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REVIEW ARTICLE

A critical review of recent dewatering technologies: Performance and applications

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Abstract: Biogas plants play a major role in Nepal's renewable energy efforts. However, managing the by-product remains challenging due to its high water content. The high water content increases the difficulty in transporting, storing, or reusing the material, especially in rural and farming areas. Dewatering provides a practical solution by removing moisture, thereby transforming the slurry into a drier, more manageable material. This review compares several dewatering technologies used in agriculture, industry, and wastewater treatment, with a focus on how they can help manage biogas slurry in developing countries such as Nepal. Various machines, such as screw presses, belt presses, and centrifuges, as well as novel method including thermally assisted mechanical dewatering (TAMD), are included in this review. These technologies were compared based on key factors, including moisture removal rate, energy consumption, nutrient saving, and operational parameters. Results show that TAMD gives the best moisture removal, whereas screw presses use less energy and keep useful nutrients in the digestate. Low-cost and fuel-free machines also show potential for small-scale use in rural areas. Despite these options, the data, infrastructure, and support to apply these technologies widely are still insufficient in Nepal. This paper highlights the need for improved local research, enhanced policies, and increased investment to enlarge the scale of these systems. Doing so could help Nepal maximize the value of its biogas plants, providing cleaner energy and enhancing agricultural productivity.

Keywords: Dewatering; Organic fertilizers; Biodigestate; Sun drying; Total solid; Thermally assisted mechanical dewatering

1. Introduction

A biogas plant utilizes various organic waste to produce energy through natural breakdown by anaerobic processes; hence, it stands as one of the most effective and sustainable sources of renewable energy. Biogas is the largest contributor to modern renewable energy resources in Nepal, producing 256,100 tons of oil equivalent, having a 65% share in renewable energy in the Fiscal Year (FY) 2079/80.[1] Up to FY 2023/24, there are 450,770 domestic biogas plants and 369 institutional biogas plants installed in Nepal.[2] Biogas production is an essential renewable energy source, but its adoption has been declining due to environmental concerns and challenges in managing the slurry by-product.[3] The slurry generated from biogas plants has high moisture content, making it difficult to transport, store, and utilize efficiently. One effective way to address this issue is through dewatering, which reduces the moisture content and transforms the slurry into a manageable solid-state material.[4] This process enhances the functionality of the slurry for various applications, such as organic fertilizer production and biofuel processing. By reducing water content, dewatering improves the calorific value of the sludge, making it more energy-efficient and suitable for combustion or further treatment.[5]

Dewatering machines have versatile applications across various sectors, significantly improving efficiency in material handling and resource recovery.[6] In the agricultural sector, dewatering is crucial for managing animal manure, crop residues, and biogas slurry. It helps to convert these waste materials into high-quality organic fertilizers with improved nutrient retention that can be stored easily.[7] Different crops, including duckweed and alfalfa, can be dewatered and utilized for multiple purposes, such as mixing with biogas slurry to produce various fuels based on their contents.[8] In addition, dewatering reduces waste volume, lowering transportation costs and enhancing sustainability in farming practices. In the food processing industry, dewatering machines play a crucial role in removing moisture from products such as cassava pulp, potato starch, and fruit residues. This improves the shelf life, quality, and ease of processing for food ingredients.[9] Dewatering also aids in starch extraction, reducing energy consumption in drying processes.[10]

The mining sector benefits from dewatering machines for removing water from blastholes, mine sludge, and mineral processing waste. Effective dewatering ensures better handling of mining residues and enhances efficiency in mineral extraction with minimal energy consumption.[11] In wastewater treatment and sludge management, dewatering is crucial for reducing the water content in sewage sludge, making it easier to transport and dispose of, thereby decreasing environmental impacts.[12] It also helps in producing solid waste for further treatment, such as composting or energy recovery through incineration. Most water treatment plants utilize sludge conditioning to improve sludge dewatering.[13] The sludge dewaterability needs to be enhanced through conditioning processes to reduce the volume of sludge.[14] Similarly, in biomass energy production, dewatering increases the calorific value of biomass fuels, making them more efficient for combustion. Reducing moisture content in biomass enhances its energy output, making it a viable alternative to fossil fuels.[15] The widespread application of dewatering machines across these industries underlines their importance in optimizing resource use, improving waste management, and enhancing sustainability.

Studies in Europe and East Asia have explored the integration of anaerobic digestion with nutrient recovery units and thermal drying to maximize bioresource valorization while minimizing environmental impact. To utilize the biodigestate as a fertilizer, the digestate should be of the highest quality and free from pathogens, physical and chemical impurities, and pollutants. This can be achieved by using anaerobic digestion feedstocks of controlled quality.[16] Despite these innovations, challenges remain in terms of scalability and energy efficiency, as well as the treatment of variable bioslurry compositions, particularly in developing countries.[17]

Previous reviews mainly emphasized the lack of region-specific performance data and cost-optimized technologies for biodigestate dewatering. This review aims to bridge the gap by synthesizing recent advancements in dewatering machines, particularly in developing countries such as Nepal. By comparing performance metrics across various sectors and applications, this paper highlights both the technical feasibility and economic viability of applying modern dewatering technologies for improved bioslurry management. It also discusses underexplored opportunities such as thermally assisted mechanical dewatering (TAMD) and low-cost, fuel-free solutions, thereby offering insights into policymakers, engineers, and researchers aiming to enhance the circular economy potential of anaerobic digestion systems.

2. Review methodology

This review paper followed a structured and systematic approach to identify, analyze, and select relevant literature on dewatering technologies applied for agricultural, industrial, and mining purposes. The primary objective is to investigate the performance, efficiency, and industrial applicability of various dewatering machines. The systematic approach applied to this review is shown in Figure 1.

3. Dewatering technologies

Dewatering methods can be categorized into two different categories: natural dewatering and mechanical/artificial dewatering. Natural dewatering relies on gravity settling and porous surfaces, whereas mechanical dehydration involves machinery and processes to remove moisture from the particles.[18] There are various methods for moisture content removal using mechanical dewatering technologies. Among the methods, vibrating screen (78%) and belt press (67.6%) achieve the highest total solid content, demonstrating superior dewatering performance. Centrifugal separation (47%) and inclined stationary screen (37.4%) provide moderate efficiency, whereas roller press (38.5%), screw press (34.4%), and hydrocyclone (26.5%) show intermediate results. On the lower end, filter press (21.5%), screen separation (22.5%), and rotating screen (18%) have the least effectiveness in removing moisture, making them less suitable for applications requiring high solid content.[19] The comparison of total solid content with different dewatering technologies is shown in Figure 2.

The findings suggest that high-performing methods, such as the vibrating screen and belt press, are ideal for industries needing maximum moisture removal to improve material handling and reduce drying costs. Moderate-efficiency methods, such as centrifugal separation and inclined stationary screens, offer a balance between dewatering efficiency and operational feasibility. In contrast, lower-performing methods may still be useful where partial moisture removal is sufficient or when energy and operational constraints limit the use of high-performance technologies.[20] The selection of an appropriate dewatering method depends on factors such as cost, energy consumption, and the specific requirements of the application.[21]

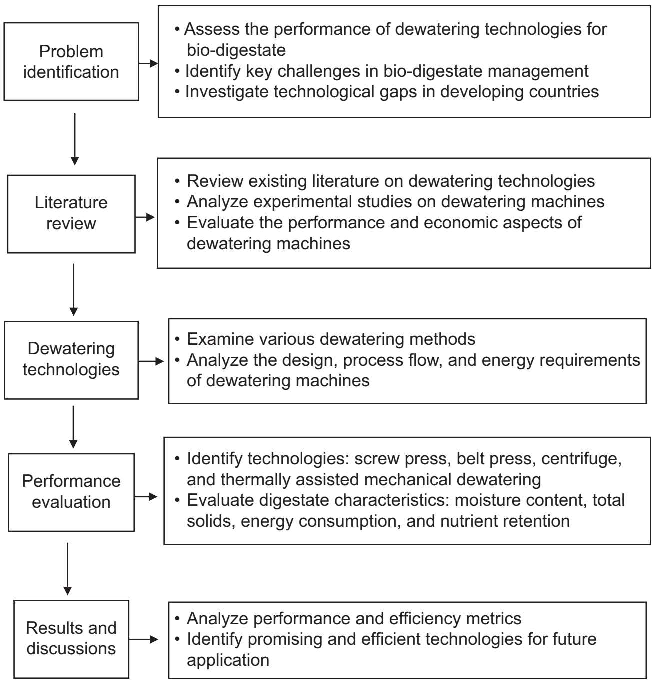

Figure 1. The systematic approach applied to the current review

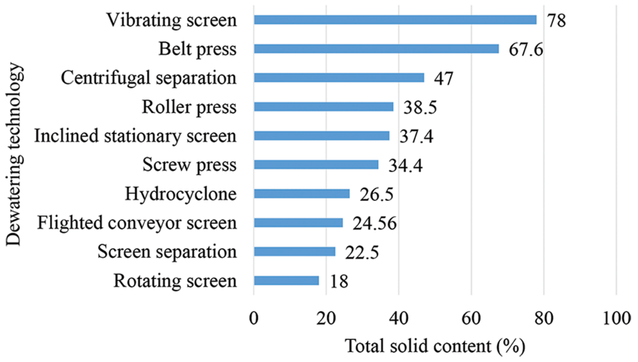

Figure 2. Comparison of various mechanical dewatering technologies based on total solid content

The screw press dewatering machine effectively compresses the biodigestate, allowing it to be used for numerous purposes. Screw press dewatering devices are also less energy-intensive, therefore lowering their operating cost over their lifetime.[22] Since they have fewer moving components, the maintenance frequency is also lower. The higher initial investment and limited capacity of the machine are the main drawbacks of the screw press machine.[23] Based on previous researches and experiments, the screw press dewatering machine is considered the most beneficial item to design. This machine retains higher amounts of nitrogen, phosphorus, and potassium in the solid output compared to other dewatering systems. Its low energy consumption and effective solids removal make it a viable option for both dewatering and nutrient conservation.[24] However, preserving nutrients may result in lower total solid output compared to methods such as centrifuge or belt press dewatering.[25] Therefore, when choosing the right system, one should consider the trade-off between maximizing nutrient retention and achieving efficient solids separation, depending on the specific application requirements. In practical terms, industries that prioritize nutrient conservation, such as those involved in agriculture or fertilizer recovery, may prefer this system, even if it results in lower total solids.[26] An experiment performed in 2011 demonstrated that it would not be possible to reduce the total solid content in the liquid fraction below 40% of the total mass of the solid–liquid mixture, as the solids would be in dissolved form and cannot be removed by pressure filtration.[27]

On the other hand, applications focused on achieving the highest possible dewatering efficiency, such as wastewater treatment plants, might favor technologies such as belt press or centrifugation, which remove more moisture but may lead to greater nutrient loss.[28] Thus, the choice of technology should align with the end-use goals, whether they are nutrient recycling, moisture reduction, or energy saving.[29]

TAMD is an advanced technique designed to enhance the energy efficiency of liquid–solid separation processes.[30] This method improves the performance of conventional dewatering systems by integrating controlled heat flow into the mechanical dewatering operations, thereby accelerating moisture removal. While the concept of applying heat in dewatering is not entirely new, TAMD introduces a novel approach by optimizing specific operating conditions, i.e., maintaining temperatures below 100°C and pressures under 3000 kPa. This careful regulation ensures that the liquid remains in its liquid state, preventing phase change and excessive energy consumption.[31] By reducing the energy required for moisture removal, TAMD presents a significant opportunity for industries to improve process efficiency, minimize environmental impact, and decrease operational costs, making it a promising solution for various applications, including wastewater treatment, agriculture, and industrial processing.

Sludge dewatering equipment has been specifically designed to handle its challenging properties, such as compressibility and fine particle size. These characteristics result in dense filter cakes, making the sludge resistant to settling and compression.[32] Therefore, effective dewatering requires applying compressive forces directly to the solid phase. Commonly used equipment includes membrane plate presses, belt filters, and decanter centrifuges. To enhance performance, chemical pre-treatment and the selection of appropriate filter cloth are often necessary. While filter presses typically produce drier solids, the choice of equipment ultimately depends on factors including desired dryness, process requirements, and cost.[33] A previous study demonstrated the importance of establishing a reliable dewatering index to optimize the dewatering process. Few studies have focused on the correlation between the conditioning index and the dewatering efficiency.[13]

Significant advancements in biodigestate treatment have been achieved through extensive research, technological innovations, and large-scale infrastructure development. In contrast, Nepal's efforts in this field have been limited to small-scale surveys, preliminary studies, and localized research. This lack of comprehensive data and large-scale implementation hampers the effective design, strategic planning, and successful execution of bioslurry dewatering and wastewater treatment projects. As a result, challenges persist in ensuring the smooth operation, long-term sustainability, and scalability of these initiatives.

4. Performance parameters of dewatering machines

Dewatering machines are essential in various industries, including wastewater treatment, mining, food processing, and the ceramic industry, for removing moisture from solids and reducing waste volume.[11] Selecting an appropriate dewatering machine requires careful consideration of several performance parameters to ensure efficiency, cost-effectiveness, and sustainability.[34] The key factors to evaluate include technologies implemented, moisture reduction efficiency, energy consumption, processing capacity, operational and maintenance costs, environmental impact, and adaptability to different materials.[35] The parameters involved in the performance evaluation of dewatering machines are:

(i) Technologies implemented: The technologies implemented for dewatering in agricultural, industrial, and water treatment plants vary across different fields based on machine design, dewatering process, and chemicals used.[36] This will alter the performance of the machines in terms of time and energy consumption, moisture reduction, machine size, operational and maintenance costs, as well as machine capacity.

(ii) Moisture reduction efficiency: The primary function of a dewatering machine is to extract water from solids efficiently. The final moisture content of the processed material determines its usability, transport costs, and subsequent processing needs.[37] Machines such as filter presses and centrifuges offer high efficiency in moisture reduction. However, the effectiveness varies based on the material properties, particle size distribution, and binding forces of the water.

(iii) Energy consumption: Energy efficiency is a critical factor in dewatering processes, as excessive energy consumption increases operational costs and environmental impact.[38] Centrifugal dewatering systems typically require more energy due to high-speed rotations, whereas belt presses and screw presses operate at lower energy demands.[39] In addition, integrating energy recovery systems, such as heat exchangers, can further optimize energy use in thermal drying applications.[40]

(iv) Processing capacity and throughput: The ability of a dewatering machine to handle large volumes of material per unit time is essential for industrial-scale applications. High-capacity machines, such as vacuum belt filters, can process significant amounts of slurry continuously, whereas batch-operated filter presses may have limitations in throughput.[41] The selection of a machine should align with the required production rate and the variability of input feed consistency.

(v) Operational and maintenance costs: Long-term operational costs, including maintenance, labor, and replacement parts, influence the overall economic viability of a dewatering system.[42] Machines with complex mechanical components, such as decanter centrifuges, may require frequent maintenance and skilled labor, increasing their operating expenses. Conversely, screw presses and belt filters have simpler designs with lower maintenance requirements, making them cost-effective alternatives.[33]

(vi) Environmental impact and sustainability: Sustainability considerations include waste reduction, energy efficiency, and water reuse potential. Dewatering machines that minimize sludge volume and enhance resource recovery contribute to environmental sustainability. In addition, low-chemical or chemical-free dewatering methods are preferred to reduce the environmental footprint.[43]

(vii) Adaptability to different materials: Different industries require dewatering machines with varied capabilities to handle materials with diverse compositions, viscosities, and particle sizes. Some machines perform well with fibrous materials, such as in the pulp and paper industry, whereas others are designed for high-density sludge, as seen in wastewater treatment.[44] Selecting a machine that offers versatility ensures long-term adaptability to changing process requirements.

5. Comparative analysis of dewatering machines

The performance of various types of dewatering machines has been evaluated to assess their effectiveness in different aspects. The changes in moisture content in the dewatered digestate in multiple studies were reviewed. Most studies employed the sun-drying method, followed by dewatering, to reduce the moisture content in the biodigestate. The weight of the biodigestate was decreased to 5.46 kg from 10.38 kg after 72 h of sun drying, along with a 30.2% increase in the percentage of total solids. Other than that the pH value changed from 6.9 to 4.8. In terms of nutrient retention, the total Kjeldahl nitrogen reduced from 0.3% to 0.09%, the available phosphorus decreased from 89.67 mg/kg to 81.48 mg/kg, and the available potassium from 1,637.5 mg/kg to 860 mg/kg.[18] The reduction percentage of the biodigestate parameters after 72 h of sun drying is represented in Figure 3.

In the same study, the combination of sun drying and dewatering processes was employed to evaluate their effectiveness in reducing the moisture content in the biogas slurry sample. The weight of the biodigestate reduced from 95.44 kg to 32.74 kg. The pH value changed from 8.4 to 7.8, whereas the concentration of total solids changed from 15.95% to 24.32%. In terms of nutrient retention, the total Kjeldahl nitrogen increased from 0.36% to 0.42%, the available phosphorus decreased from 81.48 mg/kg to 70.84 mg/kg, and the available potassium decreased from 1,005 mg/kg to 911.44 mg/kg after dewatering.[18] The reduction percentage of the different parameters of the biodigestate after dewatering is represented in Figure 4.

An experimental testing and performance analysis was conducted on a dewatering machine by varying

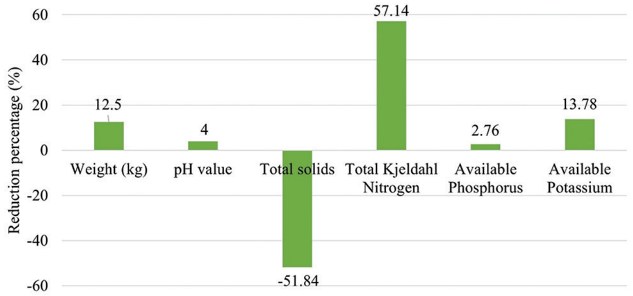

Figure 3. Changes in parameters after 72 h of sun drying

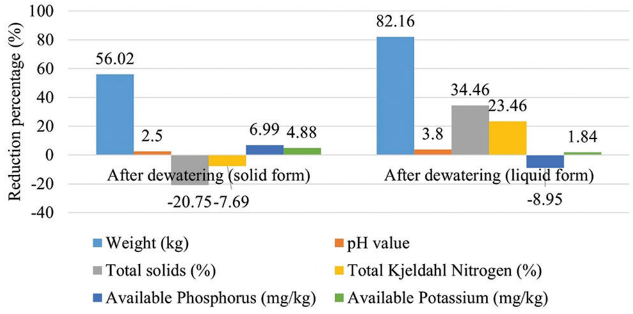

Figure 4. Changes in parameters after the dewatering process

Note: The solid and liquid form both uses the combination of sun-drying and dewatering process. The solid form means the total amount of solid present in the biodigestate, whereas the liquid form means the total liquid present in the bio-digestate after the dewatering process.

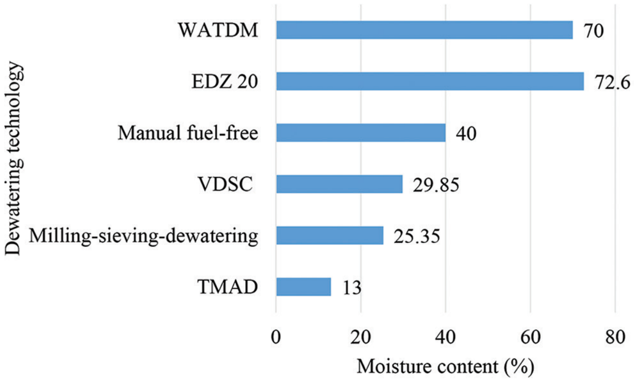

Figure 5. Moisture content of digestate after dewatering

Abbreviations: TMAD: Thermal-mechanical assisted dewatering; VDSC: Vertical double-squeeze cassava; WATDM: Water-absorption-trough dewatering machine.

operating speeds using a variable frequency drive. It was identified that 8 rpm was the optimal speed for system operation. At this speed, the system demonstrated its highest efficiency, achieving a liquid yield of 92.02% and an extraction efficiency of 73.12%.[45] The results highlighted the importance of precise speed control in optimizing performance, maximizing resource recovery, and enhancing overall system effectiveness in the dewatering process.

Olusegun and Ajiboye[46] developed a vertical double-squeeze cassava pulp dewatering machine to handle 200 kg of cassava pulp. The machine featured acme-threaded screws operating at a principal stress of 100 N/mm^2 and a torque of 1,182 kN/mm, powered by a 7.5-horsepower single-phase motor with an efficiency of 40%. It effectively reduced the moisture content of fine cassava pulp from 80% to 29.85% in 33.72 min, which was approximately seven times faster than the International Institute of Tropical Agriculture manual batch-type machine. The machine also achieved 10 – 20% greater removal of toxic water and enhanced gari production by a factor of seven.

Mudryk *et al.*[47] utilized the EDZ 20 strength machine with replaceable screens of 0.1 – 0.3 mm to dewater digestate under varying pressures (0.58 – 2.91 MPa). The highest rate of moisture loss occurred at 1.74 MPa (30 kN), although additional increases in pressure yielded diminishing returns. Using a 0.3 mm screen, the maximum reduction in moisture content was <7.4%, with only 2.5% additional mass loss when pressure increased from 2.32 MPa to 2.91 MPa, indicating a performance threshold for mechanical pressure-based dewatering.

Mahmoud *et al.*[31] applied thermal-mechanical assisted dewatering (TMAD) to alfalfa biomass using a two-factor central composite experimental design. At 80°C and pressure conditions ranging from 300 kPa to 3000 kPa, the method removed up to 83% of inherent water, compared to only 43% using mechanical dewatering alone. A regression model with $R^2 > 88\%$ was used to predict final dry solid content. The optimized process required <150 kWh/m^3, reducing energy consumption by over 30% and achieving up to 87% total solids after thermal drying.

Marcel *et al.*[48] developed an integrated milling-sieving-dewatering system for grain slurry, which improved extraction efficiency and reduced moisture content. The system achieved a moisture content of 25.35% with a specific energy consumption of 183 kJ/kg under optimal conditions: 70 L/h water feed, 10 rpm sieving speed, and 90 kPa vacuum pressure. This represented reductions in moisture content of 19.64% and energy consumption of 19.13% compared to the original design settings.

Afeni *et al.*[49] fabricated a manually operated fuel-free dewatering machine designed for blasthole water removal in mining. It achieved an average discharge rate of 0.27 L/s and a mechanical efficiency of 76%, offering an environmentally friendly and cost-saving solution. Annual dewatering cost savings exceeded 90%, and the device can operate on solar power, making it a sustainable alternative in remote areas. The performance assessment of various dewatering machines implemented for different materials is illustrated in Table 1 and Figure 5.

Among the technologies assessed, TMAD achieved the lowest final moisture content (13%), showcasing the significant enhancement that thermal input provides. The vertical double-squeeze cassava machine also performed well, reducing moisture to around 29.85%, outperforming traditional manual or batch-type equipment. The milling-sieving-dewatering system reduced the moisture content of starch slurry to 25.35%, while EDZ 20, operating under mechanical pressure without thermal aid, achieved a modest 7.4% moisture reduction, resulting in higher final moisture content (>70%). The manual fuel-free machine offers sustainability benefits but is primarily used for water pumping, not fine particulate dewatering. The water-absorption-trough dewatering machine method indirectly improves moisture-related estimations and is not a direct dewatering method.

Table 1. Analysis of various dewatering machines

Machine/study	Material processed	Technology type	Key parameters	Moisture reduction/final moisture	Energy use	Notable outcomes	References
Vertical double squeeze machine (2009, Nigeria)	Cassava pulp	Screw press (vertical, dual-squeeze)	100 N/mm^2 principal stress, 1182 kN/mm torque	80% moisture reduced to 29.85% for fine materials, 65% moisture reduced to 33.6% for coarse materials, in 33.72 min	7.5 HP motor at 40% efficiency	7 times faster than International Institute of Tropical Agriculture, with 10 – 20% more toxins removed	46
EDZ 20 (2016, Poland)	Digestate	Compression with replaceable screens	0.58 – 2.91 MPa	Maximum 7.4% reduction achieved using 0.3 mm screen	N/A	Diminishing returns of above 2.32 MPa	47
MTE (2007, Europe)	Low-rank coal	Mechanical thermal dewatering	200°C, 5 MPa	Final pore volume below 0.2 cm^3/g achieved	N/A	Shrinkage at the macro-mesopore level; reduction in porosity	50
TMAD (2011, France)	Alfalfa biomass	Thermal-mechanical assisted dewatering	80°C, 300 – 3000 kPa	83% water removed (up to 66% TS); 87% TS with drying	<150 kWh/m^3	30–35% energy saving; regression model R^2=88.47%	31
WATDM (2021, China)	Moist soil	Spectroscopic dewatering correction	Wavelengths: 1400 and 1900 nm	Indirect improvement in SOC accuracy	N/A	Corrected soil moisture interference in SOC models	51
Milling-sieving-dewatering (2021, Nigeria)	Grain slurry	Combined sieving-drum-vacuum	70 L/h, 10 rpm, 90 kPa	Final moisture content: 25.35%	183 kJ/kg	Increased throughput (87 kg/h), decreased energy consumption (−19.13%)	48
Manual fuel-free machine (2021, Nigeria)	Blasthole water (mine)	Manual piston-pump	Reciprocating pump, solar-ready	N/A (Discharge rate: 0.27 L/s)	No fuel	90% cost savings; 0 emissions	49

Abbreviations: HP: Horsepower; MTE: Mechanical thermal expression; SOC: Soil organic carbon; TMAD: Thermal-mechanical assisted dewatering; TS: Total solid content; WATDM: Water-absorption-trough dewatering machine.

6. Conclusion

Effective dewatering of biodigestate is vital for unlocking the environmental, agricultural, and economic benefits of biogas systems. This review demonstrates that modern dewatering technologies, especially TAMD and screw press systems, significantly improve moisture removal, nutrient retention, and energy conservation. However, their adoption in Nepal and other developing countries is hindered by a lack of large-scale implementation and technical infrastructure. Low-cost alternatives, such as sun drying in combination with mechanical dewatering or manually operated, fuel-free systems, offer viable solutions for decentralized and small-scale applications. Moving forward, a targeted strategy that includes pilot projects, capacity building, research on local feedstock characteristics, and supportive government policy will be essential. By integrating appropriate dewatering technologies into Nepal's renewable energy and agricultural sectors, the country can advance toward a more circular and sustainable bioeconomy, transforming waste into a resource while reducing environmental impact and enhancing rural livelihoods.

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Conflict of interest

The authors declare they have no competing interests.

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Availability of data

All data presented in this article are included within the manuscript.

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