*Original Research*

# Implementation of Sustainable Practices in Textile Processing Mills of Lahore, Pakistan

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## Abstract

This project study assesses the effectiveness of sustainable practices for minimizing water use, energy conservation and wastewater pollution reduction in 21 textile processing units of Lahore, Pakistan that volunteered and participated in the project study. Detailed assessment audits were conducted to identify the hotspot inefficient areas in terms of water, energy and wastewater. After that, the most feasible best techniques for cleaner production were deciphered through a multi-criteria decision-making process. A total of 45 techniques were listed. Each suggested option was discussed thoroughly with the management of the mills in order to determine their economic viability and techno-applicability. Business case scenarios were built with investment options and payback times for all techniques. Each mill chose the practices most suitable to them and implemented the selected best water management practices and cleaner production techniques with the help of the project team, which conducted regular audits of all mills in order to assess the implementation process and to determine improvements caused by sustainable practice. It was observed that approximately 67% of selected industries achieved a 10-30% reduction in wastewater pollution. All mills achieved a water consumption reduction ranging 1-19.5%. Furthermore, 80% of industries also achieved an improvement in their energy efficiency ranging 0.2-60 MJ x $10^6$/Year.

Keywords: cleaner production, best available techniques, sustainable production, textile, water management

## Introduction

Industrial activities contribute massively to water pollution. Keeping in view the rate of industrialization and economic growth, it is expected that the global water demand would increase to as much as 1500 billion $m^3$ by the year 2030 [1]. Globally, water sustainability and pollution prevention is recognized as a significant issue that needs immediate attention [2]. Textile industries are highly water intensive and also produce considerable wastes and effluents [3]. The repeated rinsing process for removing unfixed dyes results in huge amounts of water consumption [4] and simultaneously augments wastewater generation [5]. Therefore, reduction in volume of water consumed is a major concern for textile industries [6].

Over the last two decades, multiple methods of sustainable production have been developed [7].

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Cleaner production methods are aimed at preventing huge volumes of resource consumption and also target reduction of pollution generation [8]. This is achieved through identification of processes during production that can be tailored to become more resource efficient [9]. Furthermore, when industries adopt cleaner production technologies, they tend to reduce their production costs, meet the environmental policies and regulations of their country and also improve their competitiveness in the market [10].

Integrated pollution prevention and control (IPPC) was the primary European framework with directives for environmental performance monitoring in industries. It includes the use of best available techniques (BAT) present in BAT reference documents called BREFs. These are usually used as a reference when choosing best practices for water management in textile industries. Countries outside the European Union such as Turkey also follow these BREFs to promote sustainable water use in their industries [11].

In 2013, Ibanez-Fores et al. [12] suggested a method for recognizing sustainable and most relevant BATs for industrial units. This method revolved around the life cycle assessment (LCA) approach in order to select the most suitable BAT options for pollution control and water conservation. The method was illustrated by implementation on a ceramic tile-making unit.

However, in 2015, Ozturk et al. [13] worked specifically on the textile industry and recommended that control methods within the plant of textile industries can be useful in decreasing water and energy consumption. Their methodology included a comprehensive plant survey to identify recoverable streams and the evaluation of unnecessary water usage in a textile mill. Moreover, the wastewater generation was estimated and its characterization was also conducted. Their study demonstrated that implementing BATs could result in enhancing the water efficiency of the mill.

## Textile Industry in Pakistan

The textile sector is the largest industry of Pakistan in terms of labor force employment, exports and production. Globally, Pakistan is ranked No. 12 among textile product exporters. It contributes 8.5% to Pakistan's GDP and 52% in exports. Conspicuous textile products in Pakistan include fabrics made out of cotton, knitwear (hosiery), cotton yarn, bed wares, readymade garments, towels, synthetic textiles and unprocessed cotton [14]. As far as water consumption is concerned, large industries are more water efficient as their investment size is high compared to small and medium enterprises. Additionally, medium industry manufactures high-quality products with conventional machinery. The efficiency of the processes is thus compromised and resource management is not at its optimum. On the contrary, small industries are involved in small-scale specific productions and are less of a burden on natural resources.

## Water and Chemical Consumption in the Textile Industry

In a textile mill, wet processes like dyeing and washing require high inputs of water. The ranges of water consumption on average are between 3 to 932 L/Kg [15, 16]. Furthermore, high chemical consumption is characteristic of textile processes [17]. In Pakistan, according to the cleaner production institute, Pakistan (CPI), in the textile processing sector, an industry with water consumption of 75 L/Kg of product or less is considered water efficient. Those ranging between 76-200 L/Kg are moderately efficient and those with water consumption of greater than 200 L/Kg of product are water inefficient. CPI also assesses that about 53% industries range between moderately water efficient and inefficient. In terms of pollution load, the textile BREF document of IPPC specifies that COD levels of textile effluents range between 13 and 390 g COD/Kg product [18]. Additionally, textile wastewater is difficult to treat and identifying the correct approach of cleaner production may be challenging [19]. However, there have been successful studies that claim that COD loads of textile wastewater may be decreased by 25-50% through implementation of proper cleaner production methods [20, 21]. The multi-criteria decision-making method is usually a useful method in determining eco-friendly options for sustainable production [22].

In Pakistan, environmental regulations are not the key drivers of cleaner production initiatives. Pressure from international businesses that are customers of Pakistani textile industries is the main reason for industries to invest in cleaner production options. Furthermore, long-term cost reductions are also a motivating factor in this regard [23]. Considering these factors, a project was conducted to evaluate and assess the implementation of various BATs to reduce wastewater generation and improve water and energy conservation.

The main objectives of this research project were to help and guide textile industries towards cleaner and sustainable water management practices. The study targeted 21 industries that extended their cooperation and support for the initiative. Their willingness to tread the path of sustainability was the primary success of the study, which aimed to reduce water consumption and pollution load in the participant industries depending on the extent of changes made in their processes. BATs applied for water management in the project were called as best water management practices (BWMPs).

## Methodology

The study was carried out in three phases (Fig. 1). In the first stage, the selected industries were surveyed for on-site investigations. An in depth audit was conducted of all processes occurring in the textile industry in order to identify inefficient areas where best practices for water management, energy conservation and wastewater pollution reduction could be suggested and implemented. The audits were conducted under the UNEP framework for environmental audit methodology. Data was collected for water consumed during the production processes and COD levels in wastewater.

The second phase of the research and implementation project involved determining BATs/BWMP options on the basis of the IPPC and recommendations by the project team. Multi-dimensional analysis tools aided in the selection of relevant BATs/BWMPs [24]. The recommendations were given and follow-up surveys were conducted to see the implementation of BATs/BWMPs. Furthermore, calculations were made for water efficiency status and wastewater pollution load status for all 21 industries included in the study.

In the third phase, water management, energy conservation and pollution problems were listed, and their potential BATs/BWMPs solutions identified and delineated along with the investments required for implementation and their payback times. The BATs/BWMPs were divided into three business case categories based on business priority: i) Frequently implemented with very high payback periods ii) Important with moderate to high payback periods and iii) Absolute, i.e., comprising a full menu of BATs/BWMPs mentioned in the above two categories. The first set of options were those that were not too

hard to implement; were low-cost and the payback time was less. Examples of such techniques include reusing cooling water and the RO rejected water. The second scenario included options that were important for achieving environmental sustainability but they were high-cost techniques and their payback times also ranged between one to three years. The third business scenario included implementation of all BATs/BWMPs. The 21 industries included in the study were presented with all three scenarios.

The solutions were proposed to the technical management of the industries, and financial feasibility and technical viability were discussed. The industries were mobilized to implement absolute or any set of options as per their requirements and priorities. Once the above-mentioned process was complete and the industries had implemented the recommended BATs/BWMPs according to their feasibility, the impacts of the implementation of BATs/BWMPs were calculated after detailed surveys and collection of data from the industries. The parameters included in the study of impacts were percentage reduction in water consumption, chemical recovery (Kg/Year) and annual saving in millions (Pakistani Rupees/PKR).

## Results and Discussion

The specific water consumption, wastewater production and COD levels in wastewater for all 21 industries are presented in Table 1.

The results highlighted that only 2 out of the 21 industries were water efficient, 13 were moderately water efficient and 6 were inefficient as per the Cleaner Production Institute standard of water consumption of 75 L/Kg of product considered as water efficient. As far as the COD levels are concerned, all textile mills had high levels of COD in the wastewater produced per day. In order to establish environmental sustainability, BAT/BWMP options were considered to increase water and energy efficiency of the mills as well as to reduce water pollution loads.

### BATs/BWMPs

A detailed survey of the industries was conducted to identify areas where best practices could be applied to initiate sustainable production in the mills. In 2013, Greer et al. [25] suggested that it can be deciphered from the literature that by implementing such practices, water use may be reduced by 1-6% and energy by 0.3-10%. The identified BATs/BWMPs for water conservation, energy conservation and wastewater pollution reduction are as follows:

### Practices to Reduce Water Consumption

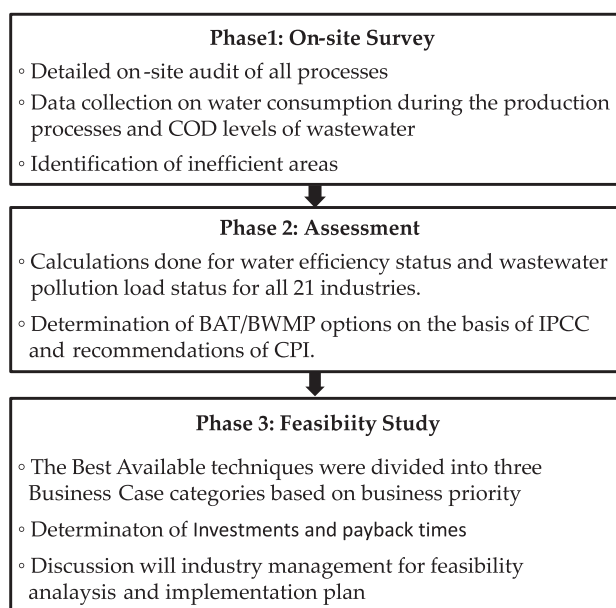1. Maintaining pipes and improving their quality and condition to control any leaking.

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**Phase1: On-site Survey**
◦ Detailed on-site audit of all processes
◦ Data collection on water consumption during the production processes and COD levels of wastewater
◦ Identification of inefficient areas

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**Phase 2: Assessment**
◦ Calculations done for water efficiency status and wastewater pollution load status for all 21 industries.
◦ Determination of BAT/BWMP options on the basis of IPCC and recommendations of CPI.

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**Phase 3: Feasibiity Study**
◦ The Best Available techniques were divided into three Business Case categories based on business priority
◦ Determinaton of Investments and payback times
◦ Discussion will industry management for feasibility analaysis and implementation plan

Fig. 1. Framework for the methodology used in the study.

Table 1. Water consumption, wastewater production and COD levels in wastewater,

| Industry No. | Production (kg/d) | Water Consumption ((Liter/Kg of Product) | Wastewater Production (Liter/Kg of Product) | COD (Kg/day) |
|---|---|---|---|---|
| 1 | 31,487 | 131 | 118 | 3610 |
| 2 | 26,522 | 130 | 117 | 2555 |
| 3 | 13,759 | 215 | 177 | 2077 |
| 4 | 38,427 | 74 | 61 | 1304 |
| 5 | 25,465 | 97 | 82 | 2419 |
| 6 | 22,743 | 98 | 81 | 4188 |
| 7 | 8,617 | 313 | 257 | 2174 |
| 8 | 4,267 | 157 | 135 | 1115 |
| 9 | 42,990 | 94 | 71 | 2419 |
| 10 | 26,676 | 142 | 121 | 3374 |
| 11 | 32,016 | 80 | 67 | 4689 |
| 12 | 16,093 | 88 | 71 | 3230 |
| 13 | 32,864 | 103 | 81 | 2142 |
| 14 | 25,465 | 231 | 199 | 9706 |
| 15 | 54,900 | 66 | 60 | 5214 |
| 16 | 26,475 | 82 | 69 | 2358 |
| 17 | 4,320 | 177 | 161 | 201 |
| 18 | 8,890 | 427 | 337 | 770 |
| 19 | 15,240 | 350 | 318 | 12683 |
| 20 | 53,000 | 132 | 91 | 8635 |
| 21 | 5,334 | 372 | 326 | 776 |

2. Reusing the cooling water from processes such as singeing, therm oil heaters, cooling drums, compressors, caustic recovery plants, chillers, etc.
3. Reusing the RO rejected water for spraying at boiler wet scrubber/cyclones or processes that do not require high quality of water.
4. Reducing the diameter of the pipes to decrease water use.
5. Using water showering technique in rope and jigger machines for washing of fabric.
6. Using wastewater at boiler wet scrubbers instead of freshwater and wastewater mechanical screens can also be washed with the same.
7. Controlling of washing points to avoid any wastage of water.
8. Cleaning of printing machine screens by water hoses with nozzles.
9. Installing trigger nozzles to improve water efficiency.
10. Reusing the water used for process washing for washing in other processes.

11. Collecting and reusing blanket washing water. The Synchronization of blanket washing water with the movement of printing machine can help avoid water wastage during machine shut off.
12. Installing automatic level control switches at water storage tanks.
13. Installing water flow meters.
14. Collecting and reusing the soaper.
15. Using wastewater for washing pigment drums as well as cleaning color kitchen floors.
16. Cleaning wet floors contaminated with chemicals through dry cleaning methods.
17. Creating awareness and sensitizing workers about the importance of water conservation, energy efficiency and pollution reduction.
18. The machines should have automatic shut-off valves.
19. Washing printing machine screens by a washing machine installed for the purpose.
20. Disposing the boiler ash in dry state.

### Practices for Energy Conservation

1. Changing the already existing machines to countercurrent mode in order to improve energy and water efficiency.
2. Installing temperature and pressure gauges at process vessels
3. Monitoring the performance of motors to improve efficiency.
4. Using copper wires for rewinding motors as they are more energy efficient.
5. Noting the number of times a motor has been rewound in record so that the process should not be repeated more than three to four times.
6. Reusing the steam condensate as boiler feed water.
7. Monitoring the TDS levels in the boiler water and boiler blow down be conducted.
8. Installing temperature controllers and steam flow meters.
9. Installing energy-efficient motors.
10. Installing energy-efficient water turbines.
11. Placing a steam and condensate recovery system.
12. Placing heat exchangers in hot wastewater streams.
13. Preheating process streams with flue gases of generators/oil heater exhaust to conserve energy.
14. Using motors with inverters.

### Practices to Reduce Wastewater Pollution

1. Reusing process washes that have a low chemical content can be used to make chemical solutions.
2. Reusing the residual printing paste for the same process or disposed of in dry state.
3. Monitoring and optimizing the amount of chemicals consumed.
4. Reducing the amount of bleach used for fabrics dyed black or very dark.
5. Collecting leaks and spills in catch pans.

Table 2. Business Case Scenario-01: Frequently implemented with very high payback periods.

| Business Priority-01 Solution Options | Financial Overview | | |
|---|---|---|---|
| | Investment PKR 000 | Saving PKR 000 | Simple Payback (Months) |
| **Water Management** | | | |
| Leakage control, maintenance of pipelines, piping improvement | 10-100 | 20-200 | 6 |
| Collection and reuse of cooling water from singeing, compressors, therm oil heaters, chillers, cooling drums, caustic recovery plant etc in the process | 15-100 | 30-200 | 6 |
| Reuse of RO rejected water/softener regeneration water for showering at boiler wet scrubber/cyclones or in the process where high quality water is not required | 30-60 | 60-120 | 6 |
| Use of reduced sized diameter pipes for water use | 20-100 | 30-150 | 8 |
| Implementing water showering at fabric in rope and jigger machines for effective washing with optimum water consumption | 5-50 | 6-60 | 10 |
| Use of wastewater instead of fresh water at boiler wet scrubber and for cleaning of wastewater mechanical screens | 25-100 | 30-120 | 10 |
| Control of floor and other washing points | 10-50 | 12-60 | 10 |
| Use of nozzles at water hoses to clean printing machine screens | 10-15 | 15-25 | 8 |
| Installation of water trigger nozzles at water hoses | 10-15 | 15-25 | 8 |
| Reuse of process washes of one process as washing water for other processes | 20-100 | 25-125 | 10 |
| Collection and reuse of blanket washing water, Synchronize blanket washing with printing machine movement to avoid water wastage during machine shut off machine | 15-50 | 25-85 | 7 |
| Installation of automatic level control switches at water storage tanks | 10-50 | 11-55 | 11 |
| Installation of water flow meters | 10-200 | 11-220 | 11 |
| Collection and reuse of soaper wastewater for washing pigment drums and color kitchen floor cleaning | 50-100 | 60-120 | 10 |
| Use of dry cleaning methods to clean the wet floor contaminated with chemicals | 5-10 | 6-11 | 11 |
| **Energy Conservation** | | | |
| Change existing machines to countercurrent mode to reduce energy and water consumption | 10-75 | 12-90 | 10 |
| Installation of temperature and pressure gauges at process vessels | 5-50 | 6-60 | 10 |
| Monitoring and evaluation of motors performance and improve system accordingly (loading adjustment, replacing over/under sized motors) | 50-300 | 75-450 | 8 |
| Use of high quality copper wires for rewinding of motors | 50-200 | 55-220 | 11 |
| Keep record of motors rewinding and replace motors after three to four times of rewinding | 100-200 | 120-240 | 10 |
| Collection and reuse of steam condensate as boiler feed water | 100-150 | 625-1200 | 2 |
| Conduct boiler blow down after measuring TDS levels in the boiler water | 10-20 | 30-60 | 4 |
| **Wastewater Pollution Reduction** | | | |
| Reuse of process washes containing low content of chemicals for making chemical solutions | 100-250 | 245-610 | 5 |
| Collection of residual printing paste from pigment drums and pumps to use in the process again or disposing it off in dry state | 25-50 | 35-65 | 9 |
| Monitoring chemical consumption at process recipes (use of calibrated beakers for chemical dosing) | 5-10 | 10-20 | 6 |
| Apply less extensive bleaching for those fabrics which undergo black or dark shaded dyeing | - | 50-120 | - |
| Chemical storage with catch pans underneath chemical containers to collect leaks and spills | 50-200 | 55-220 | 11 |
| Collect and dispose solid waste at appropriate dumping site instead of throwing into wastewater drains | 10-50 | - | - |
| Total | 760-2,655 | 1,674-4,931 | 5-6 (Average) |

Table 3. Business Case Scenario-02: Important with moderate to high payback periods.

| Solution Options | Financial Overview | | |
|---|---|---|---|
| | Investment PKR 000 | Saving PKR 000 | Simple Payback (Months) |
| **Water Management** | | | |
| Conduct training of workers and managers on water conservation, energy efficiency and pollution reduction aspects | 200-300 | - | - |
| Installation of automatic water shut off valves at machines | 500-1,000 | 165-330 | 36 |
| Installation of washing machine for printing machine screens | 60-70 | 30-35 | 24 |
| Disposal of boiler ash in dry state instead of washing it in the drain with water | 300-3,000 | 100-1,000 | 36 |
| **Energy Conservation** | | | |
| Installation of temperature controllers, steam flow meters etc | 400-600 | 265-400 | 18 |
| Installation of energy efficient motors | 1,000-2,000 | 925-1,850 | 13 |
| Installation of efficient water turbines | 200-300 | 160-240 | 15 |
| Installation of efficient steam and condensate recovery system | 1,000-3,000 | 800-2,400 | 15 |
| Installation of heat exchangers at hot wastewater streams | 500-750 | 500-750 | 12 |
| Preheating of process streams with flue gases of generators/oil heater exhaust | 1,000-2,000 | 1,000-2,000 | 12 |
| Inverters on motors | 200-400 | 200-400 | 12 |
| **Wastewater Pollution Reduction** | | | |
| Installation of caustic recovery plant | 3,000-4,000 | 3,000-4,000 | 12 |
| Use of treated water with RO/softener | 1,000-2,000 | 500-1,000 | 24 |
| Automatic chemical dispensing system | 2,000-3,000 | 650-1,000 | 36 |
| Establishing laboratory for chemicals purity monitoring | 500-1,000 | 160-350 | 36 |
| Disposal of boiler ash in dry state instead of washing with water in the drain | - | - | - |
| Total | 11,860-23,420 | 8,455-15,755 | 17-18 (Average) |

6. Solid waste should not be thrown in wastewater drains.
7. Installing caustic recovery plant.
8. Using treated water with RO/softener.
9. Using an automatic chemical dispensing system.
10. Establishing a laboratory for chemical purity monitoring.
11. Disposing of boiler ash in a dry state rather than through washing.

All solution options were divided into the business case scenarios described in the methodology section along with their financial overview. Table 2 shows all the BATs/BWMPs delineated into Business Case Scenario 1 along with the investment required, savings expected and the payback period in months. Table 3 shows all options suitable for Business Case Scenario 2. The textile processing sector first priority set of BATs/BWMPs implementation had a very clear business case. The investment amount was in the range of PKR 0.8-2.6 million, depending upon the size of the industry, pays back in less than a year with annual benefits of PKR 1.7-4.9 million, in terms of water conservation (5-30%), chemical savings, energy efficiency (5-10%) and pollution reduction (10-30%). The textile processing sector's second priority set of BATs/BWMPs implementation also had a very clear business case. The investment amount was in the range of PKR 11.8-23.4 million, depending upon the size of the industry, which pays back in less than two years with annual benefits of PKR 8.5-15.8 million in terms of water conservation (5-30%), chemical savings, energy efficiency (5-10%) and pollution reduction (10-30%). The textile processing sector absolute set of BATs/BWMPs, which included a full implementation of all two above-mentioned scenarios, included an investment amount in the range of PKR 12.6-26.1 million, depending upon the size of the industry, paid back in less than one and half years with annual benefits of PKR 10.1-20.7 million, in terms of water conservation (5-30%), chemical savings, energy efficiency (5-10%) and pollution reduction (10-30%).

Table 4. Impacts of BATs/BWMPs implemented in 21 textile industries in Lahore, Pakistan.

| Industry No. | Investment (Million PKR) | Impacts of BATs/BWMPs | | | | | | Payback Time (Months) |
|---|---|---|---|---|---|---|---|---|
| | | Water Reduction (m³/Year) | % Water Use Reduction | Energy Reduction (MJ x 106/Year) | Chemical Recovery (Kg/Year) | Pollution Reduction (10-30%) | Annual saving (Million PKR) | |
| 1 | 2.567 | 89,320 | 7.5 | 2.0 | 15,950 | Yes | 7.99 | 3.6 |
| 2 | 0.953 | 211,617 | 19.5 | 2.0 | - | Yes | 2.64 | 4.3 |
| 3 | 0.027 | 19,600 | 4 | 1.3 | - | <10 | 1.00 | 0.4 |
| 4 | 0.666 | 16,275 | 14 | 0.3 | - | <10 | 0.29 | 27.6 |
| 5 | 0.083 | 112,200 | 15 | 34.0 | - | <10 | 0.89 | 1.0 |
| 6 | 3.985 | 67,200 | 7 | 5.0 | 181,632 | Yes | 16.76 | 2.8 |
| 7 | 3.290 | 56,100 | 11 | 6.2 | 204,000 | Yes | 19.00 | 2.0 |
| 8 | 3.530 | 31,250 | 5 | 3.0 | 175,000 | Yes | 14.54 | 2.8 |
| 9 | 1.115 | 29,000 | 14 | 3.5 | 15,000 | Yes | 3.06 | 4.0 |
| 10 | 3.515 | 11,600 | 1 | - | 164,604 | Yes | 11.56 | 3.6 |
| 11 | 5.810 | 61,750 | 5 | 23.9 | 245,960 | Yes | 34.55 | 2.0 |
| 12 | 0.235 | 119,750 | 13 | 60.0 | - | <10 | 6.27 | 0.5 |
| 13 | 3.525 | 93,960 | 10 | 1.4 | 279,648 | Yes | 21.32 | 2.0 |
| 14 | 0.130 | 85,150 | 4.5 | 0.92 | 204,750 | Yes | 15.17 | 1.0 |
| 15 | 0.135 | 55,825 | 9 | 0.2 | 94,050 | Yes | 3.55 | 0.5 |
| 16 | 3.580 | 63,000 | 5 | 2.8 | 191,565 | Yes | 15.58 | 2.7 |
| 17 | 28.975 | 330,000 | 17 | 17 | - | Yes | 13.55 | 25.5 |
| 18 | 2.125 | 7,500 | 1 | 0.24 | - | Yes | 0.19 | 131.4 |
| 19 | 0.051 | 31,938 | 3 | - | - | <10 | 0159 | 3.8 |
| 20 | 1.710 | 79,205 | 3 | - | - | <10 | 2.22 | 9.2 |
| 21 | 0.375 | 69,351 | 31 | - | - | <10 | 0.34 | 12.9 |

## Level of Success Achieved

Table 4 presents the impacts of implementation of BATs/BWMPs in 21 textile industries of Lahore, Pakistan. It can be observed that approximately 67% of industries achieved a 10-30% reduction in wastewater pollution. All mills achieved a water consumption reduction ranging between 1-19.5%. Furthermore, 17 industries also achieved a certain level of improvement in their energy efficiency. These achievements are attributed to the detailed audits of the industries, identification of inefficient areas in terms of water consumption, energy consumption and wastewater pollution and implementation of BATs/BWMPs to improve the efficiency of the processes so that the industries may contribute to environmental sustainability.

## Conclusions

This study involved the implementation and assessment of the most relevant and sustainable BATs/BWMPs for reducing water consumption, conserving energy and wastewater pollution reduction in 21 textile processing mills of Lahore, Pakistan. The primary audits indicated that only 2 out of the 21 industries were water efficient, 13 were moderately water efficient, and 6 were inefficient as per the Cleaner Production Institute standard of water consumption of 75 L/Kg of product considered as water efficient. As far as the COD levels are concerned, all textile mills had high levels of COD in the wastewater produced per day. In order to establish environmental sustainability, BAT/BWMP options were considered to increase water and energy efficiency of the mills as well as to reduce water pollution loads. Business cases were

calculated and presented to industry management and the economic feasibility and techno-applicability of the options was considered. Post implementation audits were conducted in order to deduce the improvements in water and energy efficiency of the mills as well as reduce wastewater pollution. Approximately 67% of industries achieved a 10-30% reduction in wastewater pollution. All textile mills achieved a water consumption reduction ranging between 1-19.5%. Moreover, 17 mills also improved their energy efficiency by 0.2-60 MJ x $10^6$/Year.

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## Conflict of Interest

The authors declare no conflict of interest.

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