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Case Report

Sludge Management in the Textile Industries of Bangladesh: An Industrial Survey of the Impact of the 2015 Standards and Guidelines

Md. Badal Miah [1,2], Md. Sazzadul Haque [3], Md. Abdul Khaleque [1] and Rafael M. Santos [2,*]

1 Department of Environmental Science and Management, Independent University, Bangladesh, Dhaka 1229, Bangladesh; miahm@uoguelph.ca (M.B.M.); akhaleque@iub.edu.bd (M.A.K.)
2 School of Engineering, University of Guelph, Guelph, ON N1G 2W1, Canada
3 Department of Biological Systems Engineering, Virginia Tech, Blacksburg, VA 24060, USA; mdsazzadul@vt.edu
* Correspondence: santosr@uoguelph.ca

Abstract: The textile sector of Bangladesh has positively contributed to a significant impact on its national economy and employment opportunities due to its rapid growth. The increasing number of wet processing units has led to a growing amount of wastewater volume as well as textile sludge (a byproduct of wastewater or effluent treatment plants). In 2015, the government of Bangladesh instituted the "Bangladesh Standards and Guidelines for Sludge Management". Therefore, this case study aimed to assess these standards' impact on the textile industry's sludge management practices, informing academic scholars of the research opportunities available, and serving as a policymaking tool for various other South Asia and Southeast Asia economies. The sludge management situation of thirty-six industries (namely, twelve dyeing, twelve printing, and twelve washing) was herein assessed through a self-administered questionnaire survey of respondents from the respective 'Top Management' and 'Environmental Chemical Responsible' (ECR) departments. Among the findings, the assessment revealed that neither treatment procedures nor reuse and recycling activities are present for sludge management in any of the studied industries. The responsible personnel from the textile industries have not undergone any level of technical training, and 41.7% of the printing industries still dump sludge in the open environment. The majority (83%) of stakeholders are unaware of the dangers and potential effects of improper sludge treatment. The key factors—responsibility, knowledge, behavior, and consideration—analyzed in this study, together with the study's recommendations, will be a vital step forward in formulating policy advocacy for hazardous sludge management within the textile sector of Bangladesh.

Keywords: clothing industry; bibliometric analysis; pollution and treatment; cleaner production; health hazards and risks; sustainable development goals; South Asia

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1. Introduction

Clothing and related textiles are one of the major fundamental commodities of human beings throughout history. As with other developing nations, textile is the dominant sector in the growth of Bangladesh's economy [1–3], which has secured the second position in global apparel exporting after China [4]. As the top export-earning division, more than 81% of the export revenue—USD 34.0 billion in FY 2019–20—was generated from this sector, which contributes a large share to the country's GDP (Gross Domestic Product) growth [5]. The textile sector of Bangladesh produces different ready-made garments (RMGs), knit and woven wear, denim, and other clothing products for different international apparel and fashion brands [6], which has created opportunities for more than 4.20 million people to work under this sector [7]. Although this sector has made a massive contribution to the country's economic development [8], the manufacturing processes of textile industries are also responsible for harmful impacts on the environment [9]. To accomplish the Sustainable Development Goals (SDGs), especially Goals 6, 9, and 11, developing economies such as Bangladesh must improve the management and treatment of textile wastewater and sludge. The achievement of SDG Goal 12 can also assist developed economies that depend on garments imported from these nations.

The wet processing unit of textile industries includes processes such as pretreatment, coloration (dyeing and/or printing), washing, and finishing [10–12]. A huge amount of freshwater, synthetic dyes and chemicals, and other materials are used in the wet processing unit [13–15], either in a batch process or continuous process or a combination of these two processes [16]. Due to the use of hazardous, poisonous, and slowly biodegrading chemical compounds and auxiliaries, this sector is a significant source of environmental contamination and textile effluents [13,17]. The printing process in textiles is similar to the dyeing process, where one or more colors are used on the face part of the fabric with unique designs as opposed to traditional dyeing [18]. Around the textile industries of the world, more than 700,000 t of dyestuffs are consumed in a year, where 5.0–50.0% of the used dyes remain unfixed on the fabric and find their way to the textile effluent [19]. Wastewater from the textile sector was estimated to be 145.0, 201.0, and 317.0 million m^3 for the years 2011, 2015, and 2020, respectively [20]. Textile effluent contains several heavy metals, hazardous substances, and other harmful substances including grease and oil. These contaminates are frequently incorrectly or only partially handled before being released into nearby water bodies [20,21].

Sludge and textile effluent contamination endanger agriculture and public health by causing respiratory and gastrointestinal issues, food poisoning, and other ailments [21]. Sludge is a semisolid byproduct that is a natural byproduct of the process [22]. The treatment process, manufacturing chemicals, and coagulation agents all affect the sludge quality [23]. Textile sludge frequently comprises organic and inorganic substances, chemical nutrients, aromatic dyes, and numerous heavy metals, including chromium, nickel, copper, lead, zinc, aluminum, and cadmium [24,25]. Due to its makeup, adequate treatment and safe disposal procedures are required [26]. Sludge disposal in public spaces poses a serious concern for public health, since it can contaminate the soil, surface water, and groundwater [25]. When sludge is dumped into landfills or burned in incinerators, the produced leachate, gases, and ash contents release secondary pollutants into the environment [26]. With a production rate of 1.14 kg per m^3 of wastewater produced in 2012, they produced 36.39 Mt of sludge [27,28]. According to the “Bangladesh Standards and Guidelines for Sludge Management” [29] sludge is divided into three categories: Category A, which comprises municipal and equivalent sludge; Category B, which includes sludge from industries such as the CETP (Central Effluent Treatment Plant); Category C, which contains sludge from industries that handle hazardous waste, including the CETP. In the guideline, the Department of Environment (DoE) recommends seven management options: anaerobic digestion, aerobic digestion, controlled landfill, thermal incineration, agricultural use, land application, and recycling [29]. As of now, this is just a recommendation for the management of sludge; further investigation is required to find any flaws and determine whether additional conditions are needed in order to transform it into an act or a law. The major challenges associated with sludge management as reported in the “Bangladesh Standards and Guidelines for Sludge Management” are summarized as follows [29]:

- Sludge generated from different units of an ETP (effluent treatment plant) is mixed without any sort of separation.
- An appropriate treatment and/or disposal method cannot be defined because of the complex mixture of sludges.
- Incineration or landfill sites are not equipped with the necessary arrangements, capacities, or standards for sludge waste.
- Unavailability of reuse or recycling technologies due to excessive cost or not having sufficient space or skilled manpower.
- Analysis of all potential pollutants from wastewater in various units is not performed.

Given the associated pollution (Table 1) impacts of textiles industries and the government of Bangladesh's instituted standards, it was therefore the goal of this research to assess the impact of these standards on the sludge management practices in the textile industry. To this end, a structured industrial survey was conducted with industry stakeholders. This article presents the design and results of the survey and discusses its implications for the future of textile sludge management in Bangladesh. The goal is for the study to inform academic scholars of the research opportunities available, and to serve as a policymaking tool for various other South Asia and Southeast Asia economies.

Table 1. Physicochemical parameters of textile sludge in Bangladesh.

Parameters	Textile Sludge Characterization Values of Different Parameters from Numerous Studies		
	[30]	[31]	[32]
pH	6.73	4.5–5.0	8.28
Moisture content	90.0%	35.0–75.64%	64.60%
Organic Matter	69.48%	-	11.73%
Nitrate	256.3 mg/L	-	-
Sulphate	4295.8 mg/L	3000.0 mg/L	-
Arsenic (As)	1.52 mg/L	-	-
Chromium (Cr)	363.3 mg/L	0.668 mg/L	34.5 mg/L
Copper (Cu)	183.5 mg/L	-	118.8 mg/L
Lead (Pb)	109.4 mg/L	-	-
Zinc (Zn)	353.7 mg/L	-	201.5 mg/L
Nickel (Ni)	92.7 mg/L	-	-

We have conducted a bibliometric analysis using Web of Science with the keywords 'textile' and 'sludge', limited to articles, to identify available published papers. The results are impressive on a global scale, though opposite from Bangladesh's perspective (Figure 1). Surprisingly, to date, no industrial survey of the textile industry in Bangladesh has focused on sludge management practices, and the implications of the 2015 standards have not been reported in the literature; as such, these characterize the novelty and timeliness of the study. There are about five thousand textile businesses in Bangladesh, most of which create hazardous sludge. Only eighteen publications relating to "textile" and "sludge" could be found on the Web of Science, which motivated us to draft the present research and contribute to the field.

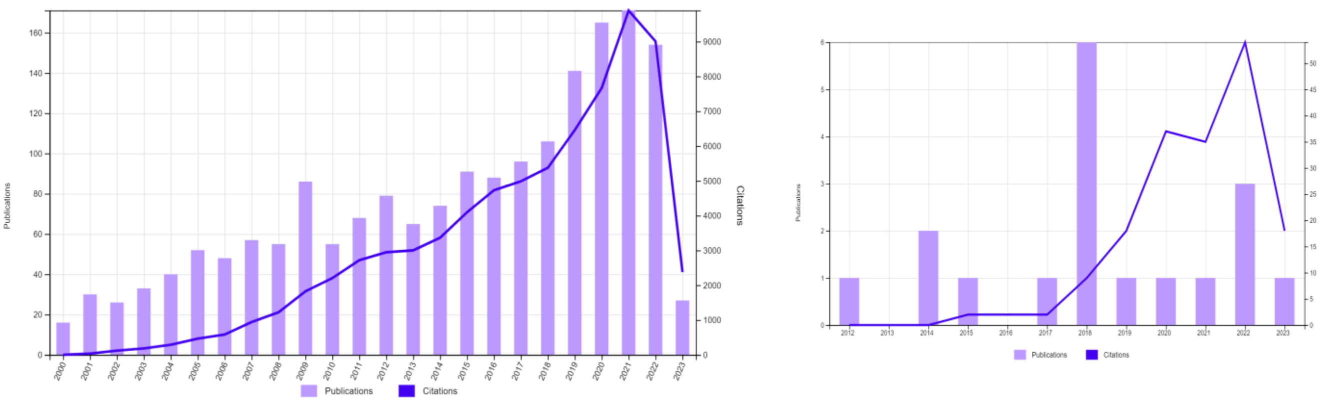

Figure 1. A comparison of papers and citations between global and Bangladesh contexts.

Two recent industrial survey studies [33,34] assess the state of green supply chain management and circular economy initiatives in Bangladesh but do not focus on the technical aspects related to hazardous sludge management, treatment, disposal, and reuse. Ullah et al. [35] prepared sludge–clay mixed bricks with the sludge collected from a dyeing and finishing factory located within the Savar EPZ (Export Processing Zone) area of Bangladesh. Rahman et al. [31] reported the usage of sludge as a partial replacement of sand in mortar and concrete that has exhibited compressive strength values of 20.0 and 12.0 MPa, respectively, and commented that sludge can be a potential agent for building materials. Nessa et al. [28] conducted a study to identify the reuse potential of textile sludge in agricultural activities. Nevertheless, none of the research addressed sludge management inside the plant compound and the challenges businesses confront in doing so. For industrial hazardous waste management policy, governance, and disposal option formulation, knowledge about the source and an attitude toward it are fundamental needs. In this regard, the action plans for the management of hazardous waste can only be articulated if the risk profile of the hazardous component (i.e., sludge) can be identified from the source, as suggested by Misra and Pandey [36].

At present, factory-level sludge management practices and attitudes toward them are the basic components for the planning and implementation of sustainable sludge management options in Bangladesh. To the best of the authors' knowledge, no other studies have contributed to this fact. As such, the present case study fills the gap by providing comprehensive information about thirty-six textile industries' current state of sludge management practices. It is believed that this study will serve as an evidence-based response from the perspective of industrial practitioners on sludge management, which will eventually be a viable element in the decision-making process in postulating sustainable sludge management practices within the textile sector.

2. Methodology

Despite being a vital hub for the global apparel market in sourcing denim garments, denim washing factories in Bangladesh are producing an enormous amount of wastewater and sludge that are consequently responsible for public and environmental health vulnerabilities, the corrosion of sewer lines, and groundwater pollution [37].

The present study investigated a total of thirty-six textile industries, of which twelve dyeing, twelve printing, and twelve (denim) washing factories were included in the assessment. The industries are situated within the Dhaka (13 factories), Gazipur (18 factories), and Narayanganj (5 factories) administrative areas of Dhaka Division, Bangladesh (refer to Figure 1). Based on the production capacities of these thirty-six factories, it was found that the annual average production capacity for the dyeing industries is 16,420 t, 22,715 t for printing, and 9528 t for washing. These 36 factories were the survey respondents of a subset of 100 such industries representing the largest units within the study area of greater Dhaka (Figure 2), which represent close to half of the total number of such industrial units (246) in Bangladesh [38]. All the industries considered have ETPs in their respective factory areas, where biological and chemical treatment processes are applied to the generated wastewater and sludge. Sludge management is thus a vital step for the ECR department and the top management.

2.1. Study Design

Given the objective of the present study, a self-administered questionnaire survey was conducted among the top management and ECR departments of the studied factories. The complexity of questions in a research interview is a crucial factor that can impact data validity and response rates. To ensure good understanding and high response rates, it is recommended that researchers use simple questions that are easy for interviewees to comprehend. Moreover, ref. [39] found that using simpler questions can lead to higher response rates and fewer missing responses in survey research. The respondent selection was carefully made, with the respondent from the top management of these factories referring to the owner and/or CEO of a particular industry and the general manager as the concerned respondent from the ECR section. Since some of the factories have no ECR department, the responsible person from the Compliance Department was considered for the survey. As the study aimed at identifying the present situation of sludge management at the factory's end, a total of 13 closed-ended questions were prepared, of which 5 were for the top management and the rest of the 8 questions were for the ECR respondent. The questions are given in Appendix S1 of the Supplementary Material. A face-to-face interview with the respondents was conducted from December 2020 to June 2021 with the questionnaire form that was filled out by the respondents themselves. Of the respondents, only three (8.3%) out of thirty-six were female general managers in the studied textiles from the ECR section, and all the respondents (100%) from the top management were male. The average age group of the top management was in the range of 40–45 years, and the ECR department had an age range of 25–35 years, with a master's degree as the highest education level, mostly from a chemistry background.

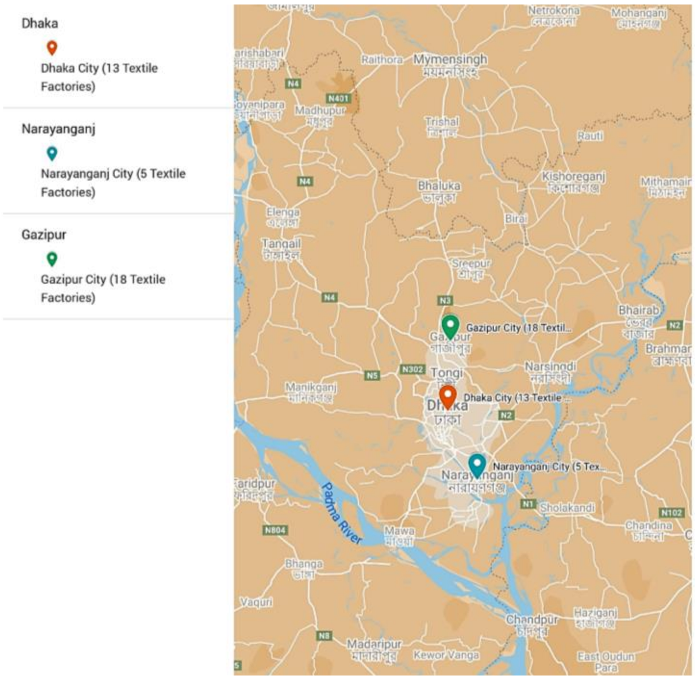

Figure 2. Map showing the distribution of the studied textile factories.

2.2. Data Processing and Analysis

Based on the received responses, it was found that a total of 72 responses were recorded from the 36 factories; within each factory, both top management and ECRs were taken into consideration. The collected responses were organized into Microsoft Excel 2019 with the heading of Dyeing, Printing, and Washing sections in separate sheets, and further categorization between the Top Management and ECR departments. Due to the confidentiality agreement with the studied textiles, the names of the factories were coded with DS for dyeing, SP for printing, and WS for washing factories. A descriptive analysis was performed to find out the characteristics of the responses from the two major divisions of the factories. Later, chi-square tests were also conducted to analyze the responses with the key factors (see Table 2)—knowledge, responsibility, behavior, and consideration—for textile sludge management. Moreover, a multinomial regression analysis was conducted to show associations between the independent variables and related key factors concerning sludge generation in the studied factories in three domains. The results were represented with the odds ratio (OR) and a 95% confidence level. All the statistical analyses were conducted in the IBM Statistical Package for the Social Sciences (SPSS) software, version 25.0. The margin of error of the survey results, calculated from Cochran's formula [40], is estimated to be 13% for the 95% confidence level (and 11% for the 90% confidence level). It should be noted that, with industrial surveys, it is only possible to collect data from willing respondents; moreover, the survey population is relatively small. Hence, the total number of respondents (36) out of the sampled population (100) impacts the margin of error estimated, but does not affect the overall conclusion of the case study.

Table 2. Associated factors with the questions that were asked to the top management and ECR department of the studied textiles.

Factors	Items of Questions	Responsible Respondent from
Responsibility	Responsibility of the compliance department Responsibility of the ECR department	Top Management
Behavior	Consideration of the sludge management	
Knowledge	Knowledge about the impact of sludge mismanagement	
Consideration	Willingness to train the ECR department for sludge management	
Responsibility	Requirement of any certification for sludge management Current practices for storing sludge The time period for storing sludge in the factory The procedure of disposal after storing Monitoring after sludge disposal	ECR Department
Behavior	Consideration toward the management of sludge	
Knowledge	Having any kind of training on sludge management	
Consideration	Reasons for doing sludge management	

3. Results

From the obtained operational parameters, the average wastewater and sludge generation rates, along with the ETP capacities of the studied dyeing, printing, and washing factories, are given in Table 3, and are also more visualized in Figure 3. It is also clearly seen from the right side of Figure 3 that all the facilities have enough ETP capacity to treat their wastewater. The average annual production of wastewater (1,035,072.25 m^3) from the dyeing industries was the highest, which contributed to the largest sludge production (52,032 kg/year) factories in the textile sector of Bangladesh. The calculated fact attests to the fact that a substantial amount of water and chemicals are consumed in this wet processing unit, which gives rise to the wastewater and sludge amounts. To compare the ETP capacities with the wastewater generation rate, the ETPs are well above the generation rate of wastewater for treatment. However, no potential sludge treatment procedures (i.e., anaerobic digestion—biogas production; aerobic digestion—composting; soil conditioner for agricultural use; recycling into brick, cement, or asphalt making) as suggested by the DoE [29] were found to be in effect in these industries. The main findings based on the key factors in these industries are given in the following sections.

Table 3. Average sludge generation rate from the studied industries (n = 36).

Industry Type	n	Wastewater Generation Rate (m^3/d)	ETP Capacity (m^3/d)	Sludge Generation Rate (kg/d)
Dyeing	12	2835.8	5065.0	143.0
Printing	12	237.9	820.0	14.0
Washing	12	756.0	2335.0	99.0

3.1. Dyeing Industries

In the dyeing industries, the responsibility towards the sludge management from the concerned Compliance and ECR departments was seen to be 100% (t = 5.284; $p < 0.0001$), while the majority of the dyeing industries' (66.7%) behavior toward the sludge management was seen to be a requirement from the brands (t = 5.798; $p < 0.0001$). From the question of knowledge about the impacts of mismanagement of textile sludge on the environment, it was found that 75% of the respondents (t = 4.857; $p < 0.001$) from the top management were unaware. Although the majority of the respondents (66.7%; t = 5.448; $p < 0.0001$) from the top management were willing to train the ECR department on sludge handling and management, a considerable portion (25%; $p < 0.0001$) of the respondents were not willing to engage the ECR departments in such training programs (see Table S1 in the Supplementary Material). Referring to Figure 4, the results of the study make it clear that owners of certain organizations have very little awareness of sludge management, with 75% of them having an insufficient understanding of the topic. The positive aspect is that 66.7% of respondents said they would train their accountable parties if necessary.

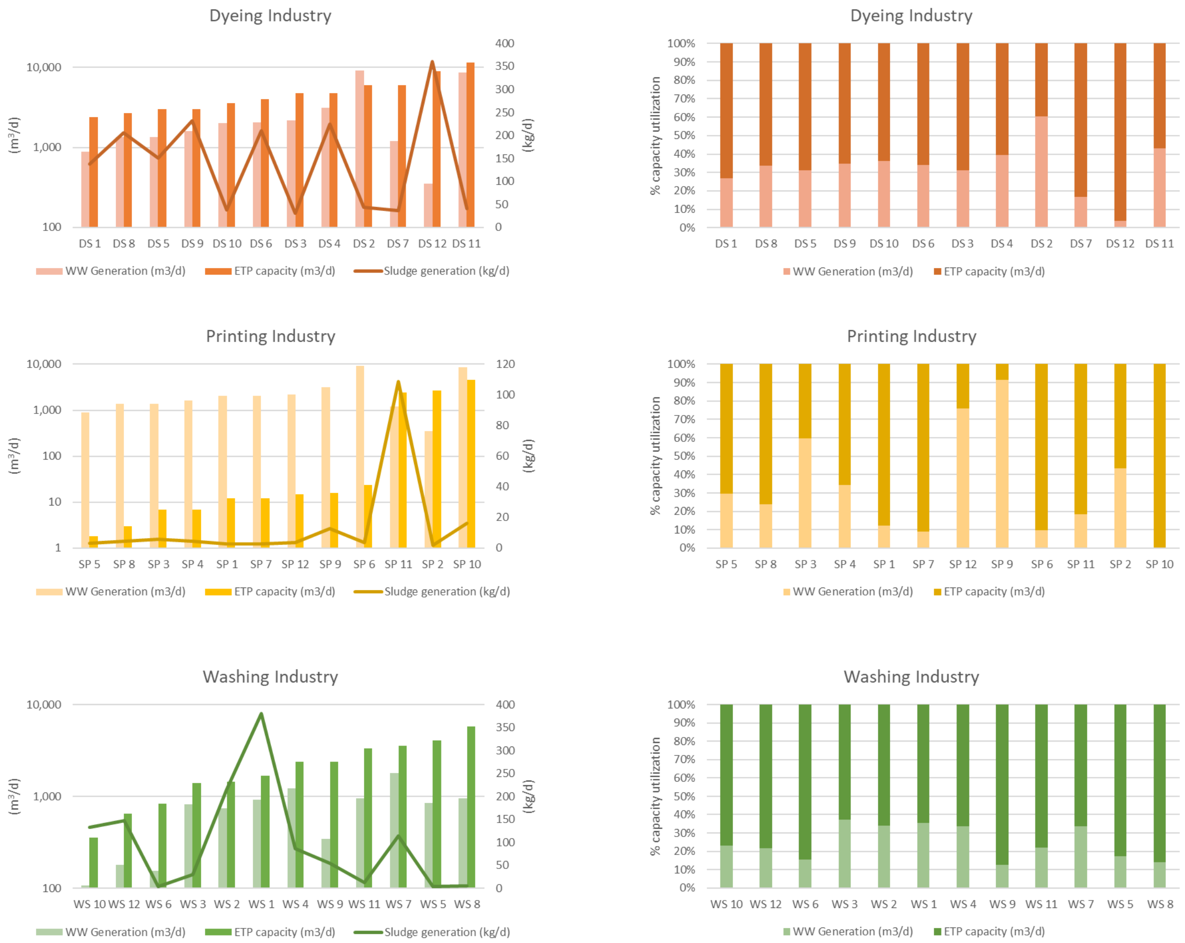

Figure 3. Graphical display of the WW generation, ETP capacity, and sludge generation per day (**left**) and ETP capacity utilization (**right**).

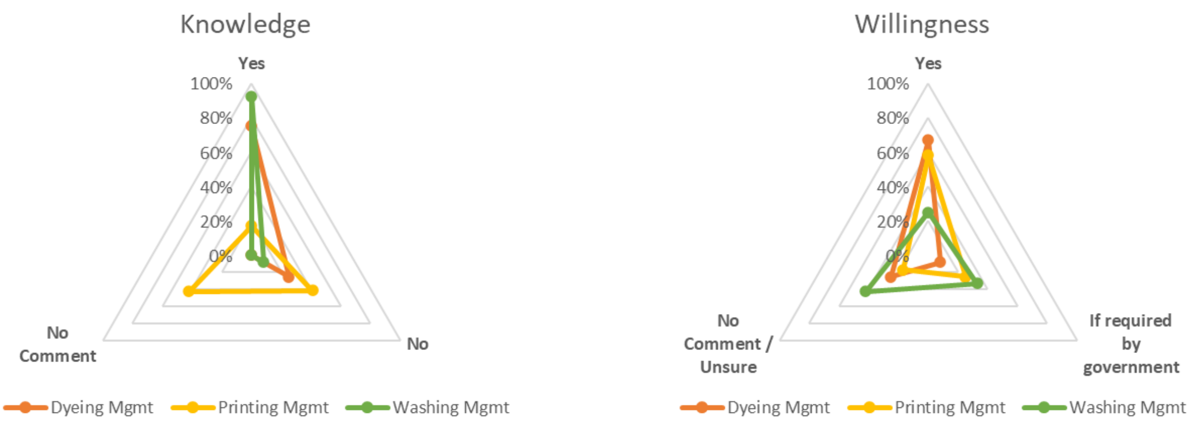

Figure 4. Knowledge and willingness of dyeing, printing, and washing management levels.

In Table S2 in the Supplementary Material, the responses recorded from the ECR department of the dyeing industries are presented. There was no training the ECR department received on sludge handling and management; thus, 100% of the respondents were unaware of its management (t = 4.323; $p < 0.001$). Half of the respondents from the ECR department of the dyeing industries consider sludge management as a brand requirement, while the rest consider it a regular content of solid waste (t = 5.159; $p < 0.0001$). The factory-level practice of storing sludge was in the storage areas designated for it (n = 10; t = 5.368; $p < 0.0001$). A majority of the dyeing textile factories (58.3%) store sludge for a period of 6 months (t = 2.687; $p < 0.021$), and 66.7% of the factories dispose of sludge through third party agreements, while the rest dump it in landfill sites (n = 2; 16.7%) and open areas (n = 2; 16.7%), respectively. There is no monitoring system (n = 10; t = 5.320; $p < 0.0001$) after the disposal of sludge in any of the dumping methods. The ECR section of the dyeing factories considers sludge management as only a part of management decisions (n = 6; 50%; t = 5.007; $p < 0.0001$) as with the other industrial activities (e.g., process operation, routine check). Environmental Compliance Representatives (ECoRs) at all organizations lack sludge management awareness and expertise. In particular, the survey discovered that 100% of ECRs lacked training or comprehension on this subject (Figure 4).

3.2. Printing Industries

Among the surveyed printing textile factories (see Table S3 in the Supplementary Material), the compliance department was found to be 100% responsible (t = 5.284; $p < 0.0001$) for sludge management, while half of these industries do not have any ECR section within the industrial premises (t = 4.89; $p < 0.0001$). As with the dyeing industries, the major portion (58.3%) of the printing industry's behavior towards sludge was found to be a mere requirement from the brand, while the remaining portion did not want to comment ($n = 5$; 41.7%; t = 5.545; $p < 0.0001$), as they have no sludge management infrastructure and they do not require it from any public or private institution. A sizable portion (83.3%) of the respondents from the top management did not have any knowledge about the hazardous impact of sludge mismanagement on the environmental quality (t = 4.458; $p < 0.001$). However, a positive attitude ($n = 7$; 58.3%) towards the consideration of training on sludge handling and treatment techniques for the employees was noticed among the respondents (t = 5.507; $p < 0.0001$). Many owners of specific organizations have insufficient knowledge of sludge management, with as much as 83% of them having a poor grasp of the topic. The fact that 58% of the participants indicated they would be happy to offer training to the accountable parties, if necessary, nevertheless, is heartening (Figure 4).

In the quest of identifying the present sludge management situation at the printing factory level, the ECR department was found to be incapable, since no representative from the concerned department was equipped with the necessary training on sludge handling and treatment (n = 12; 100%; t = 4.323; $p < 0.001$). Unlike the dyeing facilities, the major portion (n = 9; 75%) of the printing facilities store sludge around the ETP area and dump sludge into the open space ($n = 5$; 41.7%). The ECR section of the studied industries feels that sludge management is just as general as general solid waste management procedures ($n = 12$; 100%; t = 5.284; $p < 0.0001$), unlike its counterpart dyeing industries (see Table S4 in the Supplementary Material).

3.3. Washing Industries

Bangladesh has secured a considerable place in the global denim market for its quality, cheap labor, and abundant freshwater supply. In the denim sector, the washing process plays a significant role in providing quality output to the fabric. However, analysis reveals that the compliance department has the largest share ($n = 9$; 75%) in giving support to the sludge management decision, along with the administrative work, while the same number of factories do not have the ECR section ($n = 9$; 75%; t = 4.452; $p < 0.001$), which is particularly the responsible agency within the textile premises for sludge management. As for the behavior towards the sludge management work, unlike the dyeing and printing factories, the majority of the washing industries made no comments ($n = 5$; 41.7%; t = 4.615; $p < 0.001$), which infers that they have no interest in the issues of the environment caused by the mismanagement of sludge. Such a proposition is also supported by the factor of knowledge, as the highest number of respondents (n = 11; 91.7%) among the top management of washing factories do not have any knowledge about the impact of sludge mishandling and improper disposal (t = 4.374; p < 0.001). Moreover, the majority of the owners of these industries did not want to associate their employees with any kind of training program on the safe disposal and management of sludge (see Table S5 in the Supplementary Material). Up to 92% of owners of certain organizations have a poor understanding of sludge management, which is a large amount. However, it is reassuring to see that 58% of respondents are open to offering necessary training to those in charge (Figure 4).

As with the other two studied sectors of the textile industries, respondents from the ECR/Compliance department have no training in sludge handling and management (n = 12; 100%; t = 4.323; p < 0.001). As the level of knowledge about the hazardous impact of sludge is unknown among the respondents, the majority of these industries consider sludge a regular waste and dump it with other solid waste materials in open spaces (n = 3; 25%) and landfill sites (n = 2; 16.7%). However, a significant portion of the respondents did not comment (n = 4; 33.3%), as they dispose of sludge without any sort of consideration for the environmental hazards, and no industry has any kind of monitoring (100%) after the improper disposal of sludge contents (t = 5.284; p < 0.0001), as given in Table S6 in the Supplementary Material. In addition to that, all the respondents agreed that the sludge from the ETP is considered a general type of waste (100%) and dumped without any kind of treatment (t = 5.284; p < 0.0001).

3.4. Factors Affecting Sludge Generation

Table 4 presents the multinomial regression model analysis results of the behavior and consideration toward the current sludge management on the generation of sludge in the studied industries. Concerning the highest sludge-producing industry (DS 12) in the dyeing domain, it can be observed that DS 8 and DS 11 had higher odds of producing 1.209 times more sludge (CI = 0.354–4.123; p = 0.092) with the current sludge management behavior. As for the printing industries, SP 1, 5–9, and 12 had the highest odds of producing 1.497 times more sludge (CI = 0.238–9.425; p < 0.0001) with the present sludge management behavior of seeing sludge as a normal type of waste or consideration only as a brand requirement without any care for the harmful impacts from it. The highest sludge production about the present sludge management behaviors and considerations were statistically significant for the washing industries. The WS 12 factory had the highest odds of producing sludge among the studied industries in this domain (OR = 12.000; CI = 1.560–92.287; p = 0.017), while the WS 11 (OR = 11.000; CI = 1.420–85.201; p = 0.022) and WS 10 (OR = 10.000; CI = 1.280–78.117; p = 0.028) showed significance in generating sludge with the current behavior toward the management of sludge. Similarly, a gradual increase in the sludge generation rate was also observed for the WS 9–12 factories, which had shown higher odds (OR = 3.07, 3.222, 3.364, 3.498; CI = (1.022–9.224), (1.077–9.634), (1.129–10.021), and (1.178–10.389); p = 0.046, 0.036, 0.029, 0.024) of generating sludge in consideration of sludge management, similarly to normal waste disposal practices, respectively.

Table 4. Effects of sludge management behavior and consideration toward the sludge generation rate in the Dyeing, Printing, and Washing factories.

Dyeing Industries							
Factory ID	Sludge Generation (kg/yr)	Behavior			Consideration		
		OR	95% CI	p-Value	OR	95% CI	p-Value
DS 1	50,266	0.710	(0.129–3.892)	0.156	0.657	(0.100–4.303)	0.192
DS 2	16,090	0.710	(0.129–3.892)	0.156	0.657	(0.100–4.303)	0.192
DS 3	11,005	0.710	(0.129–3.892)	0.156	1.000	(0.222–4.500)	0.0001
DS 4	81,970	1.000	(0.258–3.872)	0.0001	0.657	(0.100–4.303)	0.192

Table 4. *Cont.*

Dyeing Industries							
Factory ID	**Sludge Generation (kg/yr)**	**Behavior**			**Consideration**		
		OR	**95% CI**	***p*-Value**	**OR**	**95% CI**	***p*-Value**
DS 5	55,012	1.000	(0.258–3.872)	0.0001	0.657	(0.100–4.303)	0.192
DS 6	76,884	1.000	(0.258–3.872)	0.0001	1.000	(0.222–4.500)	0.0001
DS 7	13,451	1.000	(0.258–3.872)	0.0001	0.657	(0.100–4.303)	0.192
DS 8	74,878	1.209	(0.354–4.123)	0.092	1.000	(0.222–4.500)	0.0001
DS 9	84,650	0.710	(0.129–3.892)	0.156	0.657	(0.100–4.303)	0.192
DS 10	13,630	1.000	(0.258–3.872)	0.0001	1.000	(0.222–4.500)	0.0001
DS 11	15,144	1.209	(0.354–4.123)	0.092	1.000	(0.222–4.500)	0.0001
DS 12	131,404	1					
Printing Industries							
Factory ID	Sludge generation (kg/yr)	Behavior			Consideration		
		OR	95% CI	*p*-value	OR	95% CI	*p*-value
SP 1	1075	1.497	(0.238–9.425)	0.0001	1.497	(0.238–9.425)	0.185
SP 2	681	1.000	(0.118–8.503)	0.0001	1.000	(0.118–8.503)	0.0001
SP 3	2163	1.000	(0.118–8.503)	0.0001	1.000	(0.118–8.503)	0.0001
SP 4	1700	1.000	(0.118–8.503)	0.0001	1.000	(0.118–8.503)	0.0001
SP 5	1234	1.497	(0.238–9.425)	0.0001	1.497	(0.238–9.425)	0.185
SP 6	1280	1.497	(0.238–9.425)	0.0001	1.497	(0.238–9.425)	0.185
SP 7	1020	1.497	(0.238–9.425)	0.0001	1.497	(0.238–9.425)	0.185
SP 8	1575	1.497	(0.238–9.425)	0.0001	1.497	(0.238–9.425)	0.185
SP 9	4612	1.497	(0.238–9.425)	0.0001	1.497	(0.238–9.425)	0.185
SP 10	6000	1.000	(0.118–8.503)	0.0001	1.000	(0.118–8.503)	0.0001
SP 12	1300	1.497	(0.238–9.425)	0.0001	1.497	(0.238–9.425)	0.185
SP 11	39,730	1					
Washing Industries							
Factory ID	Sludge generation (kg/yr)	Behavior			Consideration		
		OR	95% CI	*p*-value	OR	95% CI	*p*-value
WS 2	78,680	2.000	(0.181–22.056)	0.571	1.809	(0.547–5.988)	0.332
WS 3	11,234	3.000	(0.312–28.841)	0.341	2.213	(0.702–6.974)	0.175
WS 4	31,530	4.000	(0.447–35.788)	0.215	2.542	(0.826–7.817)	0.104
WS 5	1213	5.000	(0.584–42.797)	0.142	2.823	(0.931–8.559)	0.067
WS 6	1732	6.000	(0.722–49.837)	0.097	1.809	(0.547–5.988)	0.332
WS 7	41,887	7.000	(0.861–56.895)	0.069	1.955	(0.603–6.336)	0.264
WS 8	2039	8.000	(1.001–63.963)	0.050	2.089	(0.655–6.664)	0.213
WS 9	19,920	9.000	(1.140–71.037)	0.037	3.071	(1.022–9.224)	0.046
WS 10	48,594	10.00	(1.280–78.117)	0.028	3.222	(1.077–9.634)	0.036
WS 11	4500	11.00	(1.420–85.201)	0.022	3.364	(1.129–10.021)	0.029
WS 12	53,870	12.00	(1.560–92.287)	0.017	3.498	(1.178–10.389)	0.024
WS 1	139,031	1					

Note: DS 12, SP 11, and WS 1 were used as reference factories for these calculations.

4. Discussion

The findings of the case study showed that managing textile sludge in Bangladesh faces considerable problems. The uncontrolled dumping of sludge into water bodies and open land due to a lack of sludge management legislation and the absence of treatment procedures in textile mills might pose risks to the environment and human health. Due to the lack of a mandated legal requirement, many businesses do not check their sludge for hazardous materials, which is particularly alarming. Additionally, there is no system in place for monitoring the sludge once it has been given to outside waste management contractors, despite the fact that only 36% of manufacturing units follow this practice. The results show that top management staff in the dyeing, printing, and washing industries have a severe lack of knowledge about the negative effects of improper sludge management on the environment. It is concerning that, overall, 83% of the stakeholders are unaware of the dangers posed by the incorrect treatment of sludge, and it shows a lack of knowledge and comprehension of the possible impact. Particularly, 75% of respondents from the dyeing sector, 83.3% of respondents from the top management of printing industries, and 92% of owners of washing factories had insufficient knowledge about sludge management.

Concerningly, a substantial percentage of respondents said that they did not fully comprehend the problem, which emphasizes the urgent need for further education and awareness of good sludge management techniques to lessen environmental harm [41]. The survey revealed that the respondents are eager to learn and to train their colleagues who are responsible for the same tasks. This positive attitude towards learning and sharing knowledge is a promising outcome of the survey.

In half of the manufacturing units, there is no Environmentally Responsible Person (ERP), which raises serious questions about environmental management and accountability. The management of environmental risks is the responsibility of an ERP, who also ensures compliance with environmental laws. According to the findings of our survey (Figure 5), 75% of those who work in washing factories treat sludge as regular waste without taking brand standards into account. The remaining 25%, in contrast, consider the unique needs of the brands they work with. Sludge management is accountable for 50% of respondents who work in dyeing facilities, whereas 42% of respondents who work in printing facilities view it as a brand necessity.

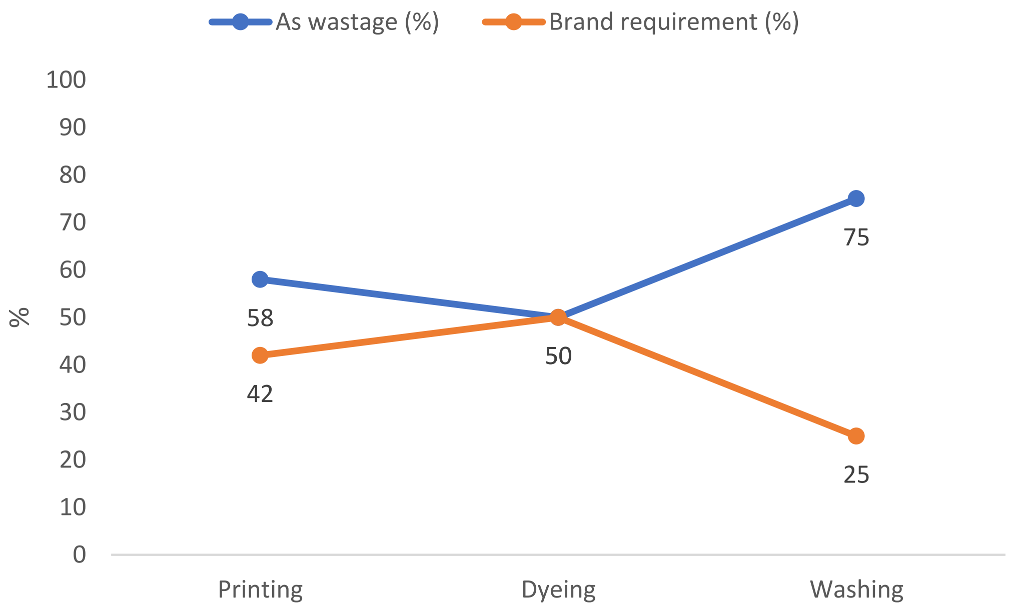

Figure 5. ERP perception of sludge management; a waste or a brand requirement?

A great deal of studies have focused on textile sludge management through different waste valorization processes in the context of Bangladesh. For instance, Ullah et al. [35] prepared sludge–clay mixed bricks with the sludge collected from a dyeing and finishing factory located within the Savar EPZ area of Bangladesh. The sludge content of 10% in the prepared brick sample resulted in more than 24.0 MPa as the compressive strength and less than 10% as the water absorption rate, which is ranked as the best quality brick. Moreover, the addition of 20% and 30% sludge content in the bricks showed a compressive strength of greater than 15.0 Mpa and a water absorption rate of less than 15%, which are regarded as Grade A bricks according to Bangladesh Standards (BDS 208) [42,43]. A similar approach in preparing brick using textile sludge, cohesive soil, and distilled water was reported by Anwar et al. [27], wherein the samples showed a compressive strength value of more than 20.0 Mpa with sludge mixed in different ratios. Rahman et al. [31] reported the usage of sludge as a partial replacement of sand in mortar and concrete that exhibited compressive strength values of 20.0 and 12.0 Mpa, respectively, and noted that sludge can be a potential agent for building materials. Pervez et al. [44] conducted a study to identify the reuse potential of textile sludge in agricultural activities. The applied sludge content ranged from 0 to 100% of the organic soil amendment and demonstrated a higher concentration of N, K, P, and Fe as plant nutrients than the commonly used organic manure. The authors concluded that the textile sludge can be a potential source of a soil conditioner for agricultural usage if only the harmful elements—Cr, Pb, and Zn—can be treated and removed. Another area of attention is the possible presence of microplastics in textile sludge, which could pose a risk when used in agricultural applications. The study of Hossain et al. [45] investigated this relationship in Bangladesh soils near textile industries, and although MPs were detected in both soils and textile sludges, they could not find a causal relationship to the use of sludges, thus pointing to other possible sources of MPs. Still, the study calls for the detection and removal of MPs in textile sludges before they are used in agricultural settings, which evidently requires strong regulatory programs to ensure these risk-mitigating steps are widely implemented.

The developed strategies—composting, agricultural usage, anaerobic digestion, recycling into brick and mortar—for sludge management across the textile industry as guidelines by the DoE [29] were found to be not in full effect in any of the studied textile industries. However, Haque [46] regarded such failure as a lack of implementation in the existing waste management infrastructure in Bangladesh, despite textile sludge being a valuable resource. As commented by Li et al. [47], to develop effective industrial waste management policies and strategies to reutilize waste [48], knowledge about the current waste handling practices and considerations from the source (i.e., industrial facilities) are the basic steps. The present case study provides an in-depth analysis of the elements—knowledge, responsibility, behavior, and consideration—related to sludge management in Bangladesh's textile industry. Based on the findings, the study recommends specialized policy assistance and the creation of sustainable infrastructure to enhance sludge management in the textile industry.

According to the present case study, sludge creation will continue to climb alarmingly in the near-term unless immediate action is taken. Regulations for sludge management and treatment procedures must be put in place to manage these issues, and stakeholders must be made aware of them. As Sharma et al. [49] posited, sludge management policy must by design enable affordable yet sustainable solutions, and as such, elements of consistency and synergy are critical. Sharma et al. [49] exemplified this based on various European Union directives issued between 1986 and 2012 that call for waste minimization first, and waste recycling and recovery otherwise. Notably, the regulations classify cleaner sludges as "positive waste" to enable its agricultural use [50], but this classification is intended primarily for sewage sludges rather than textile sludges. Alongside policy, however, what the present case study stressed based on the survey results is that awareness of sludge management is as important, and among surveyed industries it is almost the same whether it is a larger or smaller plant, as shown in Figure 6. In light of the fact that larger dyeing operations will initially have a greater impact, it would be more effective to start training or awareness campaigns with them. This can include offering plant owners and employees instruction and materials on how to handle and dispose of sludge properly, as well as the development of a strong monitoring and reporting system to guarantee compliance with regulations. Moreover, appointing an ERP in each production facility could guarantee that environmental responsibilities are taken seriously and that the right policies are in place to manage industrial waste, including sludge.

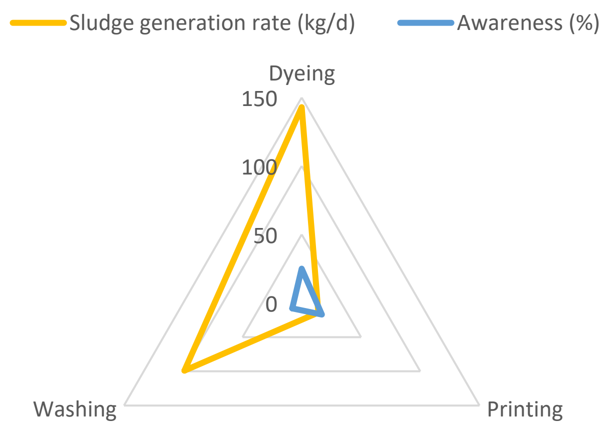

Figure 6. Sludge generation rate and awareness of dyeing, printing, and washing industries.

5. Conclusions

The country's economy and employment prospects have benefited from Bangladesh's rapidly expanding textile industry, but it has also generated a significant quantity of textile sludge. This case study evaluated the sludge management situation in thirty-six industries, including dyeing, printing, and washing, with an emphasis on the procedures utilized in Bangladesh's textile industry. Despite the government's establishment of sludge management guidelines in 2015, the study discovered that there are still no treatment methods for textile sludge and no reuse or recycling activities in any of the analyzed industries. A considerable number of printing industries continue to dump sludge in the environment, and responsible staff from the textile sectors also lack technical training. Many stakeholders are also not aware of the risks associated with incorrect sludge treatment. Moreover, they are not familiar with the DoE guidelines, and they do not know how to implement the suggestions outlined in them. To improve sludge management in the textile industry, the study suggests creating regulations for sludge management and treatment procedures, management awareness, appointing an ERP/ECoR in each production facility, receiving specialized policy assistance, and investing in sustainable infrastructure. This study emphasizes the urgent need for improved sludge management methods and the accessibility of various disposal techniques to decrease the risks that unmanaged sludge disposal poses to Bangladesh's environment and human health. It offers a valuable platform for creating policy advocacy for the control of hazardous sludge in Bangladesh's textile industry. Its findings and suggestions have important implications for decision-makers and stakeholders in Bangladesh and other economies in South and Southeast Asia dealing with comparable issues. It also suggests that there is a large gap between consumers' perception of the sustainability of textile products and the reality of the environmental impact of their production, which has important implications for a brand's Corporate Social Responsibility [51]. This research's outcome will be helpful for future researchers with more sample factories, and they may also include the relationship between the outcome of this research and its impact on the economic and social aspects.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/w15101901/s1, Table S1: Distribution of responses received from the Top Management of Dyeing industries (n = 12); Table S2: Distribution of responses received from the ECR department of Dyeing industries (n = 12); Table S3: Distribution of responses received from the Top Management of Printing industries (n = 12); Table S4: Distribution of responses received from the ECR/Compliance section of Printing industries (n = 12); Table S5: Distribution of responses received from the Top Management of Washing industries (n = 12); Table S6: Distribution of responses received from the ECR/Compliance section of the Washing industries (n = 12).

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Abbreviations

CETP: Central Effluent Treatment Plant; DoE: Department of Environment; ECR: Environmental Chemical Responsible; ECoRs: Environmental Compliance Representatives; EPZ: Export Processing Zone; ERP: Environmentally Responsible Person; ETP: Effluent treatment plant; GDP: Gross Domestic Product; OR: Odds ratio; RMGs: Ready-made garments; SDGs: Sustainable Development Goals; SPSS: Statistical Package for the Social Sciences.

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