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SYNERGY

BANGLADESHI ENGINEERS & ARCHITECTS WORLDWIDE

Welcome to Synergy Magazine:

A New Chapter for BEAWorld!

"Any steps towards the best practice of waste reduction, reuse and recycle may allow Bangladesh to stand on the global platform, as I believe our potential deserves to be displayed for the world to see."

- Engr Md Abu Eskander

Addressing Environmental Pollution and It's Mitigation

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Editorial Message

We are pleased to announce the publication of Synergy Vol. 5, in continuation of BEAWorld's commitment to excellence in professional journey. Our 4th volume offered a comprehensive depiction of the adverse impacts of environmental degradation, while also proposing innovative and practical solutions for sustainable improvement.

Among the various issues explored, urban waste emerged as a critical and persistent environmental challenge. Improper waste disposal contributes significantly to public health risks and intensifies climate change, primarily through the release of greenhouse gases such as methane during waste decomposition.

However, this challenge presents a powerful opportunity. By capturing methane and utilizing waste-to-energy technologies, we can transform a harmful by-product into a source of economic value and climate action. This not only supports environmental protection but also promotes economic sustainability.

In recognition of this, we have also incorporated AI-assisted waste management techniques to improve the efficiency and effectiveness of waste disposal processes. These emerging technologies are essential in addressing modern environmental demands.

Furthermore, we believe that ethical practices must underpin all technical and operational efforts. A strong code of ethics remains central to our work culture and is vital to achieving meaningful, long-term development.

Looking ahead, Volume 5 will expand on these important discussions. It will explore key themes such as sustainable waste management, AI applications in environmental solutions, climate resilience, and ethical standards in professional practice. We are also encouraged by the growing participation of authors from a wide range of disciplines, including an increasing number of contributions from students and early-career professionals.

We look forward to your continued engagement and contributions as we collectively work toward a more sustainable and ethically driven future.
Synergy, as the networking hub of BEAWorld, prominently features with platform news, including recent events such as the day long conference and news on Student Leadership programs.

We aim to reach out to stakeholders, including governments, institutions, and non-governmental agencies, by circulating our publication to raise awareness of waste management and enable timely action demonstrating our efforts culminate in meaningful results.

We extend our heartfelt gratitude to the authors of Synergy for their steadfast partnership and dedication to our journey. Finally, we express our profound appreciation to our readers and viewers of the BEAWORLD website for your continued online engagement.

Waste to Energy – A Necessary Step towards Development

Engr. Md Abu Eskander
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Synergy Editorial Board Member

It was December 2022; I was on a visit to Singapore. Unexpectedly, I landed in the Punggol metro station. To have a glimpse of the city, while looking around outside the station, a security guard approached me and advised to take a ride on the LRT. He also advised me to not get off at any station because it's a circular path and so it will return to the Punggol station. I accepted the tempting proposal and stepped into the LRT with my family. As a tourist, looking at the city, my curiosity compelled me to know more about the clean and well-developed city. Getting an enthusiastic response from my kids, we walked out to the city from metro station.

If you want to know something, a common way is to get in touch with someone. I'd met a local resident and asked them about the city. In our conversation, I brought up how clean the city is; everything from the greenery to the roads are in well order. The answer was overwhelming. He stated that all the waste is transported to the plant before the sunrise. Every morning here, will begin with freshness. It almost seems as if the city has a bath every morning. The discussion continues. Waste is transported to waste-to-energy power plant. I am an electrical engineer by profession, so my curiosity accelerated. He gave me some guidance to know more about it.

At present, I am a residence of Abu Dhabi, the capital of UAE. This city is ranked first out of 382 global cities in the 2025 standings. Abu Dhabi has held Numbeo's title of the world's safest city for almost a decade, which reflects the state's ongoing efforts to enhance quality of life for citizens, residents and visitors.

Knowing the best waste management practice in Singapore and Abu Dhabi, led to me to think, wouldn't it benefit us to adopt such systems in Bangladesh?

Waste to Energy - Feasibility

Astonishingly, there are four incineration plants in Singapore, geographically small island country, which are also known as waste-to-energy (WtE) plants. TuasOne waste-to-energy Plant is the one which attracted my attention more. Because it was developed under Public-Private-partnership framework, in addition, it was developed under a design, build and operate model.

Let us try to discuss some data comparison with Singapore, as country and two cities of Bangladesh.

Place	Total population	Total land	Solid waste consumption in all WTE plant daily	Power generation in all WTE plant
Singapore (Country)	6.04 million	735.7 sq.km	9710 tonnes	278 MW
Chittagong	3.23 million	168.07 sq.km	Data not available	No Plant constructed
Dhaka	10.2 million	306 sq.km	Data not available	No Plant constructed

The above table was prepared by taking data from different websites of Singapore & Bangladesh. There are no statistical data available on how much solid waste produced in the cities of Bangladesh. However, looking at the population from the table, it is easy to understand that Bangladeshi cities produce a lot of solid waste which can be used for energy production.

Before understanding, where does these waste goes, let us have a look at pictures from cities of Bangladesh to feel the importance of moving the waste from disposal places. These pictures are in fact, part of the current waste management system, can be seen in most of the Bangladeshi Cities.

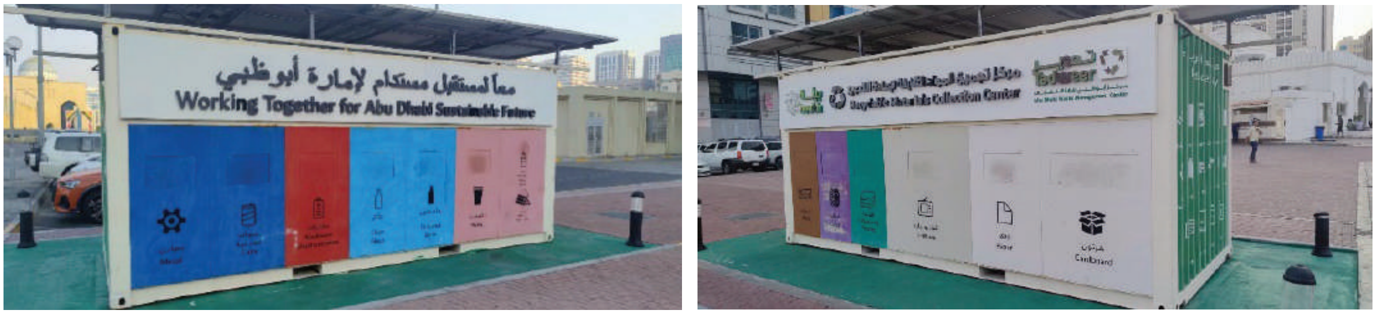
Waste collection system in cities of Bangladesh

If we can clear the waste every day, it will add value to the life of city dwellers in following ways:

- Improved public health
- Enhanced mental well-being
- Better urban aesthetics
- Reduce the traffic congestions.
- Boosted tourism and investment appeal

I quote, “A clean city at dawn shapes the mindset of its citizens for the entire day. It promotes calmness, productivity, and pride in place.”

The following pictures exhibits the modern waste collection process for recycle & reuse.



Urban waste separated by category

Wastes collection in residential or commercial area

If we can manage the waste in a modern way, then the benefits are.

- Resource conservation by recycling paper, plastic & metal waste.
- Protect the environment by reducing the air pollution & soil contamination.
- Contribution to climate change by reducing the production of methane gas and toxic liquids from landfill waste.

Waste production is continuous. So, it will be an amazing opportunity for our country, Bangladesh, to participate in global initiatives of 'Waste to Zero', focusing the waste decarbonization and reduce GHG emissions.

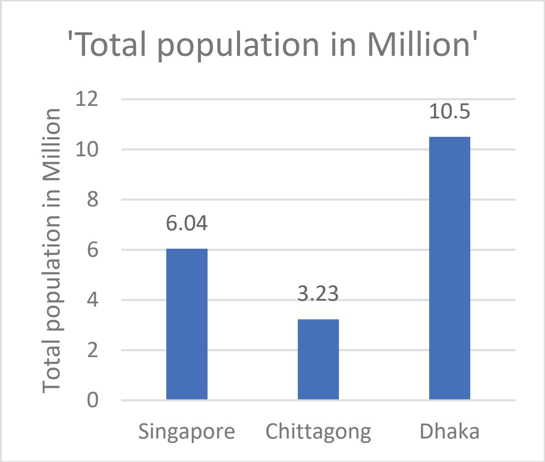
Commercial impact of an effective waste management is also enormous. We may discuss in two different simple ways.

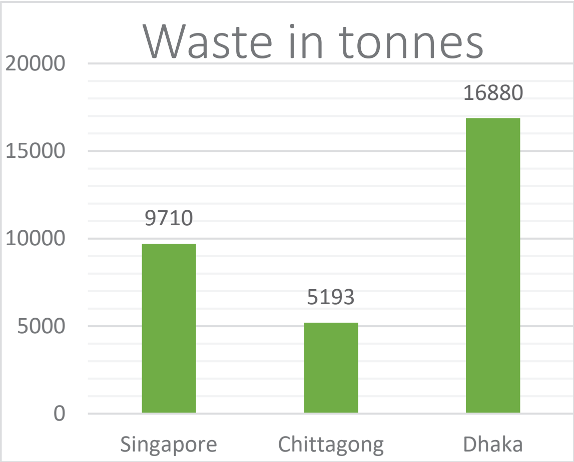
1. **Reduction of waste:** Many of us know that from collection to the disposal of the waste, it contributes to carbon emissions. So, reduction of waste generation means reduction of carbon emissions. As per the report of world economic forum, the waste sector is responsible for 20% of global methane emissions and 3.3% of global greenhouse gas emissions. So, identifying the most waste producer and making series of awareness program on Carbon Credit system, which is a monetary incentive to reduce carbon emissions, may encourage reduction of the waste. Another impact of reduction of the waste is to save on expenses for the waste collection, transportation & disposal.

2. **Reuse of waste:** Reuse of waste can be done through a good waste management which benefit the society by creating jobs in recycling centres, collection services and processing facilities. Communities can save money by selling the recycling materials. Businesses reduce their operating costs by recycling & reusing the materials. Local governments expenditure for the waste clean-up will be less. Property values will be higher for well managed waste system in their neighbourhood. Tourism may increase in cities that maintain clean street & proper waste handling. My focus today is an important aspect of the reuse of waste, which is the conversion of waste into energy for society, as mentioned earlier in the example of Singapore city.

Waste to Energy – Prospect

As shown in the graph below: a comparison between Singapore and Cities of Bangladesh, we can expect the half the waste of Singapore in Chittagong City and 1.7 times waste in Dhaka City alone.





Singapore is currently producing the electricity of 278 MW from their solid waste through four waste to energy (WtE) plant. Cities like Dhaka or Chittagong have no such type of plant and all the solid waste used for landfill only.

According to a report from ResearchGate, the current electricity demand in Chittagong is 1050 MW and in Dhaka is 4500 MW. If we take the electricity production of Singapore as a reference, then Chittagong may be able to produce electricity of 139 MW and Dhaka may produce 470 MW from their own waste. In other way, Chittagong may produce 13.23% and Dhaka may produce 10.44% of electricity from their own waste if the waste to energy plant can be built.

As per the source, Chittagong has planned a waste to energy plant to use 1000 tonnes per day, for which feasibility study completed but implementation still 'much awaited activity'. For Dhaka city also, one biopower project planned to use 7500 tonnes per day and 2x35 MW turbo generator system planned to use 3000 tonnes per day.

Waste management system – Expectation in Bangladeshi Cities

Reducing waste generation and improving waste management are crucial for mitigating climate change. In fact, this contributes to a reduction in global warming by offsetting the carbon emissions. To reduce waste, our government can provide lots of monetary incentives such as reduced tariff on imports, offer soft loan through bank for small scale industries, study loan for children which in turn multiply the advancement of society.

The big question is how the public will be interested in waste management process and how the fund will be managed for the interested individual or group to build such a plant for waste to energy (WtE) conversion. In fact, involvement of our society members, is one of the prime factors of this process.

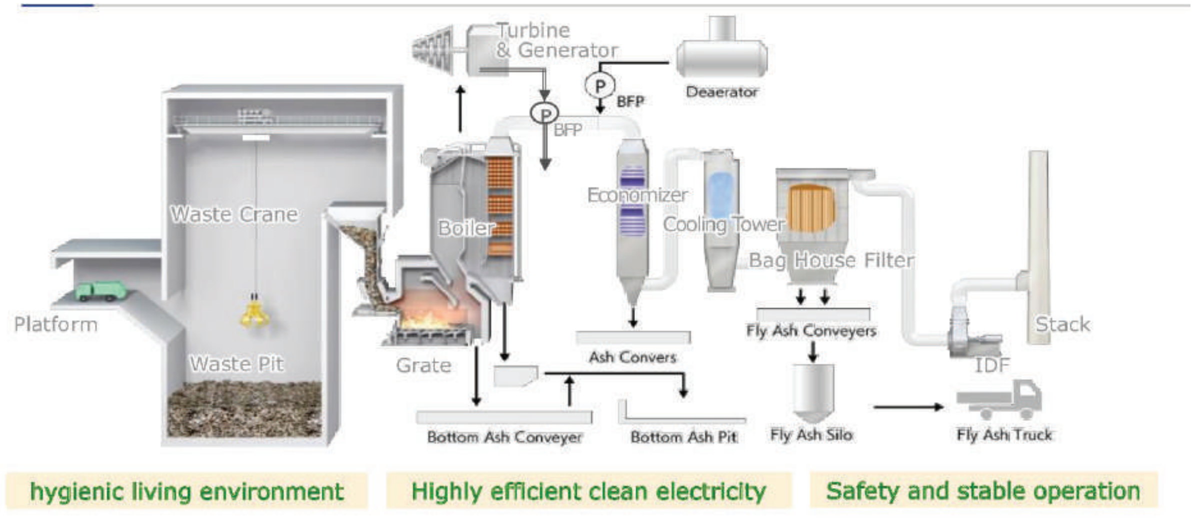
Below activities may be recommended on our society's perspective, which may facilitate the process of reduction & reuse of waste.

1. Awareness program for understanding the type of wastes and its disposal, which can be carried out in educational institutes, City corporation's ward, Industrial sites, shopping malls, tourist attractions, public transports etc. The same shall be adopted in those premises.
2. Waste collection mechanisms shall be provided by the City corporation and other relevant authorities, based on the type of waste.
3. To facilitate the transportation of collected waste, the waste to energy (WtE) plant shall be constructed in the outskirts of the city.
4. City Corporation can propose privately build-own-operate (BOO) model to the entrepreneur or Public Private Partnership (PPP) model wherever is suitable.
5. Bank can even offer some soft loan to some extent to young entrepreneurs for setting up the plant. Whereas a different group can work with process-based investment options, such as waste collection process and handling, Energy conversion & power generation, Power transmission & distribution, Landfill process handling etc.

Waste-to-Energy conversion – Process overview

The following are the steps involved with the waste to energy process,

- Collection of non-recyclable waste materials
- Delivering to the tipping floor of the plant
- Drop the waste to the waste pit
- Break down the waste and transfer to the incinerator
- Burn the waste inside the incinerator and create heat
- Use the heat in the boiler to produce steam
- Turbine will rotate with the steam and generate electricity
- Ashes produced after burning the waste will be filtered and transported for landfill.



The process of waste to energy in WtE plant.

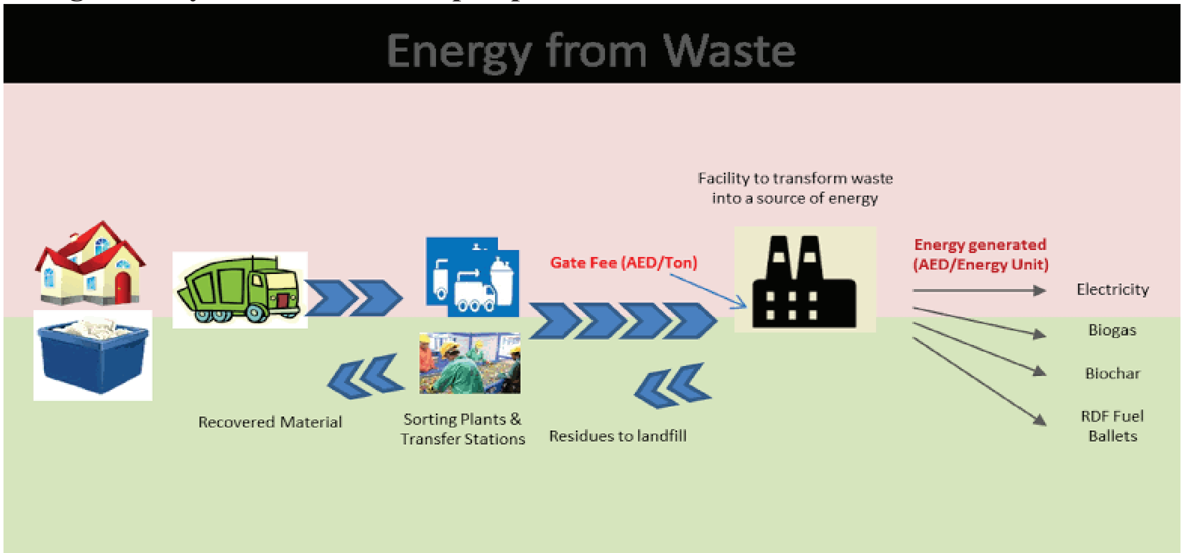
Waste to energy plant – Cost review

The cost to design & construction of a waste-to-energy plant can vary significantly based on factors such as the size of the facility, the type of waste processed, the technology used (incineration, gasification, anaerobic digestion) and the location of the plant.

However, for an understanding of the cost, I have just added the below from CPCintel data, for the installation of plant in United States.

Small scale plant (1 – 5 MW) – USD 7 – 10 million per MW
Medium Scale Plant (5 – 20 MW) – USD 5 – 8 million per MW
Large scale plant (above 20 MW) – USD 4-6 million per MW

Waste management system - Abu Dhabi perspective



Waste management practice model in Abu Dhabi

This article would be incomplete without information on the initiative of the modern AI based waste management practice in Abu Dhabi. Abu Dhabi's vision for waste management focuses on minimizing landfill waste, maximizing resource recovery, and promoting a circular economy. The key goals include diverting 80% of waste from landfills by 2030 and treating 99% of hazardous waste by 2031.

Waste collection process in Abu Dhabi:
BEEAH Group, a public-private organisation pioneering a sustainable quality of life through a diverse range of activities.

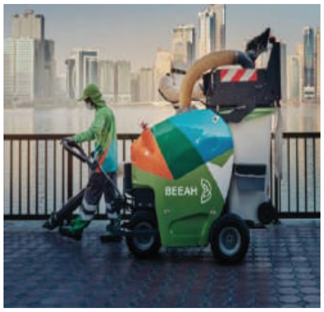
BEEAH has set a benchmark for excellence in technologically driven in waste collection and City cleaning solutions, which transforms cleaner & healthier spaces for the communities.

Key innovations in waste management:

1. **Eco-Friendly Fleet** – BEEAH operates over 2000 vehicles, including autonomous street sweepers, electric desert cleaning vehicles.
2. **Waste Pro+** - End-to-End digital waste management solutions, optimizing routes, managing operation across the waste cycle and conserving resources.
3. **AI Integration** – Utilizing the ‘AI City Vision system’ in waste collection vehicles to monitor bin status, overflowing waste, and road cleanliness in real-time through cameras.
4. **Smart Bins** – Deploying geo-tagged bins with sensors for tracking, solar-powered Wi-Fi bins for waste compaction, and encouraging recycling to maximize collection efficiency.

5. **Community Engagement** – Promoting clean cities through door-to-door awareness c, residential recycling programs, and convenient services like 'You Call, We Haul' for the safe disposal of bulky waste.

AI City Vision System



Street Cleaning

Waste collection from Bin

Waste Segregation process in Abu Dhabi:

Segregation of waste at the point of generation is an important step to optimize the recycling and resource recovery as part of an integrated waste management approach.

Abu Dhabi Urban Planning Council and respective municipalities enforced the requirement of segregation of residential waste into recyclable, non-recyclable and hazardous waste at the source, through master plan approval, building permit, Estidama certification and other tools.

This policy mandates all industrial and commercial waste generators including healthcare facilities, schools, hotels, restaurants, etc. to segregate their waste into different types based on the Waste Classification Technical Guideline.

Waste Transfer process in Abu Dhabi:

Non-compatible wastes are not transported together, and hazardous wastes are segregated and transported in a vehicle which is fit for purpose and licensed for the specific waste type.

Waste transported by licensed Environmental Service Providers (ESP) using a vehicle licensed for the specific waste being transferred. Unlicensed carriers and companies using unlicensed vehicles will be prosecuted under Law.

All transfer stations are licensed by the CWM, have an environmental permit from EAD and any other government licenses / permits required to operate legally.

Any waste generator intending to transfer waste outside the Emirate of Abu Dhabi for the purpose of treatment or recycling must obtain a permit from CWM for each trip before departure.

ESPs planned to optimize the collection routes to minimize the environmental impacts associated with transporting waste.

Energy conversion initiative in Abu Dhabi:
Tadweer Group, part of ADQ's Energy & Utility portfolio, is building the roadmap for sustainable waste practices and supporting the global shift towards a greener future. Tadweer also has ambitious international goal, convening like-minded organizations across the globe through innovative collaborations and partnerships.

Tadweer, in cooperation with Emirates Water and Electricity Company (EWEC) is developing a WtE power plant which will convert waste to energy via a high efficiency steam turbine generator set using advanced moving grate technology. It will process 900,000 tonnes of solid waste and reduce CO2 emissions by up to 1.5 million tonnes per year.

Conclusion
I started with my trip to Singapore, which led me to explore the city's, behind the scene management. Before concluding this article, I want to share another coincident that I experienced while working in 'Zayed Sports City Infrastructure' development project in Abu Dhabi in the year 2012.

I met two Singaporean engineers who were working in the 'Rihan Heights' project inside Zayed Sports City. When I met them for the first time, they told me that "We salute Bangladeshi people". With surprise, I asked them why. I am just sharing the answer with the reader not considering the correctness of it. They replied, "When we switch on TV and see any news about Bangladesh. We see water everywhere and people are roaming around for the relief or shelter. Within six months we noticed the people had built their houses and repair their damages in flood. However, the cycle repeats with another flood and people still stand up and struggle with the nature. Bangladeshis are undoubtedly brave nation."

I conclude this article with due respect to those Singaporean friends. In fact, Bangladesh is a land of opportunities, we people can achieve anything if the common people unite. For any social work people's participation is deemed significant and necessary.

Any steps towards the best practice of waste reduction, reuse and recycle may allow Bangladesh to stand on the global platform, as I believe our potential deserves to be displayed for the world to see.

Finally, I hope, following the best practices of waste management, from everyone's position, we may contribute to the aim of the Current Chief Adviser of Bangladesh Dr Muhammad Yunus, 'The Three Zeros – Zero poverty, Zero unemployment, Zero net carbon emission'.

Information sources: Websites for Singapore WtE plants, Bangladesh environment agency, Environment agency abu dhabi, BEEAH, Tadweer etc.

Ergonomics in the Garment Industry: Local Challenges and Solutions

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Figure: Sewing operators in a Bangladeshi garment factory (illustrative)

Poor ergonomics is a hidden drain on the sector, with recent studies reporting extremely high rates of musculoskeletal injuries among workers. For example, one survey found that roughly 25% of RMG workers suffered low-back pain in the past year (and 23–24% had neck pain). A Quick Exposure Check (QEC) in Bangladesh found **that 80% of sewing and inspection workers were at high risk for ergonomics-related injuries**. These injuries translate into lost workdays, quality defects, and higher claims costs. In practice, this means reduced output per shift and more errors, directly hitting the bottom line. Indeed, experts note that without ergonomic redesign, workers "cannot expect [to] serve…for a long time," as pain and fatigue force absenteeism or slowdowns. This combination of high injury rates and reduced efficiency makes ergonomics a business imperative for local garment manufacturers.

Local Ergonomic Challenges

In many factories, workstations and workflows were designed decades ago and have seen little update. Workers sit or stand on fixed-height benches and machines, often with inadequate back support or reach zones. A field study found sewing stations as close as 44″ apart (only one line had 68″ spacing), so aisles and workspaces are cramped. In this environment, even minor movements force twisting or overreach, fuelling neck, shoulder, back, and knee strain. Compounding these design gaps, **knowledge and cultural barriers** exist: baseline surveys in Bangladesh showed that line supervisors and many operators had *"limited understanding of ergonomics"*, and management rarely enforced ILO posture standards.

Figure: Bangladesh garment factory assembly line (typical conditions)

Factories tend to prioritize quotas and cost savings, with little pressure from buyers to improve worker comfort. In short, **repetitive motions**, **awkward postures**, **outdated workstations**, and **economic pressures** converge to make garment work highly straining on the body.

- **Repetitive strain:** Sewing and cutting operations involve thousands of identical arm/hand motions each shift. This repetition drives cumulative trauma: e.g., wrist/hand and low-back disorders are rampant.
- **Awkward postures:** Many workers sit hunched over or twist to reach controls/materials. Low chairs, high tables, and poor lighting mean necks, shoulders, and backs stay in stressed angles for hours.
- **Cramped workstations:** As noted, benches and machines are tightly packed. Limited legroom and minimal adjustability force unhealthy postures (short distances can make operators lift and lean excessively).
- **Socioeconomic barriers:** Factories often lack basic ergonomic equipment (adjustable chairs, footrests, mats), citing cost. Studies observe that **price pressures** from buyers and tight margins drive this: "Bangladeshi suppliers are less concerned about [worker] ergonomics" under current cost-driven regimes. Without strong external enforcement or ownership, ergonomics remains underprioritized despite its long-term cost impacts.

Practical Ergonomic Solutions

Low-Cost / Immediate Interventions

- **Breaks and job rotation:** Institute regular micro-breaks or rotate tasks among workers. Even simple work-rest cycles reduce muscle fatigue. In practice, scheduled pauses in sewing/cutting lines have been shown to reduce discomfort.
- **Chair and seating adjustments:** Supply chairs with proper **lumbar support** and adjustable height. A backrest supports the spine and distributes weight. One study recommends chairs with backrests for sewing operators to cut low-back strain. Simple footrests can help petite workers reach pedals without lifting their legs.

- **Anti-fatigue mats:** For standing tasks like cutting, use padded mats. Floor mats halve leg strain in many industries; PLOS research specifically suggests mats as a "low-cost solution" for standing-cutting operations.
- **Tool and workstation tweaks:** Angle or raise cutting tables using wooden wedges so workers don't stoop. Keep materials and tools within the "normal working area" (ideally <90° reach) to avoid overextension. Even small changes like adding padded grips or using bins with lips (instead of open boxes) can cut awkward wrist/bend postures.
- **Training & awareness:** Quickly train workers on proper body mechanics. Demonstrate correct posture (e.g., back straight, elbows close) and encourage micro-adjustments. Educational programs (even short sessions) can immediately improve habits. The PLOS study endorses ergonomics training as an effective *intervention* to reduce WMSD risks.

These interventions require minimal capital and can be implemented facility-wide within weeks. They directly target the common symptoms (aches, stiffness) and have documented payoffs in other industries.

Medium-Term Facility Modifications

- **Adjustable workstations:** Retrofit or replace tables and sewing machine mounts with adjustable-height designs. This lets workers of different sizes maintain neutral postures. For example, factories that realigned bench heights and provided variable machine stands saw measurable posture improvements among operators.
- **Workstation layout and spacing:** Where feasible, reconfigure floor layout to increase distance between stations. Even a few extra inches between benches gives employees room to reposition without hitting obstacles. Ensure aisles and walkways meet safety codes (e.g., 4–5 ft clearance).
- **Engineering controls:** Install mechanical aids to reduce manual strain. Options include lift-assist arms for heavy fabric rolls, magnifying lamps to lessen neck flexion, and foot-operated tables for easier material movement. Upgrading lighting (to reduce leaning) and ventilation (to decrease heat stress) also indirectly improves ergonomic comfort.
- **Participatory ergonomics:** Form a cross-functional ergonomics team in each plant (ideally involving engineers, line supervisors, and worker reps). This team can systematically identify trouble spots and trial improvements. One study recommends that suppliers "form a cross-functional team" (including buyer reps if present) to spearhead ergonomic fixes. Companies have found value in bringing in industrial engineers or consultants to redesign sewing stations, set proper chair heights, and train staff on new methods.
- **Lean/Kaizen integration:** Use lean manufacturing tools (5S, Time and Motion Studies, Kaizen events) with an ergonomics lens. Remarkably, an integrated lean–ergonomics intervention in Dhaka factories showed **dual gains**: higher efficiency *and* lower injury risk. One program applied TMS and 5S to sewing lines and reported significant drops in worker fatigue scores, *and* up to **32% higher worker throughput** in key processes. By addressing production bottlenecks (e.g., cutting cycle times) while redesigning workstations, managers achieved quicker cycles **and** less reported pain. This proves that ergonomic care and productivity can be complementary rather than conflicting.

Long-Term Strategic Planning and Technology

- **Ergonomic audits & metrics:** Establish ongoing risk assessments (using tools like the ILO Handbook on Work Systems or NIOSH QEC). Benchmark key metrics – injury rates, absenteeism, defects – and measure them before and after interventions to quantify ROI. In one trial, two

Bangladeshi factories implementing all suggested ergonomic/lean improvements saw **80–100% increases** in value-added output, underscoring the payoff of a systematic program.

- **Technology integration:** Explore advanced solutions as they mature. For example, wearable posture sensors or smartphone apps can alert operators in real time when they deviate into a risky posture. Automated fabric feeders and basic robotics can reduce heavy lifting. While these are longer-term investments, pilot trials in pilot factories have shown promise. Engaging with industry tech partners (or university research programs) can help plan such upgrades.
- **Workforce development:** Invest in long-term worker training and ergonomics culture. This includes ergonomic design education for industrial engineers and regular refresher courses for operators. As the work environment or products change, a trained workforce can adapt workstations and habits proactively.

By staging improvements from quick fixes to strategic planning, factories can continually reduce ergonomic risks while aligning with production goals. Notably, research shows even modest ergonomic investments often **pay back in months**, through higher output and fewer injury claims.

Case Study: Measurable Gains from Ergonomic Upgrades

A multi-factory study in Dhaka illustrates what coordinated action can achieve. Researchers partnered with six garment plants to redesign workstations, apply 5S and time-motion improvements, and train staff. **Results were striking:** two factories (out of six) that fully implemented the program achieved **80–100%** increases in *value-added* production time. In practical terms, one high-volume line cut cycle times by 1–11 seconds per garment through improved layouts and multi-skilled workers. This boosted that line's output capacity by up to **32%** per hour. Simultaneously, workers in these plants reported *significant reductions in muscle pain and fatigue* after the intervention.

These local successes mirror international findings: a Bangladesh apparel supplier that overhauled sewing stations and instituted micro-breaks saw *double-digit* productivity gains, while lost-time injuries fell by over 30%. Such cases demonstrate concrete ROI: the ergonomic fixes paid for themselves in higher throughput and lower downtime. The takeaway is clear – even within cost-sensitive supply chains, targeted ergonomics programs can yield measurable business benefits.

Actionable Takeaways

- **Use standardized checklists:** Perform a formal ergonomics audit (e.g., via the ILO Code of Practice or a NIOSH QEC) to spot risk factors. Document each work station's layout, tool design, and posture issues. Track improvements over time to verify impact.
- **Implement quick fixes today:** Procure ergonomic chairs, anti-fatigue mats, and basic handle/grip pads immediately. Adjust each station so that workers' **heads, arms, backs, and legs** are in neutral zones. (Remember: OSHA guidance advises keeping controls and materials within the normal working area to avoid extended reaches.) Even simple changes like angling a table or lowering a seat can cut strain substantially.
- **Train and engage employees:** Roll out short training sessions on safe work postures and the use of new equipment. Encourage workers to report discomfort early. Empower line supervisors to enforce posture breaks and monitor compliance.
- **Measure and iterate:** Track KPIs such as WMSD complaint rates, sick days, and production errors before and after changes. For example, if a line's output rises or scrap rates fall after a workstation upgrade, quantify that as an ROI. Use these data to justify further investment.

- **Collaborate with experts/vendors:** Seek out reputable ergonomics consultants or engineering firms with apparel experience. They can recommend appropriate equipment (e.g., chairs built for sewing operators) and validate designs against international standards. Good vendors will offer fitting and adjustment services (not just hardware).

By following a checklist approach – assess, fix, train, re-measure – facilities can embed ergonomics into their culture. Small, documented successes will build the case for larger capital projects.

Next Steps for Stakeholders

- **Engineers & Technical Teams:** Adopt this article's recommendations into your production plans. Develop detailed ergonomic specifications for new workstations (for example, incorporate ISO/ANSI seat and reach standards). Use time-motion study tools to identify ergonomic bottlenecks, then adjust cycle layouts accordingly. Prepare cost–benefit analyses and pilot studies to demonstrate ROI (e.g., cite the 25–32% throughput gains above). Reference available design guidelines (ILO ergonomics Code, ANSI/BIFMA chair standards) when sourcing equipment. Establish an in-house ergonomics manual or digital resource to guide future facility design.
- **Compliance Officers:** Integrate ergonomics into existing OSH audits and risk assessments. Update checklists to include factors like reach distance, lighting, vibration, and material handling. Ensure compliance with Bangladesh labour law clauses on worker safety (e.g., BLA 2006 requiring safe machinery and training). Prepare for audits by documenting injury logs and inspection reports. Educate management on how proactive ergonomics lowers liability: for instance, mention that Bangladesh's new Employment Injury Scheme (EIS) will eventually reimburse a percentage of wages after workplace injuries, so reducing injuries via ergonomics can moderate premium costs. Work with BGMEA/BCMEA safety committees to include ergonomics standards in compliance codes.
- **Government & Industry Leaders:** Consider policies and partnerships that promote ergonomics. Support vocational training programs (perhaps via BGMEA or ILO collaborations) to teach factory managers and workers about ergonomic best practices. Tie export incentives or social compliance certifications to ergonomic training completion. Encourage research by funding pilot ergonomics projects in public–private partnerships (e.g., with Bangladesh University of Textiles or engineering institutes). Leverage the EIS and OHS frameworks by funding awareness campaigns: if factory owners know that ergonomic improvements can improve global competitiveness (and help fulfil buyer codes-of-conduct), they'll be more receptive. Finally, form inter-ministerial task forces (Labour, Industry, Health) to set national ergonomic standards and monitor sector-wide progress.

Use it as a checklist when specifying chairs, tables, material-handling routines, or audit criteria inside Bangladeshi garment factories.

Topic	Key requirement	Standard / clause
Seat height (operator chairs)	Adjustable **37.5 – 51.2 cm** (14.8 – 20.2 in) – covers 5th-95th percentile workers	BIFMA G1-2013 §5.1
Seat depth	≤ 41.5 cm (fixed) **or** include 41.5 cm with ≥ 5 cm adjustment	BIFMA G1-2013 Table 2
Seat width	≥ 48.9 cm (19.2 in) to fit 90 % ♀ / 97 % ♂ hip breadth	BIFMA G1-2013 Table 2

Lumbar-support height	15 – 25 cm above the compressed seat	BIFMA G1-2013 Table 3
Torso–thigh angle	Adjustable 90 – 120 °, ≥ 15 ° of movement	BIFMA G1-2013 Table 3
Sit-stand cutting / QC tables	Height range **57 – 124 cm** (22.5 – 48.7 in) for full G1 compliance	BIFMA G1-2013 (work-surface guidance)
Static working posture	Trunk inclination 0 – 20 ° = *always acceptable*; > 20 ° → limit duration or redesign task	ISO 11226:2000 §4.4
Neck flexion	Keep within 0 – 25 ° for prolonged tasks	ISO 11226:2000 Annex B
Shoulder elevation	≤ 20 ° (unsupported); ≤ 60 ° only if arms are fully supported	ISO 11226:2000 Annex B
Manual lifting limits (single lift)	25 kg ♂ (20-45 yrs); 20 kg ♂ (< 20 or > 45 yrs) • 20 kg ♀ (20-45 yrs); 15 kg ♀ (< 20 or > 45 yrs)	ISO 11228-1:2021 Table 3
Cumulative carrying (1-5 m distance)	≤ 6 000 kg total mass per 8 h shift	ISO 11228-1:2021 §4.2.3.2
Redesign trigger	> 15 lifts/min for > 60 min **or** any lift above the mass limits	ISO 11228-1:2021 §4.2.2.2
Sewing-station design	Work surface at or just below elbow height; wrists neutral	OSHA Sewing e-Tool – Station Design
Chair features	Height/tilt/back-rest adjustable, lumbar curve, waterfall front edge	OSHA Sewing e-Tool – Chair section
Foot-pedal reach	Position the leg so remains within a comfortable range; consider electric/pneumatic pedals.	OSHA Sewing e-Tool – Treadle/Pedal section
Anti-fatigue mats	Provide for prolonged standing at cutting tables	OSHA Sewing e-Tool – Table/Standing guidance
Alternate chair spec	Seat height range 38 – 56 cm with ≥ 11.4 cm adjustment (if using HFES instead of BIFMA)	ANSI/HFES 100-2007 §8.3

Ergonomics in Bangladesh's garment factories is no longer a side issue; it is a direct driver of productivity, quality, and workforce sustainability. By anchoring work-station design to BIFMA, ISO, and OSHA limits, managers can cut injury rates, lift throughput, and meet buyer audit requirements in one coordinated effort. The low-cost fixes outlined here—adjustable chairs, footrests, micro-breaks, and layout tweaks—deliver quick wins, while medium- and long-term upgrades position plants for sharper competitive advantage. Successful case studies show that every taka invested in ergonomics returns multiples in reduced absenteeism and higher output.

Waste Management – Best Practices for a Cleaner and Sustainable Future

Engr. Rahana Akter
Head of Construction Materials Research Laboratory
Fujairah Municipality

Introduction: Why Waste Management Matters

In today's world, the challenge of waste management goes beyond simple disposal—it is a matter of sustainability, efficiency, and responsibility. Whether we are dealing with domestic waste, industrial scrap, or construction debris, our focus must shift from throwing away to rethinking, reducing, and reusing.

As a civil engineer working in the public sector, I've had the opportunity to see how innovative practices in material testing and inspection directly contribute to better waste handling and sustainable reuse—especially in the construction sector, where the volume of waste is often high, but so is the potential for recovery.

Best Practices in Modern Waste Management

1. Recycling Construction & Demolition Waste

One of the most effective best practices is reusing construction waste—concrete blocks, bricks, and aggregates—that would otherwise go to landfill. In Fujairah, local crusher companies and block factories have implemented a practical and successful model:

"Waste concrete blocks from block factories are collected and crushed into smaller particles. These recycled aggregates are then tested and verified by laboratories like ours to ensure they meet the required quality standards."

These recycled materials are now being approved and used in ADNOC projects, as per the client's technical specifications. This process not only reduces waste but also lowers the demand for natural raw materials, making it a win-win for both industry and the environment.

2. On-Site Waste Segregation

Waste should be sorted at the source—whether on a construction site, a factory, or a residential area. Separating concrete, steel, wood, plastic, and hazardous materials makes recycling easier, safer, and more efficient.

3. Supporting Laboratories for Quality Control
Recycling is only effective if the output meets engineering standards. In our laboratory at Fujairah Municipality, we routinely test recycled aggregates for:

- Gradation and particle shape
- Water absorption and specific gravity
- Compressive strength of recycled concrete
- Chemical properties such as sulfate and chloride content

These tests give contractors confidence in using recycled materials and help enforce municipal and national quality standards.

4. Public and Private Sector Collaboration
Successful waste management requires collaboration. In Fujairah, the relationship between block factories, crusher plants, laboratories, and government regulators show how a coordinated system can reduce waste and support large-scale infrastructure programs.

5. Complying with Client Specifications
Recycled materials are now being accepted in high-standard projects like those under ADNOC, provided they comply with required specifications. This shows that sustainability and quality can go hand in hand when supported by proper testing, documentation, and control.

My Role in Promoting Sustainable Practices
As Head of the Construction Materials Research Laboratory, I support waste management best practices by:

- Testing and validating recycled materials
- Issuing technical approvals to contractors and suppliers
- Participating in inspection visits to ready-mix plants, crushers, and factories
- Promoting the reuse of tested and verified construction waste
- Providing technical guidance in public projects involving sustainable materials
- Issuing NOCs (No Objection Certificates) for crusher aggregate samples and companies upon compliance verification

Ensuring Health, Safety, and Environmental Compliance in High-Risk Worksites:
In dusty and hazardous work environments—such as crusher plants, cement factories, and construction sites—strict Health, Safety, and Environment (HSE) measures are essential to protect both workers and the surrounding environment. To minimize exposure to airborne dust, employees are required to wear appropriate Personal Protective Equipment (PPE), such as respirators, safety goggles, and protective clothing. Dust suppression systems, including water spraying and covered conveyor belts, are commonly used to control particulate emissions.

Many facilities also maintain ISO 9001 (Quality Management) and ISO 14001 (Environmental Management) certifications, demonstrating their commitment to safety, environmental protection, and international quality standards. Regular training, risk assessments, and air quality monitoring ensure compliance and support continuous improvement, creating a safer and more sustainable workplace for all.

Conclusion: Rethink Waste as a Resource

The concept of waste as a resource must be central to our strategy. The practices in Fujairah—especially the recycling of waste blocks for ADNOC-approved aggregates—show how engineering, policy, and environmental goals can align.

By applying best practices in waste reduction, testing, and reuse, we can significantly reduce the environmental impact of construction while supporting innovation and cost savings. I encourage engineers, factory managers, and decision-makers—especially from the Bangladeshi engineering community—to adopt and share these methods globally.

Fig-1: Control of the process of crushing mountains

Fig-2: Aggregate Grading size (20mm, 10mm, 5mm etc) Controlling areas

Fig-3: Control room for sample distribution based on aggregate stockpile

Fig-4: Final production aggregate sample

Fig-5: Aggregate loading areas

Artificial Intelligence in Biomedical Waste Generation Phase for Dhaka

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Biomedical Waste Management (BWM) is a process that manages waste from its creation to its final disposal. It's a growing concern globally, especially in developing countries like Bangladesh, but it doesn't always get the attention it needs. BWM is a crucial part of Integrated Waste Management (IWM). While IWM practices in Bangladesh are improving, BWM still has a lot of progress to make.

Dhaka, the capital of Bangladesh, is one of the most crowded cities in the world, with over 21 million people. Rapid growth, poor infrastructure, and high industrial activity have led to massive waste, particularly from healthcare. Many people travel to Dhaka for medical treatment, which increases the number of healthcare facilities and worsens the issue of biomedical waste management.

BWM faces several challenges, such as poor waste management systems, unclear or poorly enforced regulations, and limited use of modern technology and expertise. A major issue is the lack of general awareness and sense of responsibility among the people in charge of managing biomedical waste.

This article explores how AI can be integrated into the Biomedical Waste Generation Phase in Dhaka as a starting point for future AI-enhanced BWM. The flow of information in this article is outlined in the diagram below.

Understanding BWM & It's phases.
↓
Role of AI in BWM.
↓
Application of AI in Dhaka's Context
↓
Future of AI-Enhanced BWM

Biomedical Waste Management (BWM)

Biomedical waste refers to the waste generated by medical and healthcare activities, such as hospitals, clinics, and laboratories. This waste includes items like used needles, syringes, bandages, body fluids, and other materials that can carry infectious diseases. Effective Biomedical Waste Management involves several critical steps:

- **Proper Segregation at Source:** Ensuring that waste is properly sorted at the point of generation to avoid cross-contamination.
- **Appropriate Treatment Methods:** Methods like autoclaving and incineration are used to neutralize harmful pathogens.
- **Safe Collection and Transportation:** Ensuring that waste is safely collected and transported to treatment facilities.
- **Disposal in Certified Facilities:** The waste is then disposed of in certified landfills or recycled through specialized processes.

Broadly following four phases effectively capture the essential lifecycle of BWM: Waste Generation, Waste Collection & Segregation, Waste Storage (before transport), Waste Treatment & Disposal. While these four phases cover the core aspects, some other elements such as transportation, auditing/ monitoring, training within these phases are supporting steps.

Artificial Intelligence (AI) & Its Role in BWM

In general, AI has the potential to revolutionize the management of biomedical waste, offering solutions that can address several challenges in the complete system. Introducing automation, improving waste tracking systems, and providing valuable data for better decision-making are some of the examples. Some key ways in which AI can improve Biomedical Waste Management include:

Predicting Waste Generation: AI can analyze hospital activity to predict when and how much biomedical waste will be generated. This helps in planning better, ensuring resources are in place and preventing waste overflow.

Automating Waste Sorting: AI technology can automatically identify and sort biomedical waste at the source. This ensures proper categorization, reduces human error, and prevents contamination.

Smart Waste Tracking: AI sensors and tracking systems can monitor biomedical waste from its origin to treatment facilities. Real-time data helps optimize collection routes and schedules, ensuring safe handling throughout the process.

Optimizing Treatment Methods: AI can recommend the best treatment methods for different types of biomedical waste. By studying past data, it can suggest the ideal conditions for incineration or autoclaving to reduce environmental impact.

Supporting Decision Making: AI can provide insights into current waste management practices, helping decision-makers improve processes by suggesting data-driven changes.

AI can be integrated in broadly categorized phases of BWM as shown in following table.

BWM Phases	Generalized Application of AI (not limited to)
Phase 1: Waste Generation	• Integration of AI in Healthcare facilities central database. • AI-powered sensors and image recognition tools • Predictive Analytics for Waste generation
Phase 2: Waste Collection & Segregation	• Use of AI-based robotics for collection • Using sensors to detect material types (e.g., plastics, sharps, biohazardous materials). • AI-based systems with machine learning to automate the sorting of waste into predefined categories
Phase 3: Waste Storage (Temporarily before transport)	• AI-driven monitoring systems to track the amount and type of waste in storage • Ensuring no container overflows • Automated alert system when storage conditions (e.g., temperature) go outside acceptable ranges.
Phase 4: Treatment & Disposal	• Automated decision/suggesting for efficient & environmentally friendly treatment method based on waste categories • AI-based optimization for the waste treatment process by analyzing real-time data to control factors like temperature, pressure, and time in incinerators or autoclaves, improving efficiency and safety.

AI in Biomedical Waste Management for Dhaka

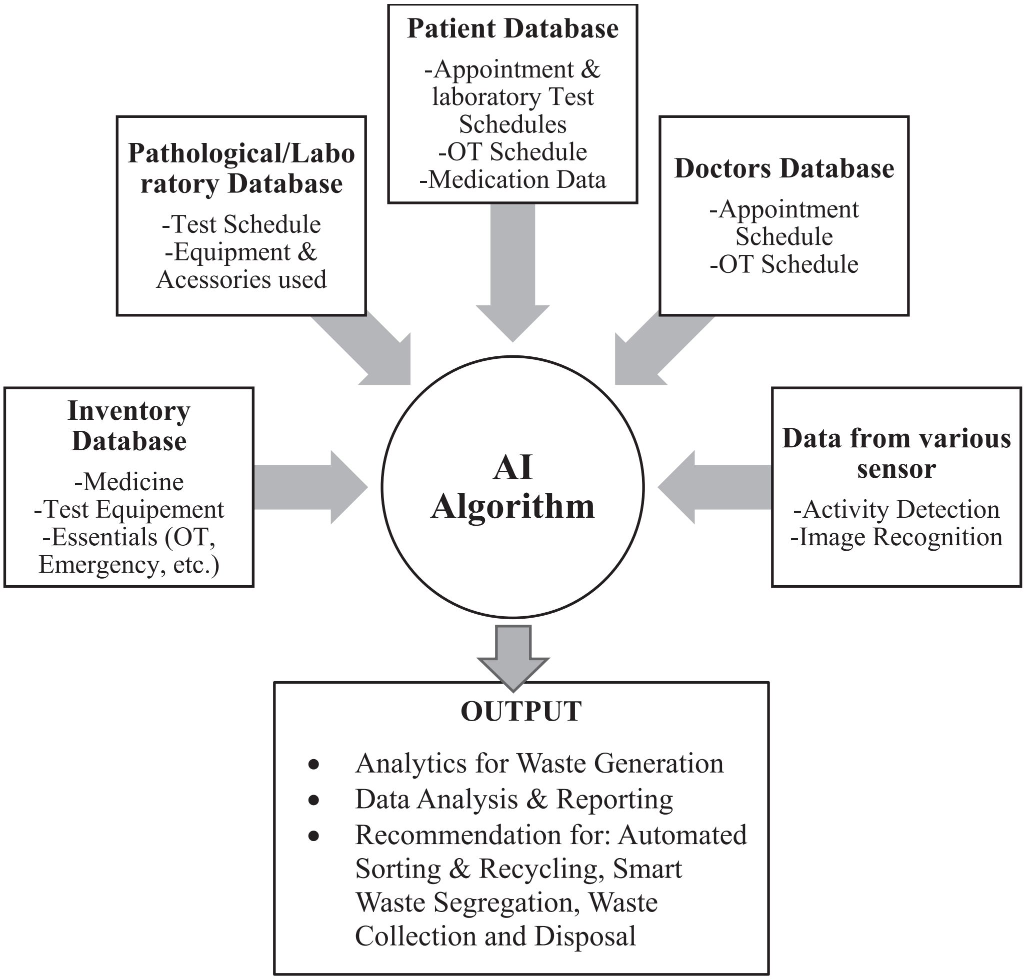
Dhaka faces a challenge in using AI for biomedical waste management (BWM) because the system isn't clearly defined or standardized. AI relies on accurate data, and without a solid BWM framework, its impact is limited. However, AI can still play a key role in specific areas, like the Waste Generation Phase. Many healthcare facilities in Dhaka already have digital systems for:

- Tracking healthcare supplies and equipment
- Recording lab test results and schedules
- Storing patient treatment data and appointments
- Managing doctor information

These facilities also use CCTV cameras to monitor activities. All this data can be used by AI algorithms. By linking AI with these existing databases, healthcare facilities can better manage the waste they generate. Focusing on the Waste Generation Phase, AI can offer immediate benefits, helping to manage waste right from the source. Some ways AI can be applied include:

- Integrating AI into central healthcare databases
- Using AI-powered sensors and image recognition with CCTV cameras
- Predicting and scheduling waste generation (e.g., quantity and timing)

AI can predict, calculate waste quantities, and automatically identify biomedical waste as it is produced. It can also classify waste types, combining all available data for more efficient management. Visual representation of the process as shown below.



Implementing AI in the waste generation phase of Dhaka's BWM offers significant benefits: primarily through enhanced data-driven insights. By leveraging existing hospital databases and CCTV footage, AI can assist in the following:

- Estimate waste generation pattern, volume, type, schedule
- Predict peak-off peak for waste generation surge-cycle
- Generate automated report of waste generation (daily, monthly, yearly, seasonal)
- Suggest appropriate collection system, storage system, segregation methods, optimization in any steps (valuable decision-making parameters for Phase-2, 3, 4)

Depending on input data & a well-defined algorithm, AI can estimate, predict and further suggest for optimized resource allocation, reduced human error and cost savings as well.

Future with AI-Enhanced Biomedical Waste Management

Using AI in the Generation Phase of Biomedical Waste Management (BWM) could be a great start for wider adoption. AI-enhanced BWM has a lot of potential benefits like being more effective, efficient, reducing errors, and controlling the environment. However, there are also challenges. One major issue is the lack of a clear, standardized BWM system across all facilities, which means the initial data quality can be inconsistent and affect AI performance. Additionally, the cost of setting up AI systems and the need for specialized skills can be a big barrier, especially for smaller or underfunded healthcare providers.

Even with these challenges, the future of AI in Dhaka's BWM looks very promising. AI could help improve waste collection routes, track waste in real time using IoT, automate sorting at treatment facilities, and even predict health risks from waste. As BWM regulations in Dhaka improve and digital infrastructure grows, AI could play an even bigger role, making waste management smarter, more efficient, and safer for the city.

Ethical Practices:

When AI is used in Biomedical Waste Management (BWM), it's important to follow ethical practices to ensure everything is handled properly. Here are the key points:

1. **Data Privacy and Security**: It's crucial to protect sensitive information, like patient data and waste details, making sure they are safe from unauthorized access.
2. **Transparency**: AI systems should be open about how they work, how decisions are made, and how they affect waste management. It's important to explain the data and algorithms used.
3. **Bias Prevention**: AI should be designed in a way that avoids biases. This helps ensure that no specific waste types or areas are unfairly impacted, leading to more effective and fair waste management.
4. **Human Oversight**: Even though AI can assist, human experts need to review its decisions to make sure it's working as it should and to avoid over-dependence on automation.
5. **Accountability**: It should be clear who is responsible for the AI's decisions in BWM. If something goes wrong, the people in charge should be able to be held accountable.
6. **Sustainability**: The use of AI should help protect the environment by making waste management more sustainable and reducing harm from biomedical waste.

Following these ethical guidelines helps ensure AI is used safely and fairly in BWM, keeping privacy, fairness, and responsibility in mind.

Conclusion:

The use of AI in Biomedical Waste Management (BWM) in Dhaka presents a significant opportunity to enhance public health and safety, while also advancing toward a more sustainable and efficient waste management system. By incorporating AI technologies, Dhaka has the chance to transform its waste management practices, minimize health risks, and create a cleaner, safer environment for residents. As the city's healthcare facilities expand, it is increasingly important for the waste management infrastructure to adapt accordingly. AI stands out as a powerful tool to tackle the complex challenges of biomedical waste disposal, offering a smart, scalable solution for the city's growing needs. Not only does AI have the potential to improve the management of healthcare waste, but it also positions Dhaka as a leader in innovative waste management strategies that could serve as a model for other cities facing similar issues.

AI-Driven Community-Centric Waste Management: Leveraging Reinforcement Learning for Dynamic Waste Sorting and Public Engagement

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Abstract
This research proposes an innovative AI-driven community-centric waste management system leveraging reinforcement learning (RL) for dynamic waste sorting optimization and enhanced public engagement. Traditional municipal waste management (MWM) systems face significant challenges in achieving effective waste sorting compliance at the source, primarily due to static classification methods and limited community participation. Our proposed framework integrates RL agents with smart bin infrastructure equipped with sensors and cameras to dynamically optimize waste sorting strategies in real-time. Additionally, we introduce a gamified mobile application that utilizes RL algorithms to personalize user engagement strategies, incentivizing proper waste sorting behavior through adaptive reward mechanisms. The system learns from continuous user interactions and environmental feedback, improving sorting accuracy and community participation over time. Preliminary simulations indicate potential improvements in sorting accuracy from 70% (traditional systems) to 90%, with projected community app adoption rates of 50%. The framework integrates seamlessly with existing AI techniques including genetic algorithms for route optimization and artificial neural networks for waste forecasting, creating a comprehensive intelligent waste management ecosystem. This research contributes to sustainable urban development by addressing the critical gap between technological capability and community behavioral change in waste management practices.

Index Terms— **Reinforcement Learning, Smart Waste Management, Community Engagement, Gamification, IoT, Sustainable Cities, Artificial Intelligence**

Abbreviation: RL; Reinforcement Learning, MWM; Municipal Waste Management; AI; Artificial Intelligence.

I. INTRODUCTION

Municipal waste management (MWM) represents one of the most pressing challenges facing modern urban environments, with global waste generation projected to increase by 70% by 2050 Bank, 2018 . The effectiveness of waste management systems heavily depends on proper sorting at the source, yet traditional approaches struggle with low compliance rates and static optimization methods that fail to adapt to dynamic community behaviors and varying waste compositions.

Recent advances in artificial intelligence have introduced various machine learning techniques to waste management, including artificial neural networks (ANN), support vector machines (SVM), and genetic algorithms (GA) for different aspects of the waste management pipeline. However, these approaches primarily focus on backend optimization rather than addressing the fundamental challenge of community engagement and dynamic source-level sorting optimization.

Reinforcement learning, a paradigm where agents learn optimal decision-making through interaction with their environment, offers unique advantages for waste management applications. Unlike supervised learning approaches that require extensive labeled datasets, RL systems can continuously adapt and improve through real-world feedback, making them particularly suitable for dynamic environments with varying waste compositions and evolving community behaviors.

This research addresses the gap in community-centric waste management by proposing a novel RL based framework that combines smart infrastructure with behavioral psychology principles to create a self-improving, community-driven waste sorting system.

II. Literature Study

2.1 AI in Waste Management

The application of artificial intelligence in waste management has evolved significantly over the past decade. El Jaouhari et al., 2025 provide a comprehensive review of AI techniques in MWM, highlighting the predominant use of ANNs for waste generation forecasting, SVMs for waste classification, and Gas for route optimization. However, their review identifies limited exploration of RL applications, particularly in community engagement contexts.

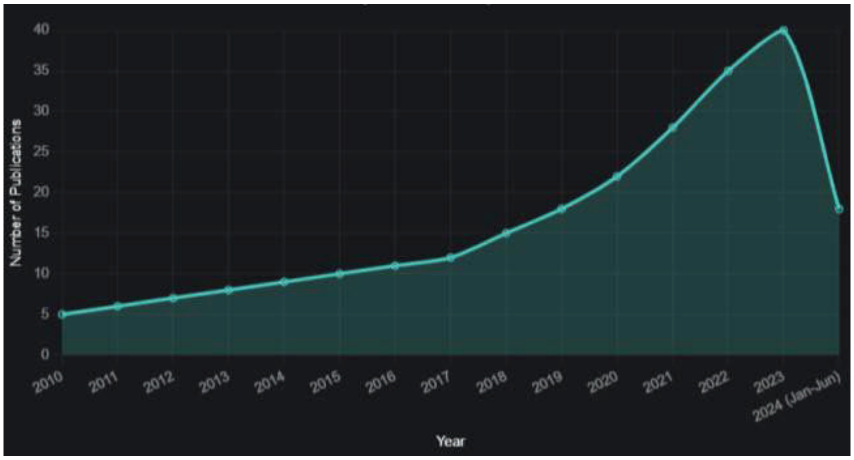

Figure 1 Growth of Al-Related Publications in Municipal Waste Management (2010-2024)

Recent studies have demonstrated the effectiveness of machine learning in various waste management applications. Gupta et al., 2019 explored the integration of IoT and machine learning for smart waste collection, emphasizing the potential for real-time optimization. Gatti et al., 2024 provided a critical review of machine learning algorithms for smart bin collection, highlighting the need for more adaptive and intelligent systems.

2.2 Reinforcement Learning Applications

While RL applications in waste management remain limited, recent research has shown promising results. Rajani et al., 2022 explored IoT-based smart waste management using deep reinforcement learning, demonstrating the potential for adaptive optimization in smart city environments. Navarro Jimenez, 2025 investigated RL models for optimizing waste management in Costa Rica, focusing on equitable recycling access through agent-based modeling.

The unique characteristics of RL - learning through trial and error, adapting to dynamic environments, and optimizing long-term rewards - make it particularly suitable for addressing the complex, multistakeholder nature of community waste management.

2.3 Gamification and Community Engagement

Community engagement in waste management has been significantly enhanced through gamification strategies. Lidia et al., 2018 demonstrated the effectiveness of WasteApp, a gamified mobile application that successfully influenced recycling behavior through reward mechanisms and social features. Their study showed that gamification can substantially improve motivational stimuli and long-term engagement.

Santti et al., 2020 explored digitalization-boosted recycling through gamification, specifically targeting young adults for enhanced waste sorting. Their research revealed that gamified solutions could effectively lead target demographics toward desired environmental behaviors. Neofotistos et al., 2023 provided real-world evidence of citizens' motivation and engagement in urban waste management through mobile applications and smart city technology.

III. METHODOLOGY

3.1 System Architecture

Our proposed system consists of three interconnected components: (1) RL-enabled smart bins with sensor arrays and computer vision capabilities, (2) a community engagement mobile application with gamified interfaces, and (3) a central optimization engine that coordinates learning across the entire network.

Smart Bin Infrastructure: IoT-enabled bins with cameras, weight sensors, and classification modules

RL Optimization Engine: Central learning system using Q-learning and policy gradient methods

Mobile Application: Gamified interface with QR code tracking and personalized rewards

Integration Layer: API framework connecting all components with existing MWM systems

Figure 2 System Framework Overview

3.2 Reinforcement Learning Model Design

The RL model employs a multi-agent approach were individual smart bins function as learning agents within a collaborative network. Each agent observes local waste composition, user behavior patterns, and environmental factors to optimize sorting recommendations and bin management strategies.

Table 1 RL components and its implementation

RL Component	Implementation	Purpose
State Space	Waste composition, bin capacity, user behavior, time factors	Environment representation
Action Space	Sorting recommendations, user notifications, capacity alerts	Agent decision options
Reward Function	Correctsorting (+10), contamination (-5), user engagement (+3)	Learning optimization
Learning Algorithm	Deep Q-Network (DQN) with experience replay	Policy optimization

3.3 Community Engagement Strategy

The mobile application implements a dual RL approach: user behavior prediction and personalized engagement optimization. The system learns individual user preferences, optimal timing for notifications, and effective reward mechanisms to maximize long-term participation.

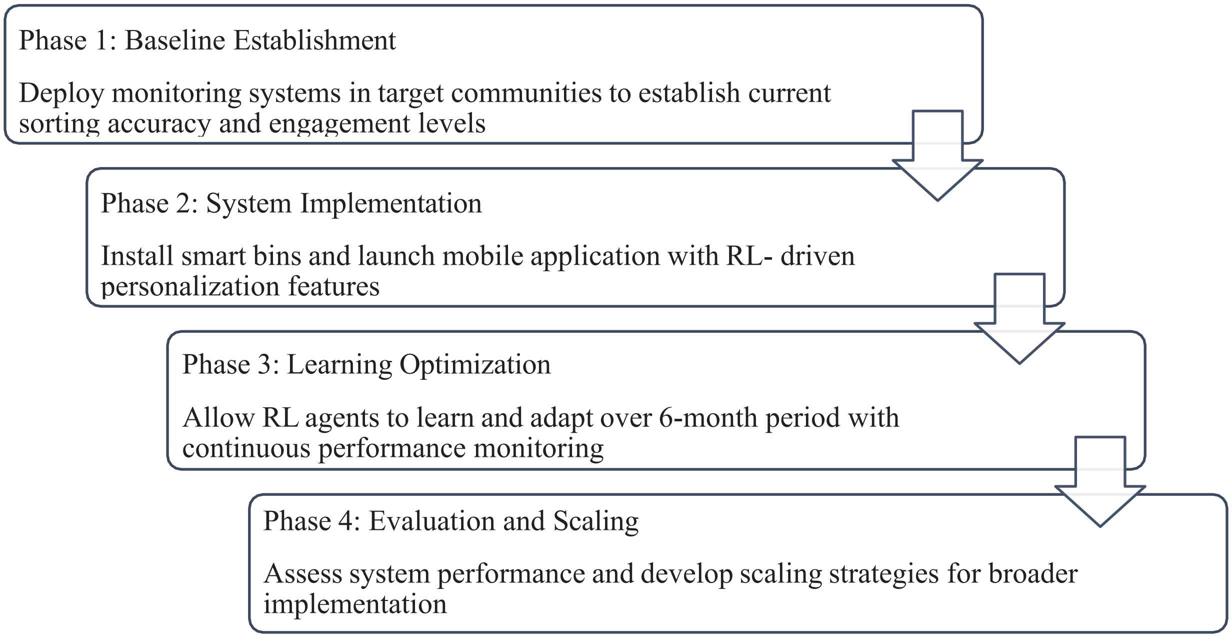

Figure 3 Methodology Phases

IV. Proposed RL-Based Waste Management System

4.1 Dynamic Waste Sorting Optimization

The core innovation lies in the RL agent's ability to dynamically adapt sorting strategies based on real-time feedback. Unlike static classification systems, our RL approach continuously learns from sorting outcomes, user interactions, and environmental factors to optimize decision-making processes.

The reward function incorporates multiple objectives: maximizing sorting accuracy, minimizing contamination, optimizing bin utilization, and enhancing user experience. This multi-objective approach ensures that the system balances technical efficiency with community acceptance and long-term sustainability.

4.2 Gamified Community Engagement

The mobile application employs sophisticated RL algorithms to personalize user experiences and optimize engagement strategies. The system learns individual behavioral patterns, preferences for different types of rewards, and optimal interaction frequencies to maintain long-term participation.

Table 2 Expected Impact of engagement features

Engagement Feature	RL Implementation	Expected Impact
Personalized Rewards	Bandit algorithms for reward optimization	Increased user retention
Social Challenges	Multi-agent cooperation learning	Community building
Educational Content	Adaptive curriculum based on user progress	Improved sorting knowledge
Feedback Timing	Temporal RL for optimal notification scheduling	Reduced notification fatigue

4.3 Integration with Existing Systems

The proposed framework seamlessly integrates with existing AI-based MWM systems through standardized APIs and data exchange protocols. The RL-generated insights enhance traditional GA-based route optimization by providing real-time bin status and predictive filling patterns. Similarly, waste generation forecasting models benefit from improved data quality and community behavior insights.

V. Experimental Design and Implementation Plan

5.1 Simulation Environment

We will develop a comprehensive simulation environment using Python frameworks including TensorFlow for deep learning implementation, OpenAI Gym for RL environment modeling, and custom modules for waste management scenario simulation. The simulation will model various community types, waste generation patterns, and user behavior profiles to validate the RL approach before real-world deployment.

5.2 Pilot Study Design

The pilot study will be conducted in a controlled urban environment with approximately 500 households over a 6-month period. The study design employs a randomized controlled trial approach, comparing RLenabled systems against traditional static sorting methods.

Duration: 6 months with 2-month baseline, 3-month intervention, 1-month follow-up
Participants: 500 households across 3 demographic segments
Infrastructure: 50 smart bins with RL capabilities
Control Group: Traditional bins with static sorting guidelines

Figure 4 Pilot Study Parameters

5.3 Evaluation Metrics

System performance will be evaluated using quantitative metrics including sorting accuracy, contamination rates, user engagement levels, and operational efficiency measures. Qualitative assessments will capture user satisfaction, behavioral change sustainability, and community acceptance factors.

VI. Expected outcomes and Impacts

VII.

6.1 Technical Performance Improvements

Based on preliminary simulations and literature review, we anticipate significant improvements in key performance indicators. Sorting accuracy is projected to increase from the current industry average of 70% to approximately 90% through RL optimization. Contamination rates sh ould decrease by 60%, while bin utilization efficiency may improve by 35%.

Table 3 Different Metrics

Metric	Current Performance	Projected Performance	Improvement
Sorting Accuracy	70%	90%	+20 percentage points
Contamination Rate	25%	10%	-60% reduction
User Engagement	30%	75%	+45 percentage points
Collection Efficiency	65%	85%	+20 percentage points

6.2 Community Impact

The gamified approach is expected to achieve a 50% mobile application adoption rate within the pilot community, with sustained engagement demonstrated through daily active user metrics exceeding 40%. Long-term behavioral change indicators suggest that proper sorting habits will persist beyond the intervention period, contributing to sustainable waste management practices.

6.3 Environmental and Economic Benefits

Improved sorting accuracy and reduced contamination will lead to higher recycling rates, decreased landfill usage, and reduced environmental impact. Economic benefits include lower waste processing costs, reduced collection frequency requirements, and potential revenue generation through improved recyclable material quality. The system's scalability suggests significant municipality-wide cost savings when deployed broadly.

VIII. Discussion and future Implication

7. 1 Technological Advantages

The proposed RL approach offers distinct advantages over traditional machine learning methods in waste management applications. The ability to learn continuously from real-world feedback, adapt to changing conditions, and optimize multiple objectives simultaneously positions RL as a superior approach for dynamic waste management environments.

7. 2 Scalability Considerations

The modular design of the proposed system facilitates scalable deployment across diverse urban environments. The RL framework can adapt to different community demographics, waste generation patterns, and cultural contexts through localized learning and customization capabilities.

7. 3 Challenges and Limitations

Implementation challenges include initial infrastructure costs, user privacy concerns, and the need for robust data connectivity. The RL approach requires sufficient data for effective learning, which may limit performance in the initial deployment phase. Additionally, ensuring long-term user engagement requires continuous innovation in gamification strategies.

IX. Conclusion

This research presents a novel approach to municipal waste management that addresses critical gaps in current AI applications through reinforcement learning and community-centric design. By combining intelligent infrastructure with behavioral psychology principles, the proposed system offers a pathway toward more effective, sustainable, and community-driven waste management practices.

The integration of RL agents for dynamic optimization with gamified community engagement represents a significant advancement in smart city applications. The expected improvements in sorting accuracy, user engagement, and overall system efficiency demonstrate the potential for this approach to transform waste management practices in urban environments.

Future research directions include exploring federated learning approaches for privacy-preserving optimization, investigating advanced RL techniques such as meta-learning for rapid adaptation to new environments, and expanding the framework to include circular economy principles and resource recovery optimization

Use of Generative Artificial Intelligence (AI) and AI-Assisted Technologies

During the preparation of this manuscript AI is used to improve readability and language of some passages. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

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Integrated Waste Management and the Application of AI: Smart Solutions for Bangladesh's Growing Waste Crisis

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Bangladesh faces escalating waste management challenges due to rapid urbanization and limited infrastructure. This research explores how Integrated Waste Management (IWM), supported by Artificial Intelligence (AI), offers a transformative path toward sustainable solutions. IWM provides a structured, inclusive framework combining waste reduction, recycling, and safe disposal, while AI enables predictive waste forecasting, optimized collection routes, automated sorting, and real-time landfill monitoring. Case studies from Dhaka, Chattogram, and Sylhet illustrate how AI-driven tools—like smart bins, drones, and robotic sorters—can improve efficiency, reduce emissions, and protect worker safety. However, ethical considerations such as protecting informal waste workers, data privacy, and ensuring equitable service distribution must be addressed. Despite barriers like high investment, data gaps, and policy delays, AI represents a turning point for Bangladesh's waste sector. With strategic planning and inclusive governance, AI-integrated waste systems can pave the way for cleaner cities and a circular economy.

Introduction

Bangladesh, like many rapidly urbanizing nations, is grappling with a mounting waste management crisis. As cities grow, populations expand, and consumption increases, major cities such as Dhaka, Chattogram, and Khulna are facing unprecedented challenges in managing the collection, segregation, treatment, and disposal of solid waste. The problem is further aggravated by limited municipal resources, unplanned urban expansion, and growing consumption patterns that contribute to ever-increasing waste volumes. In many areas, the traditional waste management infrastructure is stretched beyond capacity, resulting in overflowing landfills, environmental degradation, and public health hazards.

Against this backdrop, Integrated Waste Management (IWM) emerges as a comprehensive and holistic framework for addressing the complex and multi-dimensional nature of urban waste. Unlike conventional waste management strategies that rely heavily on disposal, IWM emphasizes the entire lifecycle of waste—from reduction and reuse to recycling, recovery, and safe final disposal—while considering environmental sustainability, social inclusion, and economic viability.

To further enhance the effectiveness of IWM, Artificial Intelligence (AI) is gaining attention as a transformative enabler. AI technologies, when integrated with Internet of Things (IoT) devices, predictive analytics, and smart sensors, can significantly improve the efficiency, precision, and responsiveness of waste management systems. From forecasting waste generation trends to optimizing collection routes and automating recycling processes, AI offers data-driven insights and automation capabilities that traditional methods lack.

In the context of Bangladesh, where informal sectors dominate recycling and waste sorting activities, and where municipal systems often lack real-time data, the integration of AI presents a unique opportunity to leapfrog traditional development stages. This paper explores how AI-enhanced IWM can address current inefficiencies, promote sustainable urban development, and align with national and global environmental goals. By analyzing case studies, technological applications, and policy gaps, we outline a roadmap for a smarter, cleaner, and more inclusive waste management future in Bangladesh.

Comprehensive Framework of Integrated Waste Management (IWM)

Integrated Waste Management (IWM) represents a comprehensive strategy for addressing the increasing complexities of waste management. Rather than relying on a singular method or technology, IWM integrates various approaches that collectively aim to minimize waste generation and maximize resource recovery. This encompasses prioritizing waste reduction at the source, encouraging material reuse, promoting efficient recycling systems, recovering energy or materials from waste, and ensuring that final disposal methods are both environmentally safe and socially responsible. Importantly, this approach seeks to balance environmental protection, social equity, and economic viability, thereby enhancing the sustainability of waste management in the long term.

In the context of a rapidly developing country such as Bangladesh, the adoption of an Integrated Waste Management system is particularly vital. Municipal authorities encounter significant challenges, including limited financial and technical resources, rapidly growing urban populations, and increasing volumes of mixed and unsorted waste, which complicate processing and disposal efforts. Additionally, a considerable portion of the recycling process relies on the informal sector, comprising waste pickers and small-scale recyclers, who often lack formal recognition and adequate support, affecting both their efficiency and working conditions.

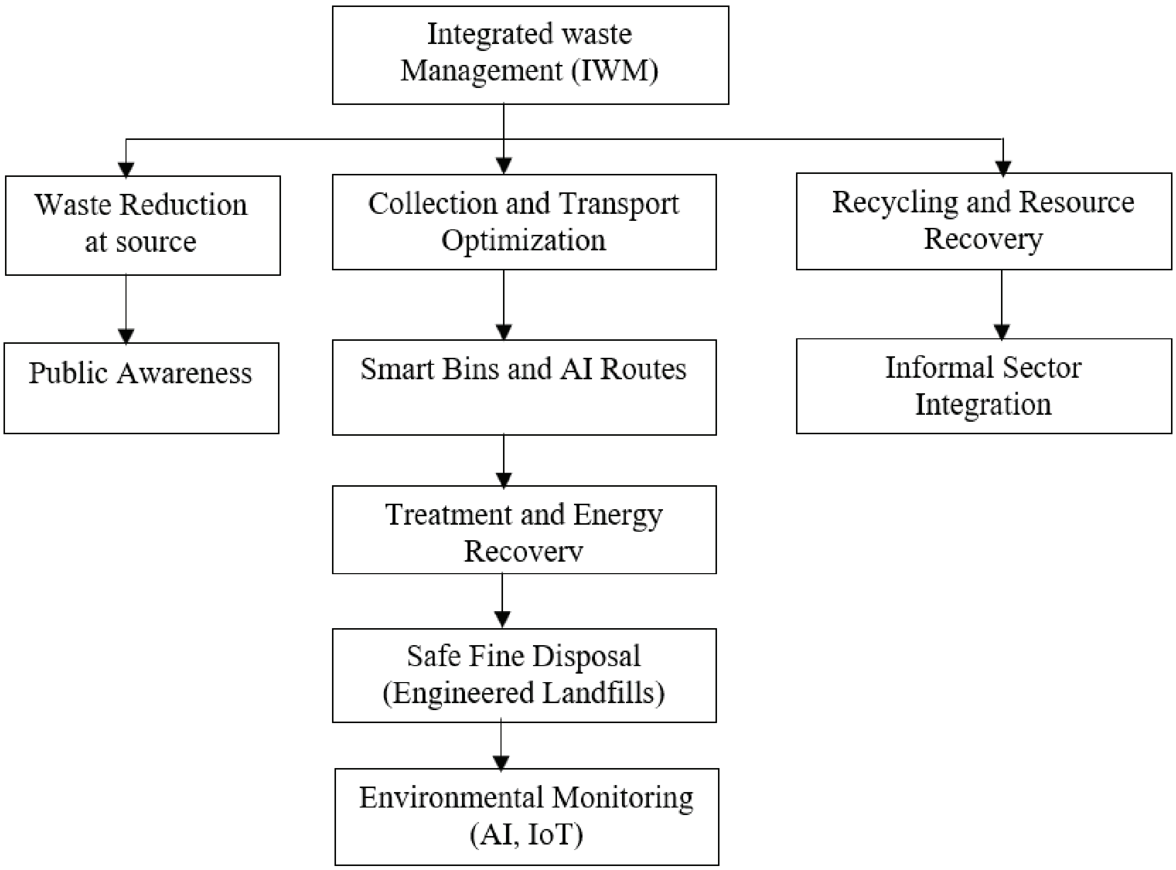

Figure 1: Integrated Waste Management Framework

IWM provides a structured and coordinated framework that can harmonize these fragmented efforts by fostering collaboration among municipal bodies, the private sector, informal workers, and community stakeholders. This collaboration not only enhances the efficiency and effectiveness of waste management practices but also promotes inclusivity and equity within the system. Furthermore, the principles underlying IWM align closely with Bangladesh's larger goals concerning climate change mitigation, environmental sustainability, and sustainable urban development. By implementing this integrated approach, Bangladesh can more effectively address its waste management challenges while making meaningful contributions to its environmental and social objectives.

Figure 2: Sorting out garbage by robotic arms

Smart Tech for Clean Streets: AI in Bangladeshi Waste Management

1. Waste Generation Forecasting and Prevention:

Cities in Bangladesh face significant challenges stemming from unreliable data regarding waste production, encompassing volume, location, and timing. By utilizing AI-based predictive analytics, it is possible to analyze various factors, including urban growth, household behaviors, economic activities, and weather patterns, to accurately forecast waste generation trends. This enables local governments and non-governmental organizations (NGOs) to effectively plan collection schedules, make informed investments in infrastructure, and implement targeted public awareness campaigns. In agricultural areas, AI can play a crucial role in reducing food waste by identifying inefficiencies within the supply chain, thereby supporting farmers and vendors in preventing spoilage.

2. Optimized Waste Collection:

In urban centers such as Dhaka and Sylhet, waste collection processes often lack consistency and efficiency. The integration of AI with Internet of Things (IoT)-enabled smart bins can optimize pickup schedules by alerting authorities only when bins reach capacity. Even in the absence of advanced hardware, AI can analyze historical collection data to determine optimized collection routes, resulting in fuel savings and a reduction in missed pickups. Furthermore, AI-powered CCTV and drone technology can assist in identifying and reporting instances of illegal dumping in public spaces, addressing a pressing concern in many urban environments.

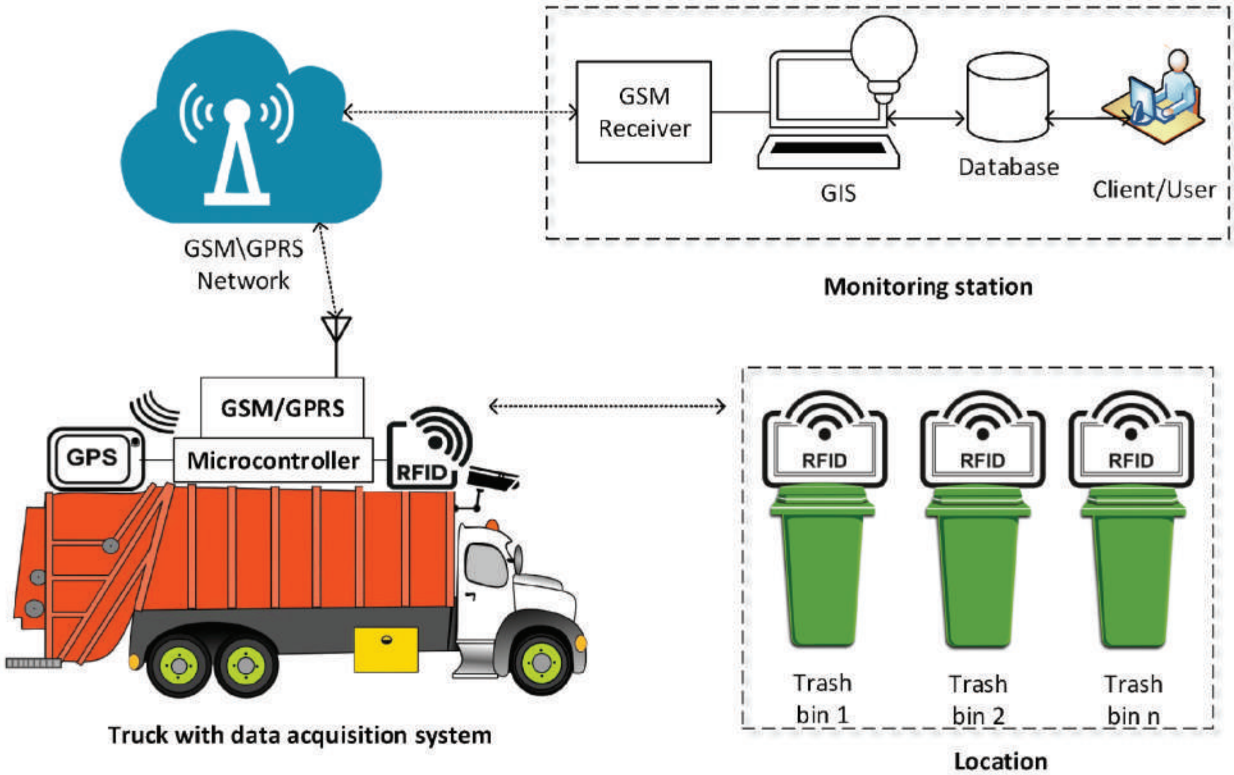

Figure 3: IoT-enabled waste truck and smart bin diagram

3. Automated Sorting and Processing:
The manual sorting of recyclables is labor-intensive and poses safety risks, particularly in informal recycling hubs such as Matuail and Amin Bazar. Implementing AI-enabled robotic arms or conveyor belt vision systems can significantly enhance the accuracy and efficiency of sorting materials, including plastics, metals, paper, and glass. Pilot initiatives utilizing AI for material identification—such as distinguishing between PET and HDPE plastics—have the potential to minimize contamination levels and increase the market value of recyclables.

4. Enhancing Recycling and Energy Recovery:
Currently, Bangladesh recycles approximately 37% of its waste, largely through the efforts of informal waste pickers. AI can further bolster this sector by enhancing micro-sorting facilities with advanced technologies that improve operational efficiency and safety. In larger urban areas, AI can optimize the operations of anaerobic digestion plants or small-scale incinerators by adjusting input mixtures and operational parameters to maximize energy output while minimizing emissions. This focus aligns with Bangladesh's increasing interest in waste-to-energy solutions as a sustainable alternative to congested landfills.

5. Landfill Management and Environmental Monitoring:
Overcrowded landfills in proximity to Dhaka and Chattogram present considerable environmental and public health challenges. AI can assist in identifying more suitable landfill sites by evaluating essential factors such

as population density, flood risks, and soil permeability. Additionally, AI-powered sensors can monitor methane gas emissions and leachate levels in real time, providing early warnings of potential environmental hazards. This proactive approach enables relevant authorities to take timely measures to mitigate risks and safeguard public health.

Upholding Ethics in Bangladesh's Smart Waste Revolution

As the integration of artificial intelligence in waste management progresses, it is imperative that ethical considerations guide its implementation. In Bangladesh, a significant concern lies in safeguarding the welfare of informal waste workers, many of whom depend on waste collection for their livelihoods. Transitioning to automated systems without providing retraining or alternative employment opportunities would be inequitable.

Additionally, any AI systems that leverage data from citizens, such as information on bin usage or video surveillance, must ensure the protection of privacy, uphold transparency, and obtain informed consent. The algorithms employed in planning waste management services should not discriminate against low-income neighborhoods, which are already facing challenges with service availability.

The ethical adoption of AI in Bangladesh necessitates inclusive policymaking, active engagement with communities, and a commitment to a just transition that prioritizes the needs of all stakeholders.

Why AI Is a Turning Point for Bangladesh

The potential advantages of artificial intelligence within the waste management sector in Bangladesh are transformative:

- **Efficiency:** Enhanced routing and scheduling can minimize missed pickups and alleviate congestion.
- **Cost-Effectiveness:** Optimized operations can substantially reduce municipal operational costs.
- **Environmental Impact:** Improved air quality, reduced open dumping, and lower methane emissions can be achieved.
- **Worker Safety:** There can be a decrease in exposure to hazardous waste and improved conditions for sorting activities.
- **Better Recycling:** The quality of recycled materials can improve, leading to enhanced resource recovery.
- **Scalable Solutions:** Digital tools can be effectively implemented in both urban megacities and rural towns.

Challenges Unique to Bangladesh

While there is evident potential for progress, several challenges must be addressed:

- **High Initial Investment:** The development of AI systems and smart infrastructure entails substantial capital investments.
- **Data Gaps:** There is a noticeable scarcity of accurate waste management data, particularly in smaller towns.
- **Integration of the Informal Sector:** Many recycling operations operate outside of regulation and remain largely unacknowledged.

- **Skill Shortage:** A limited number of municipal workers and local engineers possess the necessary training in AI applications.
- **Public Awareness:** A lack of understanding regarding recycling and technology-driven systems may impede public involvement.
- **Policy Lag:** Presently, Bangladesh lacks comprehensive regulations governing the application of AI in municipal services.

Addressing these challenges will require robust public-private partnerships, international collaboration, and the implementation of tailored pilot programs at the local level.

A Glimpse into the Future

The future of waste management systems in Bangladesh could include AI-enabled recycling kiosks in urban markets, real-time waste dashboards for city corporations, and mobile applications that empower citizens to monitor and reduce their household waste. Furthermore, AI could facilitate connections between waste producers, recyclers, and manufacturers through digital platforms, promoting a truly circular economy. Initiatives such as predictive maintenance for waste collection vehicles and automated e-waste dismantling units are increasingly becoming viable near-term solutions.

Conclusion: A Smarter, Cleaner Bangladesh

In a context where overflowing bins, clogged drains, and burning plastic are prevalent challenges, AI provides a vision for change—characterized by cleaner streets, enhanced resource recovery, and informed decision-making. If implemented in an ethical and inclusive manner, AI could assist Bangladesh in transitioning to a more intelligent and sustainable approach to waste management.

While the path forward may pose difficulties, with appropriate investments, policies, and public engagement, the challenges of today can evolve into the opportunities of tomorrow.

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Causes of Butterfly Extinction

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Habitat Destruction: Butterflies depend on specific plants and climates. Activities like deforestation, urbanisation, road and building construction destroy their habitats. Example: Common Rose (Pachliopta aristolochiae) – its larvae survive only on the Aristolochia plant; a decrease in this plant puts the butterfly at risk.

Pesticides and Herbicides: These chemicals are used to kill pests, but they also harm butterfly eggs, larvae, and adults. Example: Plain Tiger (Danaus chrysippus) – its larvae die after feeding on pesticide-exposed milkweed (Calotropis).

Climate Change: Changes in temperature and seasons disrupt breeding cycles and migration patterns. Example: Lime Butterfly (Papilio demoleus) – high temperatures reduce egg survival rates.

Pollution: Air, water, and soil pollution disturb the butterfly's natural life cycle. Example: Common Mormon (Papilio polytes) – their host plant Citrus declines due to pollution.

Loss of Plant Diversity: Butterfly larvae feed on specific host plants. Without those plants, survival is impossible. Example: Tailed Jay (Graphium agamemnon) – relies on Annona plants, which are becoming scarce.

💡 **Light Pollution:** Artificial lights at night disorient butterflies and disrupt reproduction.

🧑‍🔬 **Human Collection & Disturbance:** Many butterfly species are excessively collected for hobby, display, or research purposes, leading to a decline in their populations.

Notable Butterfly Species in Bangladesh:

Local Name	English Name	Scientific Name
রাজা প্রজাপতি	Monarch Butterfly	Danaus plexippus
সাদা ফড়িং	Great Eggfly	Hypolimnas bolina
কমন টাইগার	Common Tiger	Danaus genutia
নীল ফড়িং	Blue Tiger	Tirumala limniace
কাগজি প্রজাপতি	Paper Kite	Idea leuconoe
লাইম প্রজাপতি	Lime Butterfly	Papilio demoleus
লাল ফড়িং	Crimson Rose	Pachliopta hector

The extinction of butterflies reflects the ecological imbalance caused by unsustainable development. If timely action is not taken, future generations may only witness the beauty of butterflies in pictures. Awareness, environmental conservation, and sustainable agriculture are key to reversing this trend.

AI-Driven Landfill Monitoring and Management: Aerial Intelligence in Waste Surveillance

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The impact of landfills

Did you know that methane is a more potent greenhouse gas than CO_2? 84 times more dangerous than carbon dioxide, uncaptured methane is one of the main causes of climate change [1].

Addressing the environmental effects of landfills is crucial in light of the climate crisis. Landfills not only contribute to global warming, but they also negatively impact the public, waste valuable land that could be put to better use, and contaminate water sources through underground leachate.

The methane emitted by millions of gasoline-powered cars is equal to the millions of metric tons of methane released by municipal landfills each year. Methane not only destroys the planet but also poses a serious risk of fire. Excess air drawn in from the outside by landfill gas collection systems may lead to fires inside the landfill, which can be very challenging to put out.

On the other hand, dry spells can cause fires on the landfill surface. Wood chips and other landfill cover materials, along with a few weeks of dry summer weather, could ignite a fire instantly with a single spark. Both types of fire can undoubtedly be dangerous.

Leachate, a liquid that seeps or leaks from a landfill, may end up in nearby bodies of water. Both the environment and public health are seriously at risk from this. There is a very high likelihood that leachate will seep into groundwater because older landfills usually lack protective liners or geomembranes, two examples of modern technology. Residents who live near landfills also face the possibility of coming into contact with hazardous substances. This is particularly high during inclement weather or other natural disasters that may cause the toxic waste sites to rupture and release pollutants into the surrounding environment.

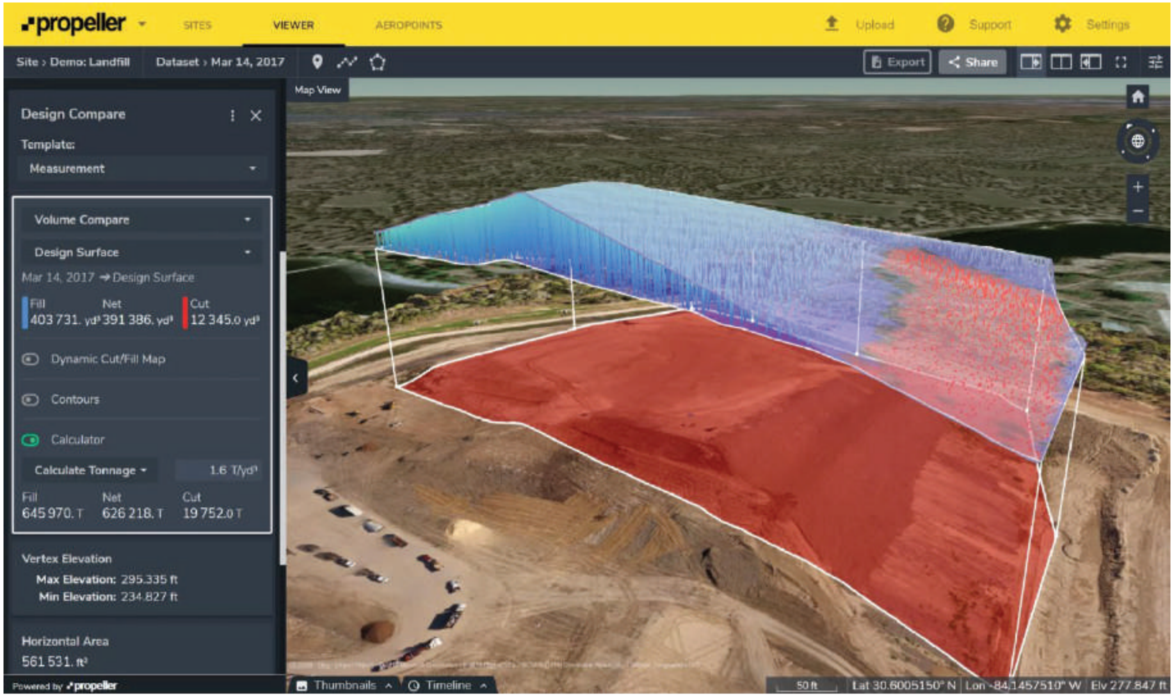
How does AI help?

Artificial intelligence reduces the likelihood of environmental hazards like leachate production and greenhouse gas emissions by enhancing waste compaction and layering techniques.

Using predictive modeling, a wide range of scenarios related to waste accumulation, decomposition rates, and gas emissions can be simulated and predicted. Better decision-making, reduced environmental impact, and improved management of landfill resources are all made possible by this proactive approach.

Additionally, predictive modeling contributes to reducing the overall waste burden and fostering the expansion of circular economy initiatives by identifying materials that can be recycled or repurposed before they wind up in a landfill.

In order to predict waste inflows, artificial intelligence (AI) systems examine vast amounts of data, including landfill usage statistics, weather data, and historical waste generation patterns. This allows for more precise planning of landfill space and resource use.



Measuring overfills and remaining airspace easily

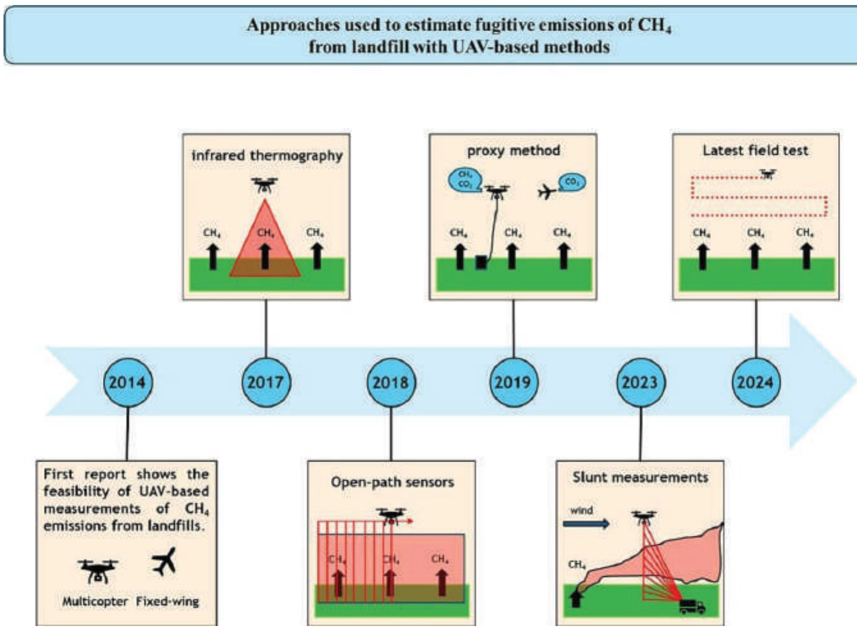
Drones Equipped with AI

The Drone Center and the UAE Waste Management Authority collaborated to deploy FlytBase software-powered autonomous drone technology at waste management facilities throughout the United Arab Emirates [2]. By integrating dock drones with specialized sensors, this technique was able to address important issues in environmental monitoring, hazardous material detection, security surveillance, and operational efficiency. Worker safety and maintenance standards are improved by the system's volumetric waste material analysis, real-time hazard detection, round-the-clock autonomous surveillance, and decreased need for manual labor.

The primary functionality and system consist of:

- Drone stations are positioned thoughtfully throughout the waste management facilities.
- Gas detection modules, thermal sensors, and specialized high-resolution cameras
- Data analytics powered by AI to identify dangerous materials, fire hazards, trespassing, and illegal dumping

Several times a day, the drones conduct planned autonomous flights to keep an eye on the entire facility. Aerial imagery, thermal data, and environmental readings are collected by sensors during flight and transmitted to the control room. To calculate waste volumes, identify potential security threats, and identify environmental hazards, the system uses artificial intelligence to analyze the collected data. When the system detects dangerous gas leaks, unlawful dumping, trespassing, or fire hazards, it immediately alerts the appropriate teams. The control room can better plan routes for waste collection and emergency response by allocating more resources based on real-time data.



Timeline of UAV-Based Methods for Estimating Methane (CH_4)
Emissions from Landfills (2014–2024)

The autonomous drone system provided more extensive monitoring capabilities than conventional fixed CCTV systems. AI-powered systems have the ability to recognize:

- Unauthorized vehicles accessing facilities
- Illicit waste disposal practices
- Trespassing incidents, particularly at night

The AI-powered number plate recognition system produced an automated log of all facility entries and potential violations in addition to identifying vehicles in real time.

Frequent LiDAR-equipped drone surveys allowed for accurate volumetric waste accumulation calculations. With this knowledge, the authorities were able to:

- Keep an eye on the daily fluctuations in waste levels in different areas.
- Determine the different kinds of materials by using AI classification to separate general waste, hazardous materials, and metals.
- Make better plans for capacity utilization.
- Keep records of adherence to the allowed storage volumes.

Important environmental data was supplied by the integrated gas detection sensors, including:

- Hazardous gas readings in real time (H_2S, CO_2, CO)
- Evaluations of air quality
- Using thermal imaging to detect possible fire hazards early

In addition to providing documentary support for regulatory reporting, this environmental data helped guarantee adherence to local environmental laws and the UAE's Vision 2030 sustainability goals.

Ethical Considerations in AI-Powered Landfill Monitoring

- Concerns about privacy arise because satellites and drones may inadvertently photograph neighboring communities or private properties when photographing landfill areas.
- Lack of transparency can lead to greenwashing, which is the suppression of pollution evidence by public or private organizations. It calls into question who owns the data and whether or not the public has access to it.
- Equity in Enforcement: Wealthier cities may have access to sophisticated monitoring technology, but underprivileged areas experience illegal and unregulated dumping, exacerbating environmental injustice.
- Over-reliance on Automation: Making decisions entirely based on AI predictions (such as false positives for unlawful dumping) without human supervision may result in poor decisions or unfair punishments.
- Access to these technologies may be limited in low-income nations, which worsens environmental inequality worldwide.

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Integrated Waste Management and Application of AI

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With the ongoing increase in urbanization, industrial development, and population numbers, efficient waste management has become crucial for both sustainability and public health. Conventional waste management systems often suffer from inefficiencies, elevated operational costs, and environmental issues. To address these challenges, Integrated Waste Management (IWM) has developed as a cohesive strategy that amalgamates various waste management techniques into a singular, cost-effective, and eco-friendly process. The rise of artificial intelligence (AI) is currently revolutionizing the operations of IWM systems by providing smart solutions for the planning, monitoring, and enhancement of waste management processes.

What is integrated waste management?

Integrated Waste Management (IWM) refers to a comprehensive approach that employs multiple strategies to manage waste sustainably. This system includes various processes such as collection, transportation, processing, recycling, treatment, and final disposal of waste materials. The fundamental principle of IWM is to reduce waste generation as much as possible while maximizing recovery from waste, all without jeopardizing public health and the environment.

The essential elements of IWM include:

- Source Reduction
- Reuse and Recycling
- Composting and Treatment of Organic Waste
- Conversion of Waste to Energy
- Landfilling for Non-recyclable Residual Waste

IWM organizes waste management methods in a hierarchical manner: prevention, minimization, reuse, recycling, recovery, and disposal.

Challenges in Conventional Waste Management

Despite progress being made, conventional waste management systems encounter a number of issues:

- Poor segregation of waste at the source
- Absence of real-time tracking of waste levels
- Suboptimal routing strategies for waste collection vehicles
- Low rates of recycling stemming from insufficient waste sorting
- Significant greenhouse gas emissions resulting from landfills

These challenges have necessitated technological advancements in the waste management field, leading to the adoption of artificial intelligence (AI).

Role of AI in Comprehensive Waste Management

Innovations such as machine learning (ML), computer vision, and data analytics are revolutionizing waste management practices. Utilizing big data, the Internet of Things (IoT), and smart algorithms, AI can tackle many of the inefficiencies present in traditional waste management systems.

1. Intelligent Waste Collection and Route Optimization

- AI systems can monitor IoT sensor data from waste bins to track fill levels in real-time. This provides:
- Adaptive routing to minimize fuel use and lower operational expenses.
- Planned collection schedules to avoid overflow problems and maintain cleanliness.
- Predictive analytics for anticipating waste generation trends.

2. Intelligent Waste Sorting

By leveraging robotic and computer vision technologies, AI can effectively identify, categorize, and separate materials like plastics, glass, and metals. This improves the recycling process by enhancing quality and reducing contamination in recycling streams.

3. Predictive Maintenance for Equipment

AI technology can track the condition of waste processing machinery and forecast potential failures, resulting in:

- Reduced downtime for operations.
- Decreased maintenance expenses.
- Extended lifespan for equipment.

4. Improved Recycling Processes

Machine learning algorithms can analyze historical data regarding material movement and user actions to suggest enhancements aimed at increasing recycling rates. They can also assist in developing incentive programs to motivate people to participate in recycling initiatives.

5. Optimization of Waste-to-Energy Processes

Artificial intelligence can streamline the operations of waste-to-energy (WTE) plants by:

- Modifying combustion settings for optimal energy production.
- Monitoring emissions for assessing environmental impact.
- Anticipating feedstock availability and energy output.

6. Policy and Decision Support

Artificial intelligence (AI) technologies can support governments and local agencies in creating waste management policies that are grounded in solid data. By simulating waste conditions, policymakers can analyze both the environmental and economic consequences of different policy choices.

Case Studies

Smart Bins in Singapore: These bins, equipped with Internet of Things (IoT) technology and linked to an AI platform, enhance the optimization of collection routes and help prevent overflow.

ZenRobotics in Finland: This company utilizes AI-powered robots to effectively sort construction and deconstruction waste with accuracy rates exceeding 95%.

AMP Robotics in the United States: This organization employs AI and robotics to boost the capacity and efficiency of recycling efforts.

Benefits of AI in Integrated Waste Management (IWM)

- **Efficiency:** Minimizes human mistakes and accelerates operational speeds.
- **Cost Savings:** Diminishes expenses related to labor and fuel.
- **Environmental Conservation:** Increases recycling rates and cuts down on emissions.
- **Data-Driven Planning:** Facilitates strategic planning and policy development for the long term.

Disadvantages and Drawbacks

Despite its advantages, the application of AI in waste management comes with certain drawbacks:

- **High Initial Costs:** The expense of setting up the technology can be substantial.
- **Data Security and Privacy:** Safeguarding the private information of intelligent systems is essential.
- **Requirement for Competent Staff:** Operators and technicians need training to manage AI systems.
- **Integration of Existing Systems:** Compatibility issues may arise with current infrastructure.

Ethical Practices

The implementation of ethical practices in integrated waste management, along with the use of AI, is crucial for aligning technological progress with societal standards and environmental care. A key ethical issue to consider is data privacy, particularly as AI systems may gather and evaluate information from homes or businesses via smart bins and IoT gadgets. It is important to maintain transparency regarding how data is used and to have strong security protocols to safeguard user rights. Additionally, AI applications should advance environmental justice, preventing marginalized communities from facing excessive burdens from waste processing facilities or being left out of the advantages offered by improved services. Ensuring equitable labor practices is vital; even though automation may enhance efficiency, it should not result in widespread job loss for waste workers without adequate retraining and integration into the changing labor market. Ultimately, the ethical development of AI in this field must focus on sustainability rather than merely seeking profit, ensuring that decisions made by intelligent systems foster long-term ecological stability and resource preservation.

Conclusion

The incorporation of AI in waste management represents a transformative shift that offers the potential for more intelligent, eco-friendly, and efficient systems. While challenges exist, the advantages of melding AI with IWM are persuasive. As municipalities and industries move toward circular economy frameworks, AI will serve as the driving force that optimizes waste management practices, conserves resources, and safeguards the environment.

Single Leap for A Great Achievement- Waste Management and a Practical Example

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Waste management presents a significant and pervasive challenge in our current economy. The accumulation of waste in the landfills, coupled with its incineration without energy recovery, contribute heavily to air pollution. This degradation of the environment extends to marine biodiversity as well, the polluted water directly impacting their habitats.

How do we go about this?
What steps do we take to mitigate, if not completely eradicate, pollution?

The first and most significant step to achieving this spreading awareness. Taking initiatives and going about it is fine enough, but having the people interested in participating is essential. Extra-curricular activities in schools count as a way of spreading awareness. Having students engrossed in works on sustainability will enlighten them and have them asking all by themselves to take part in more activities.

Organizations related to the environment and sustainability can take initiatives to propose challenges and awards to encourage these activities among schools. In Abu Dhabi, one of these include the Sustainable Schools Lead Schools Awards, which is a recognition of a school's efforts at promoting sustainability among students. This award is given by the Environment Agency of Abu Dhabi.

Our school, Shaikh Khalifa bin Zayed Bangladesh Islamia, has been participating from when it was established. These activities had brought it to its peak and made us thrice the winners of this award. The journey to achieving this is what I'd like to highlight in this article.

To come here, we had done many audits, all of which include Water, Energy, Land, Air and Waste. I'll be highlighting three of the five, namely Water, Energy and Waste, as they are related to the given topic. The awards had a point system, adding up for each task in the result.

Water Audit

For the Water audit, we had five tasks.

1. Make a team: We made a team of four respectable teachers, three responsible students, and two of the administrative team.
2. 'How much water does your school consume?': The data over an entire year was tabulated and calculated. The results were as follows:

- Consumption of water per month: 422.1 cubic metres.
- Consumption of water per day: 14.07 cubic metres.

Using a formula to calculate the Litres Per Capita Per Day (LPCD) the result was 16.34L, which is within the range (15-20). Therefore, the LPCD was within the ideal range.

3. <u>"How much wastewater does your school recycle?":</u> We were to calculate a proportion between the generated wastewater and how much of it was recycled. 727L were recycled/reused out of 920.5L, leaving 193.5L unused or sent off to sewers.
4. <u>"How much packaged drinking water does your school consume and reuse?":</u> Emphasis on the 'packaged'. The former two tasks focused on the reuse of the consumed water per day specifically in restrooms and ablution areas. This task asks for how much packaged drinking water is used daily and whether any is used in the garden for watering. The result was 0 for both criteria.
5. <u>Result:</u> Out of a hundred points, our school scored an overall of 82.64 for the water audit.

<u>Energy Audit</u>

For the Energy audit, we had six tasks.

1. <u>Make a team:</u> The team included three of our teachers, two of the administrative staff and a technician.
2. <u>"What are the sources of energy in your school?":</u> We had five main sources of energy: electricity from the grid, LPG, petrol, diesel, and renewable energy. A table of usage from these sources is as follows:

Sources of Energy	
Source	**Quantity consumed per month (in kg/litre/gallon/kilowatt)**
Electricity from grid	18059.75
Liquid Petroleum Gas (LPG)	15.4
Petrol	0.0
Diesel	2267.1
Others- Renewable energy	2011.6
Total	22353.85

This individual data was converted to joules then to individual percentage of energy consumed, which was 100%.

3. <u>"How much energy is consumed?":</u> Calculating the monthly energy consumption per capita per day then the average consumption in megajoules per day and per person. This amounted to 6.797 which was much less than the total of 60, so we scored full points in this section.
4. <u>"Does your school follow any energy conservation practices?":</u> We had to calculate two proportions for this section after conducting a survey.

$$\frac{\text{Number of people always conserving energy}}{\text{Total strength of the school}} = \frac{585}{857}$$

$$\frac{\text{Number of people sometimes conserving energy}}{\text{Total strength of school}} = \frac{276}{857}$$

5. "How much energy was saved?": A table of the energy consumption is as follows:

	Electricity from Grid (kW/h)	Liquid Petroleum Gas	Petrol (litres)	Diesel (litres)	Renewable energy (MJ)
Average per month	18059.75	15.42	0.0	2267.08	7241.67

Finding the per capita per day consumption of energy from this data our monthly consumption amounted to 6.83 and the annual 6.74. Thus, we saved 35.8 megajoules.

6. Final score: The total score was 74.52 (approx.) out of 100.

Waste Audit

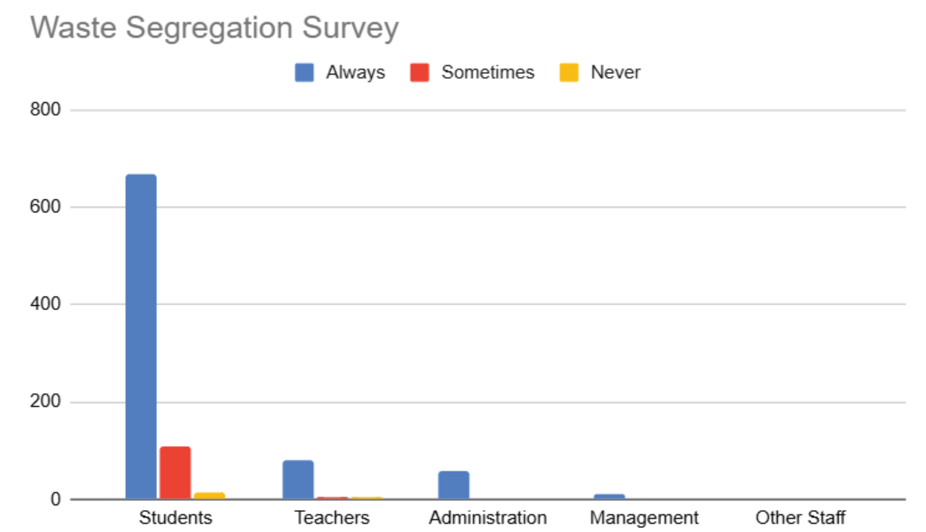
The most important and relative audit to the topic, the waste audit. It had seven tasks.

1. Make your team: The team had four teachers, two from the administrative staff, and five students.
2. "How much solid waste does your school generate?": The table on the quantity of waste recycled is as follows:

Type of solid waste	Quantity generated (kg/month/year)
Common Waste	231.85
Paper	119.58
Plastic	257.5
Wood	2
Glass, metal scrap	7.66
Medical Waste (H)	3.6
Horticultural Waste	25.6
E-waste (H)	2.5
Total	650.29

Calculating the per kg per capita per day we find that the result is far below the benchmark.

3. "What are the solid waste collection practices in the school?": After conducting a survey on the number of people the results came to:



4. "How much solid waste does your school recycle?": A table is as follows:

Type of solid waste	Quantity generated (kg/month/year)	Quantity recycled (kg/month/year)
Common Waste	231.85	0
Paper	119.58	119.58
Plastic	257.5	257.5
Wood	2	0
Glass, metal scrap	7.66	0
Medical Waste (H)	3.6	3.6
Horticultural Waste	25.6	25.6
E-waste (H)	2.5	0
Total	650.29	406.28

5. "How much municipal solid waste?": Using the table in task 1 we checked the waste according to the guidelines question: "Should this type of waste be disposed of outside of the school?" and for every yes, we added points.

6. "How do you manage chemical waste produced in school?": Calculating the chemical waste produced for every specific chemical and checking them according to the guideline questions we find that we scored 12 out of 15 points.
7. Result: We scored 85.96 out of 100.

Achieving all the criteria in the audits we were awarded by the SSI a 50,000 AED project by their contractors.

Every drop counts!

Utilizing this prize money, one of our implemented projects was the greywater recycling mechanism. Greywater recycling involves collecting, treating, and reusing greywater for non-potable applications, such as irrigation, landscaping, and flushing toilets. A greywater recycling system typically includes filtration and disinfection processes to remove impurities and make the water safe for reuse.

The system implemented at the school is straightforward: flowing water from the restrooms collects in a tank with a filtration system, then the cleaned water is stored in a separate tank and used in the irrigation pumps for the school garden. Daily measurements are taken to track the amount of water recycled. In an 8-hour school day, a student consumes approximately 6.66 litres of water. For 700 students, this amounts to approximately 4662 litres per week. This significant volume of water is completely recycled and reused, preventing it from being sent into the sewerage system and contributing to pollution.
The system operated as such:

Collection System: Grey water is collected from designated sources such as the restroom sinks and basins.

Filtration Unit: The collected grey water passes through a filtration unit to remove debris, solids, and impurities. This step prepares the water for further treatment. The water goes 6 filtration mediums and comes out clean in a collection tank.

Storage Tank: Treated grey water is stored in tanks for future use. These tanks are designed to maintain water quality and prevent contamination.

Distribution System: Treated grey water is pumped to specific applications such as irrigation systems, toilet flushing, ensuring efficient reuse.

Mentionable quotes on the project by the management of Shaikh Khalifa bin Zayed Bangladesh Islamia School:

"*At Shaikh Khalifa Bin Zayed Bangladesh Islamia School, we believe sustainability must be practical, innovative, and educational. With the large amount of water consumed weekly by our students, recycling this water prevents it from being wasted or contributing to pollution. Instead, it nourishes our school gardens and green spaces, turning waste into a valuable resource. Beyond saving water, this project is a powerful learning tool, showing our students how technology and commitment can solve environmental challenges. It proves that even small steps can create a lasting positive impact.*"
— **Kiran Akhter, Principal.**

"The Sustainable Schools Lead Schools Awards are a recognition of a school's efforts at promoting sustainability among students. This award is given by the Environment Agency of Abu Dhabi, and we have won it thrice. Grey water recycling is one of the projects that we implemented using the prize money. Recycling water from the sinks to water the school's garden saves significant amounts of water daily. Conserving water is a pressing need, especially in the UAE and adjoining countries where water is scarce. Projects like this motivate students to pursue technology that provides innovative yet simple solutions to the environmental challenges of the present time."
—**Anita Saul, Environment Coordinator.**

"Today's students should march ahead with initiatives to create a difference in the mindset for a better planet and world alike."
—**Mir Anisul Hasan, Former Principal.**

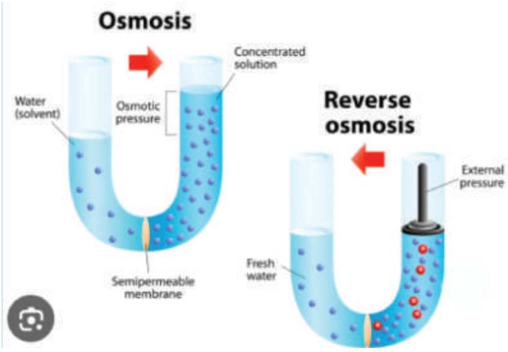
Achieving a sustainable future for waste management ultimately depends on a joint effort from all involved: governments, businesses, local communities and individuals. This requires ongoing investment in new technologies, the development of strategies tailored to each region's specific waste types and existing facilities and, most importantly, a widespread change in how people consume, supported by education and incentives.

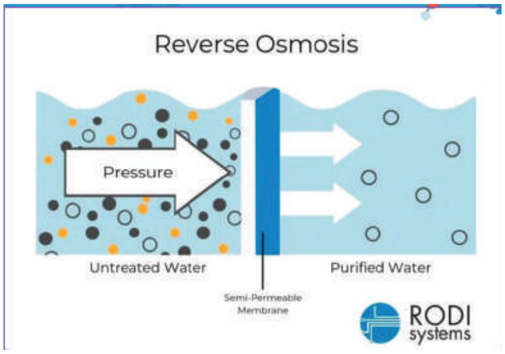
Produce Pure Water Using the Reverse Osmosis Process

Radiah Mubasshira khan Afsa
Grade 8, Islamia English School, Abu Dhabi, UAE

Osmosis

Osmosis is the process by which water molecules move across a semipermeable membrane from a region of lower solute concentration to a region of higher solute concentration. This movement occurs naturally and aims to equalize the concentration of solutes on both sides of the membrane, maintaining balance in biological and chemical systems.



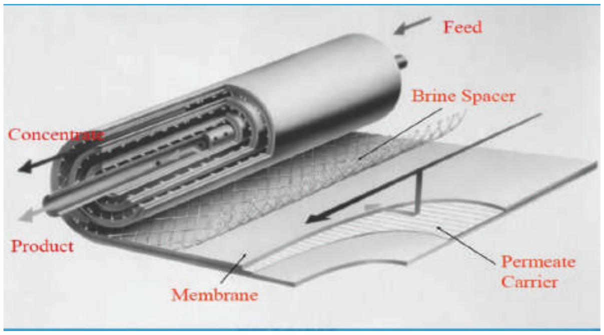


Reverse osmosis

Reverse osmosis is a water purification process where pressure is applied to force water through a semipermeable membrane, moving it in the opposite direction of natural osmosis. This process filters out impurities, such as salts, and contaminants, leaving clean and purified water on the other side. It is commonly used for drinking water purification and in industrial processes.

Semipermeable Membrane

A semipermeable membrane is a thin barrier that allows certain molecules, like water, to pass through while blocking others, such as salts and impurities. In reverse osmosis, a semipermeable membrane is used to purify water by allowing only water molecules to pass through it while blocking contaminants. This process ensures the separation of clean water from unwanted substances.



Who invented reverse osmosis?

Sidney Loeb and Srinivasa Sourirajan played a pivotal role in the development of practical reverse osmosis technology. In the early 1960s, they developed the first anisotropic semipermeable membrane, which had a thin active layer for filtration and a thicker supportive layer. This innovation significantly improved the efficiency and practicality of reverse osmosis, making it a viable method for large-scale desalination of seawater. Their work revolutionized water treatment and remains the foundation of modern reverse osmosis systems.

Reverse osmosis in UAE

The UAE, situated in a desert with limited rainfall and scarce groundwater, faces growing water scarcity due to rapid urbanization. To tackle this issue, the country has implemented seawater reverse osmosis desalination systems, which effectively remove salt and impurities from seawater and convert it into fresh water for drinking and irrigation. This technology has become a key solution for managing water resources and ensuring a sustainable water supply in the UAE.

Report: Online Conference on "Fire Hazards and Prevention" Organized by BEAWorld

On **24 May 2025**, BEAWorld organized an **11-hour online conference** titled **"Fire Hazards and Prevention."** The conference was divided into **three technical sessions**, featuring **six paper presentations**. Six experts from Bangladesh conducted awareness training on various aspects of fire hazards and prevention. A total of **512 delegates** from around the world participated, including engineers, architects, and students to whom BEAWorld issued Certificates of Participation. Each session included **Q & A, discussions, and evaluations** for comprehensive learning

Key Participants:

The six expert speakers were:

1. **Dr. Engr. Md. Easir Arafat Khan**
2. **Major (Retd.) AKM Shakil Newaz**
3. **Engr. Md. Al Emran Hossain**

4. **Engr. Md. Fazlul Bari**
5. **Engr. Md. Zahidul Haque**
6. **Engr. Mohammad Lutfar Rahman**

Conference Proceedings:
The event began at **8:00 AM** with an **opening speech by Conference Chair Engr. Rafiqul Islam Talukder P.Eng**. The session chairpersons were:

- **Prof. Dr. Maksud Helali**
- **Architect Dewan Shamsul Arif**
- **Engr. Md. Hafizur Rahman, P.Eng**

The sessions were moderated by:

- **Prof. Dr. Md. Easir Arafat Khan**
- **Engr. Md. Al Emran Hossain**
- **Engr. Shawkat Ali Khan**

Engr. Mohammad Nazmul Islam was responsible for compiling and publishing the conference report.

BEAWorld's Contribution:
Engr. Rezaur Rahman, Founder of BEAWorld, presented the organization's **vision, mission and activities.**

The discussion panel included:

- **Engr. Moazzem Hossain**, Advisor, BEAWorld.
- **Engr. Khaja Ahmed**, Advisor, BEAWorld GCC Chapter.
- **Engr. Amjad Hossain Khan**, Organizer, BEAWorld.
- **Engr. Md. Ashraful Alam PMP**, Leader -HVAC & Mechanical Engineering, BEAWorld GCC Chapter.
- **Engr. Mohammad Sarfaraz Khan**, General Secretary, BEAWorld GCC Chapter.
- **Engr. Mohammad Shahadat Hossain PMP**, Leader -Project Management, BEAWorld GCC Chapter.

From audience:

- **Engr. Kaniz** - Geotechnical Engineer
- **Engr. Gourab Dey**
- **Engr. Mohsiul Anis**, among others participated in the discussion.

Key Discussions:
Speakers emphasized the **importance of integrating fire hazard awareness into school and college curricula** to enhance public safety.

Closing Ceremony:
The conference concluded with a **closing speech and vote of thanks by Engr. Rafiqul Islam Talukder P.Eng.,** who formally announced the end of the daylong Conference.