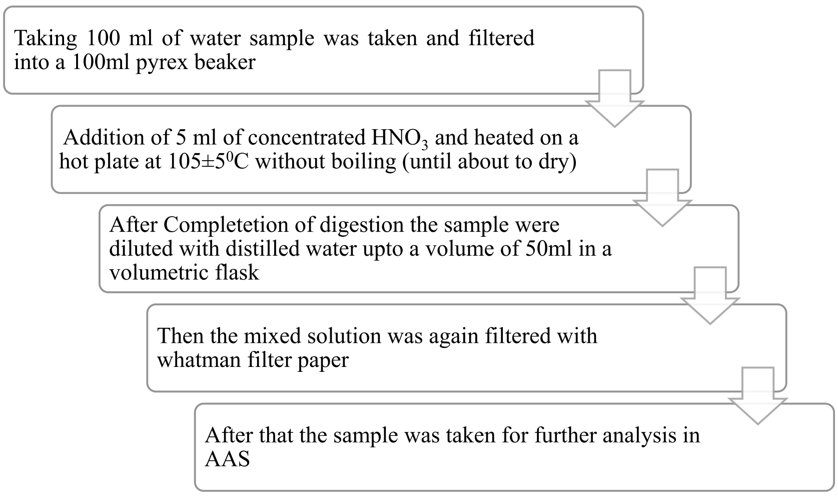

Fig. 7. The procedure of water sample digestion used for metal detection in AAS.

Soil Sample Digestion
Soil sample were digested with concentrated HNO_3 acid for heavy metal determination as described by [102].
Apparatus:
The required apparatuses were.

1. Beaker
2. Hot plate (Model MS300 H s, MTOPO, Korea)

3. 50 ml volumetric flasks
4. Pipette
5. Glass rod
6. Digital Balance (Model JJ224BCE, SI NO. 142417043025)

Reagent:

The required reagents were.

1. 65% conc. HNO_3 acid, analytical or trace-metals grade had been used
2. HCl acid
3. 80% concentrated $HCLO_4$ acid

Procedure:

At first soil sample was mashed by mortar and sieved by a 1 mm sieve. 1 g soil sample was taken into a clean beaker by a balance, and 10 ml 65% concentrated $HNO_{3,}$ and 2 ml of $HCLO_4$ acid were added for digestion. Then the solution was heated at 140^0c in a digital hot plate in a fume chamber. Then the solution was slowly boiled and evaporated on a hotplate to the lowest volume possible. Continue heating until digestion was completed. After cooling, the beaker was washed down with distilled water and transferred solution into a volumetric flask to make 50 ml (4:1): 40 ml distilled and 10 ml conc. HCl. Then the solution was filtered by Whatman (0.41 μ m pore size) into the plastic bottle and finally taken the sample for analysis by AAS. Along with the soil samples, a blank sample was digested. The total procedure is given in (Figs. 3 and 8).

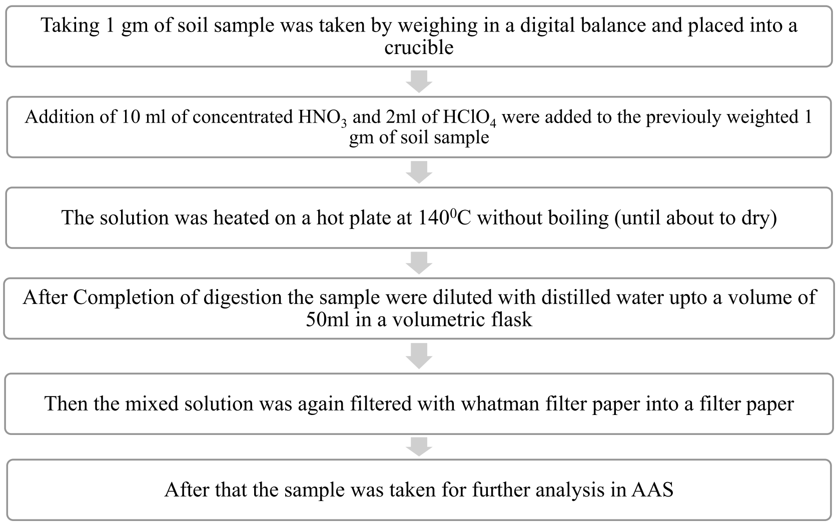

Fig. 8. The procedure of soil sample digestion used for metal detection in AAS0.

Atomic Absorption Spectroscopy

After completing the digestion process, the digested samples were preserved in the refrigerator at below 4 °C temperature. The metal was analyzed using Atomic Absorption Spectroscopy (Model-AA-7000; Shimadzu) in the South-Asian largest scientific laboratory named Wazed Miah Scientific Research Center.

Final Calculation:

After taking the reading from the AAS, the collected data was analyzed using Microsoft Excel. The following formula was used to determine the actual concentration of heavy metal in the water samples.

$$C_w = \frac{W \times 50 \times 1000 \times 1000}{1000 \times 100}$$

Where,

C_w = Metal's Concentration in water in µg/L.

W = Metal's Concentration derived from AAS reading in ppm - Metal's Concentration in ppm from blank prepared.

Standard permissible limit of metal concentration in inland water was adopted from Ref. [103].

The following formula was used to determine the actual concentration of heavy metal in the soil samples.

$$C_s = \frac{S \times 50 \times 1000}{1000}$$

Where,

C_s = Metal's Concentration in soil in mg/kg.

S = Metal's Concentration derived from AAS reading in ppm - Metal's Concentration in ppm from blank prepared.

Standard permissible limit of metal concentration in soil was adopted from Ref. [104].

Table 4
Concentration of Heavy Metal in Soil and water samples from the studied area.

Location	Statistics	Soil (mg/kg)			Water (mg/L)		
		Pb	Ni	Cr	Pb	Ni	Cr
Hemayetpur (n = 3)	Mean	0.01	12.80	124.83	0.91	18.50	4865.93
	Max	0.01	18.50	341.23	4.50	39.80	15349.00
	Min	0.01	8.07	13.10	0.01	5.35	0.01
	SD	0.00	5.28	168.91	2.01	12.74	6801.76
Lalbagh (n = 3)	Mean	46.77	25.78	11.30	8.99	10.76	0.01
	Max	93.54	35.82	18.82	22.45	24.75	0.01
	Min	2.70	14.31	0.01	0.01	0.01	0.01
	SD	45.48	10.83	9.96	12.29	9.75	0.00
Keraniganj (n = 4)	Mean	128.17	8.42	5.13	0.01	25.00	360.29
	Max	512.65	12.16	20.48	0.01	32.25	998.15
	Min	0.01	2.58	0.01	0.01	18.30	110.25
	SD	256.32	4.12	10.24	0.00	5.77	426.51

Table 5
Summary of DEA Models.

Total DMUs	90
Leather and leather products (located in Hemayetpur area)	30
Plastic and small machinery (located in Lalbagh and Islambugh area)	30
Dyeing and clothing (located in Keraniganj area)	30
Input used	2
Desired output used	1
Undesirable output used (as impact value)	1
Orientation for model	Input Oriented Model
Incorporation of undesirable output into the Model	As input
	As ratio of desirable output
Returns to scale	Variable Returns to Scale
Slack computation stage	One- stage

Table 6
The summary statistics of input and output variables

Area	Variable	Obs	Mean	Min	Maxi
Hemayetpur	Worker (full time)	30	11.28	4	20
	Wage (monthly in BDT)	30	10483.33	7000	15,000
	Raw material cost (yearly in BDT)	30	1,639,600	168,000	5,400,000
	Revenue (yearly in BDT)	30	28,300,000	450,000	3,000,000
Lalbagh	Worker (full time)	30	7.45	3	17
	Wage (monthly in BDT)	30	11216.87	7500	16,000
	Raw material cost (yearly in BDT)	30	461233.3	8000	6,552,000
	Revenue (yearly in BDT)	30	6,265,770	104,750	42,500,000
Keraniganj	Worker (full time)	30	8.95	2	18
	Wage (monthly in BDT)	30	11644.67	6000	17,000
	Raw material cost (yearly in BDT)	30	882,800	50,000	4,800,000
	Revenue (yearly in BDT)	30	14,200,000	650,000	86,600,000

Table 7
The results of efficiency analysis of informal enterprises.

DEA result for informal enterprises												
DMU	Efficiency level (Leather industries)				Efficiency level (Plastic and small machinery industries)				Efficiency level (Dyeing and clothing industries)			
1	CRS	VRS	SE	RTS	CRS	VRS	SE	RTS	CRS	VRS	SE	RTS
1	0.042	0.139	0.301	+1	0.105	0.187	0.564	+1	1	1	1	–
2	0.032	0.033	0.972	−1	0.035	0.099	0.353	+1	0.331	0.436	0.76	+1
3	0.012	0.014	0.875	−1	0.354	1	0.354	+1	0.058	1	0.058	+1
4	0.064	0.092	0.7	−1	0.181	0.184	0.982	−1	0.424	0.523	0.811	+1
5	0.038	0.04	0.938	−1	0.051	0.055	0.92	+1	1	1	1	–
6	0.188	0.233	0.808	−1	0.03	0.034	0.869	+1	0.322	0.349	0.923	+1

(continued on next page)

Table 7 (*continued*)

DEA result for informal enterprises												
DMU	Efficiency level (Leather industries)				Efficiency level (Plastic and small machinery industries)				Efficiency level (Dyeing and clothing industries)			
7	0.16	0.3	0.533	−1	0.866	1	0.866	−1	0.039	1	0.039	+1
8	0.058	0.065	0.894	+1	0.099	0.106	0.93	−1	0.043	0.11	0.394	+1
9	0.143	1	0.143	+1	0.593	0.612	0.97	−1	0.076	1	0.076	+1
10	1	1	1	–	0.133	0.158	0.841	+1	0.13	0.151	0.859	+1
11	0.026	0.042	0.625	−1	0.053	0.112	0.472	+1	0.051	0.053	0.974	−1
12	0.036	0.048	0.75	−1	0.302	0.363	0.831	−1	0.134	0.163	0.817	+1
13	0.034	0.037	0.934	+1	0.178	0.189	0.94	−1	0.3	0.414	0.725	+1
14	0.015	0.035	0.437	−1	1	1	1	–	0.265	0.28	0.949	+1
15	0.007	0.018	0.404	−1	1	1	1	–	0.1	0.105	0.958	+1
16	0.1	0.125	0.8	−1	0.45	0.566	0.795	+1	0.092	0.106	0.868	+1
17	0.105	0.14	0.75	−1	0.235	0.44	0.534	+1	0.183	0.195	0.941	+1
18	0.019	0.027	0.709	+1	0.242	0.247	0.979	−1	0.248	0.248	1	–
19	0.024	0.025	0.968	+1	1	1	1	–	0.352	0.392	0.897	+1
20	0.195	0.256	0.761	−1	0.205	0.272	0.754	+1	0.243	0.259	0.938	+1
21	0.013	0.026	0.515	−1	0.155	1	0.155	+1	0.135	0.383	0.353	+1
22	0.018	0.018	0.972	−1	0.178	0.448	0.396	+1	0.12	0.129	0.93	+1
23	0.019	0.042	0.444	+1	0.182	0.239	0.762	+1	0.042	0.056	0.756	+1
24	0.033	0.034	0.972	−1	1	1	1	–	0.115	0.123	0.935	+1
25	0.072	0.096	0.75	−1	0.48	0.696	0.69	+1	0.129	0.151	0.854	+1
26	0.056	0.058	0.968	+1	0.1	0.11	0.905	+1	0.265	0.304	0.872	+1
27	0.039	0.089	0.444	+1	0.091	0.102	0.892	+1	0.631	0.708	0.89	−1
28	0.022	0.077	0.288	+1	0.455	0.512	0.889	+1	0.097	0.106	0.907	+1
29	0.004	0.011	0.365	+1	0.173	0.241	0.72	−1	0.318	0.329	0.968	+1
30	0.003	0.009	0.353	+1	0.246	0.274	0.897	−1	0.18	0.243	0.737	−1
Mean	0.086	0.138	0.679	–	0.339	0.442	0.775		0.247	0.377	0.773	–

Table 8
The results of eco-efficiency analysis of informal enterprises (pollution minimization)

DEA result for informal enterprises									
DMU	Leather industry (Efficiency level)			Plastic and small machinery product industries (Efficiency level)			Dyeing and clothing industries (Efficiency level)		
	crs	vrs	scale	crs	vrs	scale	crs	vrs	scale
1	0.042	0.139	0.301	0.016	0.018	0.845	1	1	1
2	0.032	0.033	0.972	0.005	0.012	0.439	0.331	0.436	0.76
3	0.012	0.014	0.875	0.057	1	0.057	0.058	1	0.058
4	0.064	0.092	0.7	0.018	0.018	1	0.424	0.523	0.811
5	0.037	0.04	0.937	0.008	0.009	0.829	1	1	1
6	0.188	0.233	0.808	0.004	0.005	0.909	0.322	0.349	0.923
7	0.184	0.3	0.613	0.09	0.157	0.571	0.039	1	0.039
8	0.058	0.065	0.894	0.011	0.011	0.995	0.043	0.11	0.394
9	0.143	1	0.143	0.069	0.07	0.984	0.076	1	0.076
10	1	1	1	0.021	0.042	0.504	0.13	0.151	0.859
11	0.098	1	0.098	0.008	0.013	0.651	0.155	0.173	0.896
12	0.112	1	0.112	0.035	0.043	0.8	0.249	0.382	0.652
13	0.034	0.037	0.934	0.02	0.02	0.995	0.447	1	0.447
14	0.023	0.035	0.646	1	1	1	0.62	0.651	0.954
15	0.012	0.018	0.646	0.067	0.133	0.5	0.25	0.274	0.914
16	0.1	0.125	0.8	0.067	0.074	0.896	0.175	0.225	0.775
17	0.105	0.14	0.75	0.036	0.044	0.824	0.462	0.491	0.94
18	0.019	0.027	0.709	0.028	0.028	0.984	0.787	0.885	0.889
19	0.024	0.025	0.968	0.153	0.164	0.936	1	1	1
20	0.195	0.256	0.761	0.022	0.024	0.909	0.462	0.511	0.905
21	0.013	0.026	0.515	0.019	1	0.019	0.418	1	0.418
22	0.018	0.018	0.972	0.028	0.066	0.419	0.204	0.413	0.494
23	0.019	0.042	0.444	0.028	0.04	0.709	0.07	1	0.07
24	0.033	0.034	0.972	0.161	0.247	0.651	0.225	0.246	0.915
25	0.072	0.096	0.75	0.048	0.048	0.99	0.279	0.413	0.675
26	0.056	0.058	0.968	0.007	0.01	0.667	0.535	1	0.535
27	0.039	0.089	0.444	0.006	0.009	0.684	1	1	1
28	0.022	0.077	0.288	0.07	0.086	0.814	0.287	1	0.287
29	0.004	0.011	0.365	0.003	0.035	0.073	0.793	1	0.793
30	0.003	0.009	0.353	0.03	0.03	0.99	0.344	0.344	1
Mean	0.092	0.201	0.658	0.071	0.149	0.722	0.406	0.653	0.683

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