INTEGRATION OF WATER QUALITY ASSESSMENT AND WASTE MANAGEMENT SYSTEMS: A STRATEGIC APPROACH TOWARDS A SUSTAINABLE GREEN CAMPUS IN THE UI GREENMETRIC FRAMEWORK

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ABSTRACT

This study aims to assess the quality of surface water flowing through the campus and analyze the composition of daily waste generated. The methodology involved surface water and waste sampling conducted in September 2023. Surface water samples were collected at three strategic points: upstream, midstream, and downstream. Parameters such as Total Dissolved Solids (TDS), Total Suspended Solids (TSS), pH, Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Nitrate (NO^3-N), Dissolved Manganese (Mn), Zinc (Zn), and oil/fats, with reference to Regulation of the Minister of Environment and Forestry No. 22/2021 concerning "Water Quality Standards" for Class 2 surface water. Waste sampling was carried out to determine the volume and composition of daily waste, categorized into organic, inorganic, and hazardous materials. The results indicate significant improvements in water quality, with reductions in TDS and BOD levels over time. However, elevated nitrate concentrations downstream pose risks of eutrophication. Waste sampling revealed an average daily generation of 3,026.34 kg, with organic waste constituting 48% and plastics 30%. Based on a traditional "collect-transport-dispose" model, current waste management practices face infrastructure limitations. This study concludes that adopting integrated strategies such as composting organic waste, implementing waste banks for plastics, and applying circular economy principles can significantly enhance environmental sustainability. These measures are critical for transforming UNP Air Tawar into a resilient green campus that addresses future ecological challenges.

Key-words: *Sustainable campus; Waste management; Water quality; UI greenmetric; UNP Air Tawar.*

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1. INTRODUCTION

Global climate change is increasingly evident in populations worldwide. The 2021 report by the Intergovernmental Panel on Climate Change (IPCC) highlights an alarming rise in global temperatures, with 2019 identified as the second hottest year on record after 2016, according to the World Meteorological Organization (WMO). In Indonesia, extreme temperatures recorded in January 2020, as reported by the Meteorology, Climatology, and Geophysics Agency (BMKG), serve as tangible evidence of the intensifying effects of global warming, further accelerating climate change. This rise in global temperatures affects localized weather patterns and causes profound shifts in the hydrological cycle, resulting in prolonged rainfall and more uniform precipitation distribution across different regions. Schellnhuber et al. (2018) observed that these changes heighten the frequency and intensity of natural disasters, particularly floods. In Indonesia, increased flooding events not only cause extensive physical destruction but also deteriorate environmental quality, posing critical threats to human sustainability and the survival of ecosystems.

The worsening environmental conditions necessitate urgent action from all societal levels. Steffen et al. (2015) argue that addressing this global environmental crisis demands a collective approach encompassing both mitigation and adaptation measures. Responding to this escalating challenge, the Indonesian government, alongside other nations, has committed to adopting sustainable development as a long-term strategy. Clark et al. (2016) emphasize that sustainable development is not solely an economic framework but a holistic strategy aimed at preserving natural resources for future generations while ensuring the well-being of the current population.

Within the framework of sustainable development, Universities emerge as crucial agents of change. Evans et al. (2014) underscore that Universities, as hubs of education and research, are tasked not only with equipping the younger generation with knowledge but also with developing innovative solutions to address challenges related to climate change and sustainability. Furthermore, Universities can serve as role models by implementing sustainable practices on their campuses and within their communities. Lozano et al. (2015) note that many Universities globally have begun integrating sustainability into their curricula, research agendas, and outreach programs. Beyond their educational and research missions, Universities also play a significant role in national and global economies. As substantial consumers of goods and services, Universities can influence markets by promoting demand for green technologies and environmentally friendly innovations. Shriberg (2002) highlights that Universities can drive progress in sustainable technologies through responsible resource consumption and effective management practices.

In 2010, Universitas Indonesia (UI) introduced the "UI GreenMetric World University Rankings", a pioneering global initiative designed to evaluate the sustainability programs and policies of universities worldwide with a total of 145 campuses in Indonesia, of which Universitas Negeri Padang (UNP) Air Tawar campus ranks 59th in campus total scorers regarding the UI GreenMetric World University Rankings (Andriani et al., 2024). Sedlacek (2013) describes this initiative as a transformative step toward encouraging Universities to actively engage in addressing global sustainability challenges. The rankings evaluate performance based on six key criteria: Setting and Infrastructure (SI), Energy and Climate Change (EC), Waste Management (WS), Water Resources (WR), Transportation (TR), and Education (ED). As part of its commitment to sustainability, the UNP Air Tawar campus has adopted enhanced waste management practices. These include a waste separation system that categorizes waste into organic, inorganic, and hazardous or toxic materials. On average, the campus generates approximately 3,026.34 Kg of waste daily, with a peak of 3,523.33 Kg on Mondays due to accumulated weekend waste. Hoornweg & Bhada-Tata (2012) emphasize that effective waste management is crucial for minimizing environmental impacts, especially in urban areas such as University campuses. Gomes et al. (2008) suggest that managing organic waste through composting can significantly reduce the volume of waste sent to landfills while simultaneously supporting campus greening initiatives. Moreover, implementing a waste bank program to manage inorganic waste, particularly plastics, allows for the reuse of recyclable materials and encourages more efficient recycling practices. Mwakalinga (2014) highlights that waste bank programs not only improve waste management systems but also raise environmental awareness among students. By optimizing waste management strategies based on type and volume, the UNP Air Tawar campus can position itself as a model for sustainable practices in the education sector.

Lozano (2006) underscores that Universities bear a responsibility to reduce their environmental impact through policies and actions that support long-term sustainability. Since 2016, UNP has actively participated in the self-assessment of green campus performance through the UI GreenMetric initiative. Field observations and document analyses from 2016 to 2022 reveal that among the six evaluation criteria, Waste Management (WS) and Water Resources (WR) consistently scored lower than other categories. This indicates that there is substantial potential for improvement in waste and water management systems to achieve higher sustainability standards. The low score in the WS category indicates that current waste management practices at the UNP Air Tawar campus fall short of aligning with the standards of a green campus. At present, UNP Air Tawar relies on a traditional system of waste collection, transportation, and direct disposal to landfills, without integrating sustainable waste management principles. Additionally, the low WS score highlights the lack of a comprehensive system to record and analyze data on the volume and types of waste being managed effectively. Addressing these gaps requires focused study to accurately measure the quantity, types, and characteristics of waste generated on campus. The results of such studies can form the basis for designing a more sustainable waste management system, grounded in the principles of Reduce, Recycle, and Reuse (3R). Implementing the 3R approach would not only enhance UNP Air Tawar performance in the WS category but also bring the campus closer to achieving the standards of an ideal green campus. Similar challenges are evident in the WR category. According to the 2022 UI GreenMetric guidelines, a low score in this area indicates the absence of critical initiatives, such as water conservation programs, water recycling systems, and effective water pollution control measures. To address these shortcomings, the first step involves developing a comprehensive strategy for water-related sustainability programs. However, this process must be preceded by a thorough assessment of the quality of water bodies within the campus. The findings from such a study will provide a scientific foundation for creating sustainable water conservation, recycling, and pollution control measures. This effort is integral to the design of a sustainable campus plan for UNP Air Tawar and encompasses two key objectives, namely 1) Quantifying the daily volume and categorizing types of waste produced by the campus. This data is essential for developing a more effective and sustainable waste management system that incorporates the principles of 3R; and 2) Assessing the quality of water bodies within the campus. The results will guide the development of water conservation efforts and support the establishment of a more efficient water recycling system on campus.

This study aims to assess the quality of surface water flowing through the campus and analyze the composition of daily waste generated. Integrating a geographically contextualized approach, provides a fresh perspective on sustainable campus planning, particularly within Indonesia's environmental framework. Strategies for water recycling and waste management have been specifically designed to align with the unique geographical and ecological characteristics of UNP Air Tawar, emphasizing the interplay between natural systems and human activities. The findings of this research are anticipated to significantly contribute to UNP Air Tawar initiatives toward becoming a green campus one that is not only environmentally sustainable but also resilient to future ecological challenges.

2. METHODS

This study aimed to evaluate waste management practices and assess surface water quality at the UNP Air Tawar campus. The methodology consisted of two primary stages (surface water sampling and waste sampling), both conducted following standardized procedures to ensure data accuracy and validity.

Surface water sampling was carried out at three strategically selected locations along the river traversing the UNP Air Tawar campus (upstream, midstream, and downstream). The upstream point served as a baseline reference for assessing water quality before the river entered the campus, the midstream sampling point captured the influence of campus activities on water quality, while the downstream point evaluated the cumulative impact of campus-related activities on the river before it exited the campus area (Berila & Isufi, 2021; Ngatia et al., 2024). These locations, shown in **Table 1** and **Figure 1**, were chosen to capture a comprehensive representation of the river's water quality.

Table 1.

Coordinates of sample points.

Pickup points	S and E coordinates
Upstream	S: 00°54’00,1” E: 100°20’54,0”
Midstream	S: 00°53’48,7” E: 100°20’52,89”
Downstream	S: 00°53’39,7” E: 100°20’50,8”

The parameters for water quality assessment were measured in adherence to recognized environmental standards to ensure accurate and meaningful evaluations of surface water quality and its potential environmental impacts. These parameters included indicators such as Total Dissolved Solids (TDS), Total Suspended Solids (TSS), pH, Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Nitrate (NO^3-N), Dissolved Manganese (Mn), Zinc (Zn), and oil/fats, with reference to Regulation of the Minister of Environment and Forestry No. 22/2021 concerning "Water Quality Standards" for Class 2 surface water.

TDS and TSS are essential indicators of water quality, providing measurements of dissolved and suspended solids in water (Dewata et al., 2023). These metrics offer insights into turbidity levels and the concentration of non-dissolvable solid particles. pH, which measures the acidity or alkalinity of water, is a critical parameter as it influences chemical reactions and the viability of aquatic organisms. Furthermore, BOD and COD are parameters that determine the oxygen demand required to decompose organic matter and chemical compounds in water (Putra et al., 2024). The concentration of NO^3-N, commonly derived from agricultural runoff and human activities, serves as a significant indicator of nutrient pollution, which can result in eutrophication. Mn and Zn are also noteworthy indicators of water quality, as excessive concentrations of these metals can be harmful to ecosystems and human health. Lastly, the presence of oil and fats highlights pollution caused by oil or grease waste, which can form a surface layer, obstruct oxygen exchange, and disrupt aquatic ecosystems. Together, these parameters collectively provide a detailed evaluation of water quality and levels of pollution.

To analyze the spatial distribution of water quality parameters along the river stream, a Geographic Information System (GIS) approach was utilized, employing the kriging interpolation method. Kriging is a geostatistical technique that generates predictive spatial maps based on measured data points, providing detailed insight into the spatial variation of water quality parameters (Dewata & Putra, 2021). By mapping TDS, TSS, pH, BOD, COD, and other key indicators, this method allows for the identification of pollution hotspots and patterns of contaminant dispersion across the river system. The kriging analysis revealed distinct zones of water quality degradation, particularly in areas influenced by agricultural runoff and industrial discharge. These spatial insights are critical for prioritizing mitigation efforts, designing targeted interventions, and establishing effective policies. By integrating geographical analysis with technical methodologies, including GIS and kriging, this study offers critical insights for designing strategies to improve waste management systems and enhance water quality at UNP Air Tawar. The findings contribute to broader efforts aimed at achieving sustainable campus development, addressing local environmental challenges, and aligning with global sustainability objectives.

Waste sampling entails the systematic categorization and quantification of waste according to its type, including organic, inorganic, and hazardous or toxic materials. The data collection framework was meticulously designed to adhere to the principles of sustainable waste management, with a focus on accurately measuring the volume and composition of waste produced from diverse campus activities. This methodological approach enables a comprehensive assessment of waste types and quantities, forming the foundation for tailored waste reduction and management strategies.

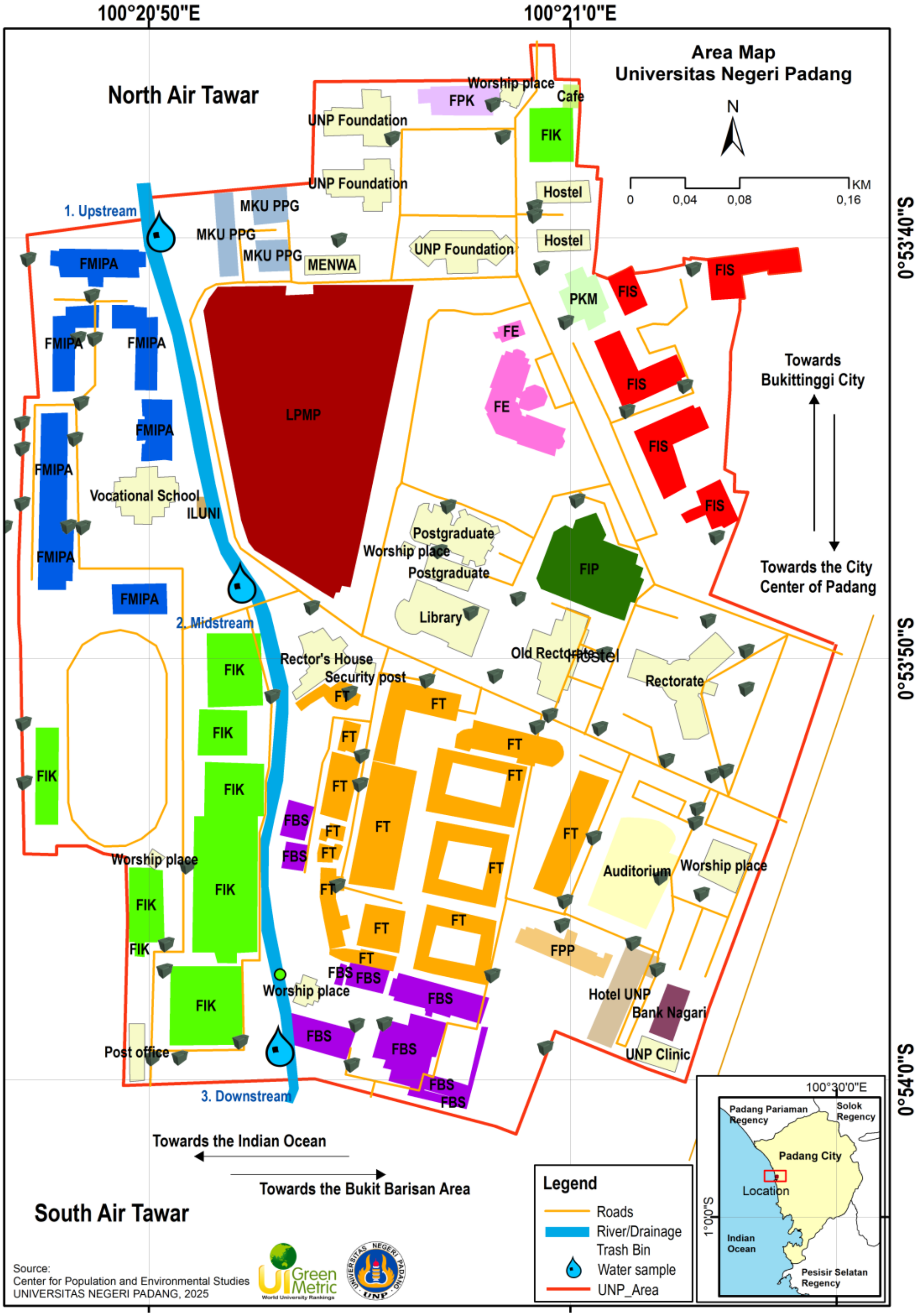

Fig. 1. Map of UNP area and sample points for water quality.

At the UNP Air Tawar campus, waste sampling was carried out to identify the composition and volume of waste generated within the area. The process was conducted by a specialized team using three motorized three-wheeled vehicles (commonly known as "bentor"), each operated by three personnel responsible for waste collection and transport, totaling twelve participants in the operation. After collection, the waste was transported to a Temporary Disposal Site (TDS), where it underwent a structured process of weighing and sorting.

The weighing process comprised two distinct stages initially, the waste was weighed as a whole, followed by a reweighing process after it had been classified into organic and inorganic categories. Waste sorting was based on its inherent characteristics. Organic waste encompassed biodegradable materials such as food remnants, kitchen scraps, yard debris, and paper products, while inorganic waste included non-biodegradable items like plastic packaging, plastic bottles, cans, glass, and similar materials. The entire procedure was conducted in compliance with the Indonesian National Standard (SNI) 19-3964-1994, which delineates guidelines for sampling and analyzing urban waste generation and composition. Following the completion of the weighing and sorting processes, the waste was stored in designated containers at the TDS before being transported to the landfill. This transportation process relied on waste transport trucks provided by the Padang City Cleaning and Parks Department.

3. RESULTS AND DISCUSSIONS

3.1 Water Quality Assessment

Water quality sampling for the water bodies traversing the UNP Air Tawar campus was carried out in September 2023. The sampling procedure targeted three strategically selected locations to ensure comprehensive coverage of the river system intersecting the campus. These locations included the upstream section behind the Faculty of Mathematics and Natural Sciences (FMIPA) Chemistry Laboratory, the midstream section near the bridge adjacent to the Rector’s residence, and the downstream section close to the Faculty of Languages and Arts (FBS). The chosen points were intended to capture variations in water quality along the river continuum, ensuring spatial representation and enabling a thorough analysis of potential pollution sources and hydrological processes. For a detailed visualization of the sampling locations, refer to **Figure 2** below. Visually, the river water flowing through the UNP campus appears turbid and unappealing, indicating potential pollution. The turbidity is primarily caused by sediment and possibly pollution from activities around the campus.

Fig. 2. Sampling locations and documentation of water sample collection

However, laboratory tests conducted on water samples from three locations in 2023 provided more encouraging results. Despite the visually dirty appearance, the laboratory analysis indicated that the water quality parameters remained below the threshold limits required for Class 2 surface water, as outlined in **Table 3**, **Figures 3**, **4**, and **5** below.

Table 2.

Results of water quality analysis in the UNP Air Tawar campus area.

Parameter	Unit	Upstream (2015)	Upstream (2023)	Midstream (2023)	Downstream (2015)	Downstream (2023)	Class 2 Standard
I. Physical							
Dissolved Solids (TDS)	mg/L	1394	598	643	914	476	1000
Suspended Solids (TSS)	mg/L	150	14.6	24.4	137	27.2	50
II. Chemical							
pH		8.54	6.42	7.44	8.13	7.02	6 - 9
BOD	mg/L	6.37	< 2	2.39	6.27	2.3	3
COD	mg/L	22	2.73	12.4	22	10.8	25
Nitrate (NO^3-N)	mg/L	1.105	3.86	2.31	2.523	5.72	10
Dissolved Manganese (Mn)	mg/L	< 0.019	< 0.015	< 0.015	0.027	< 0.015	-
Zinc (Zn)	mg/L	< 0.067	< 0.015	< 0.015	< 0.067	< 0.015	0.05
Oil/Fats	mg/L	0.067	< 1	< 1	0.8	< 1	1

Note/Sources:

1. *Laboratory of Baristand Ulu Gadut Padang, 2015.*
2. *Environmental laboratory technical implementation unit of Padang City, 2023.*
3. *Refers to Regulation of the Minister of Environment and Forestry No. 22/2021 concerning "Water Quality Standards" for Class 2 surface water.*

The physical water quality of the river running through the UNP Air Tawar campus is suboptimal, primarily due to turbidity. However, laboratory analyses confirm that its chemical and biological parameters remain within the permissible limits for Class 2 surface water. This classification, as stipulated in the Regulation of the Minister of Environment and Forestry (No. P.68/MENLHK/SETJEN/KUM.1/8/2016, updated by Regulation No. 22/2021), identifies the water as suitable for recreational activities, livestock usage, fisheries, and irrigation, although it is not intended for direct human consumption. These standards ensure that the water meets the ecological and anthropogenic requirements of Class 2 water usage. Similarly, guidelines from Ministerial Regulation No. 51/2004 on "Seawater Quality Standards" align with efforts to sustain ecological integrity. To evaluate the river condition, water samples were collected at three primary locations: 1) upstream, near the chemistry laboratory of FMIPA; 2) midstream, at the bridge by the Rector's residence; and 3) downstream, near the FBS area. These sampling sites, shown in **Figure 1**, offer insights into spatial variations in water quality. While the river appeared visibly polluted consistent with observations by Kannel et al. (2007) laboratory results affirmed compliance with Class 2 water standards, highlighting the importance of empirical analyses for accurate assessments.

GIS Kriging analysis of the spatial distribution of key water quality parameters reveals significant trends. For instance, TDS concentrations were highest upstream in 2015 but showed marked reductions by 2023, attributed to sediment management efforts. Improvements in water quality were observed over time, especially in TDS. For example, TDS levels upstream dropped from 1,394 mg/L in 2015 to 598 mg/L in 2023, while downstream levels declined from 914 mg/L to 476 mg/L over the same period. According to the World Health Organization (WHO, 2017), elevated TDS can impair water clarity, flavor, and aquatic health, underscoring the significance of these reductions. However, a concerning trend was identified in nitrate levels (NO3-N) downstream, which increased to 5.72 mg/L in 2023.

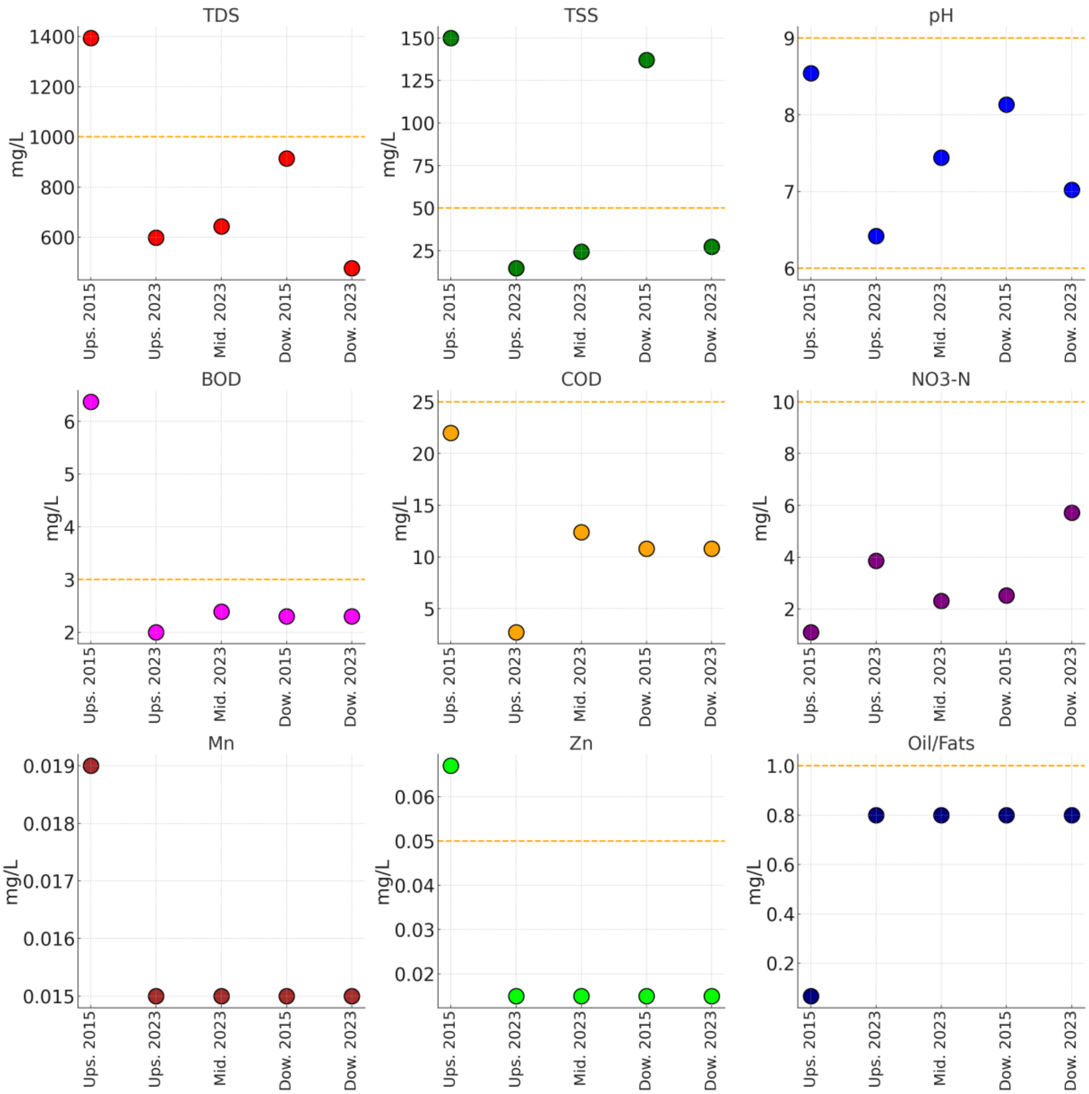

Fig. 3. Graph of water quality analysis in the UNP Air Tawar campus area.

GIS models pinpoint agricultural runoff and improper fertilizer use near the campus as key contributors to this rise. As Carpenter et al. (1998) emphasize, excessive nitrate concentrations can trigger eutrophication, resulting in ecological imbalances. This calls for more stringent management of domestic and agricultural waste in areas surrounding the campus to mitigate nitrate pollution.

Heavy metals, such as zinc and manganese, were found to be within regulatory thresholds, corroborating earlier assessments. Nevertheless, localized GIS Kriging hotspots indicate potential risks of metal leaching from laboratory facilities and infrastructure. Gupta and Gupta (2016) advocate for ongoing monitoring to ensure these levels remain compliant. Beyond water quality, this study proposes a series of geographically tailored waste and water management initiatives to address the unique environmental challenges of the UNP Air Tawar campus. Organic waste, constituting nearly half of the daily waste (e.g., food scraps and yard trimmings), is identified as a significant contributor to landfill-bound waste. Implementing a composting program could not only reduce this burden but also generate compost for campus green spaces.

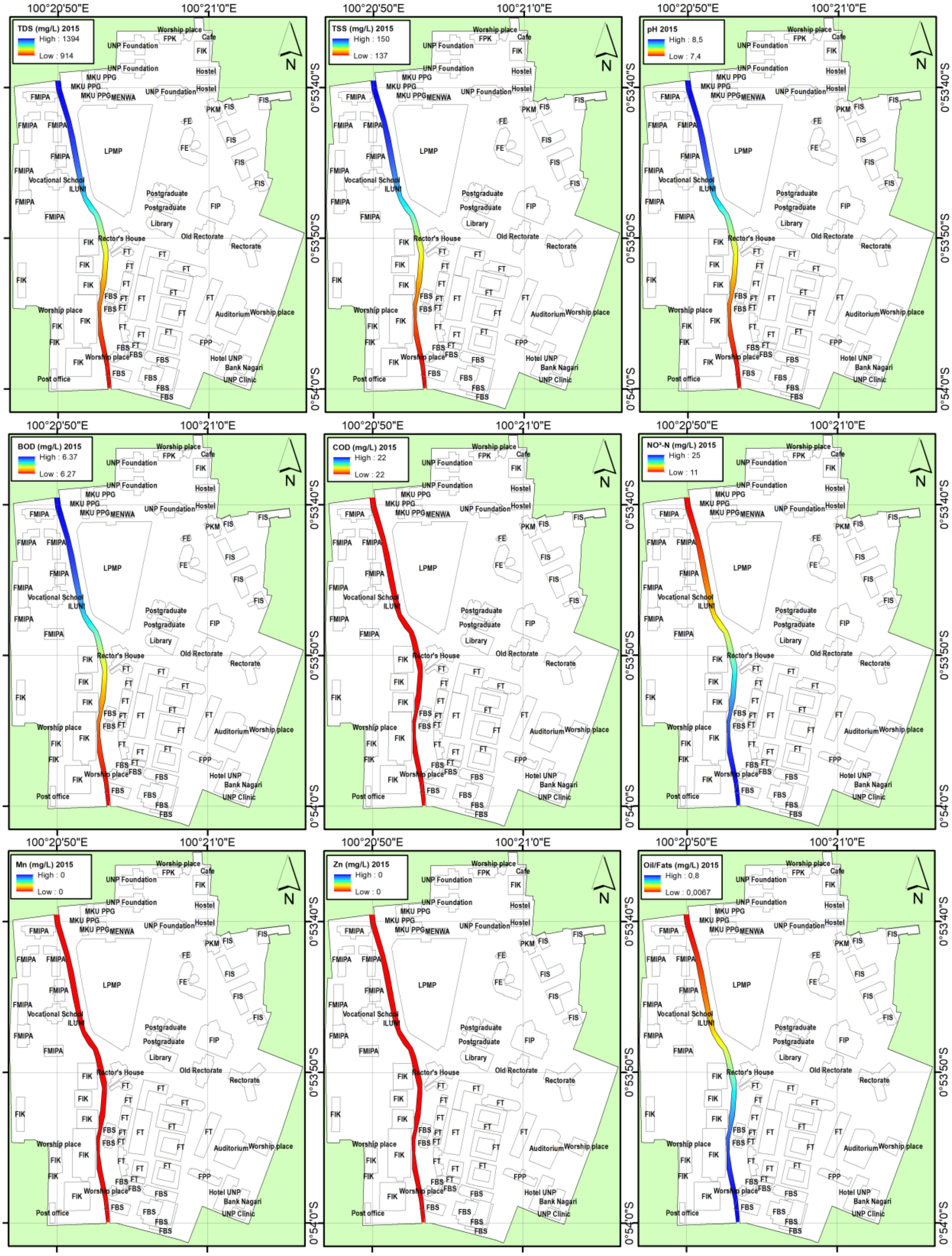

Fig. 4. Model of river water quality 2015 in the UNP area.

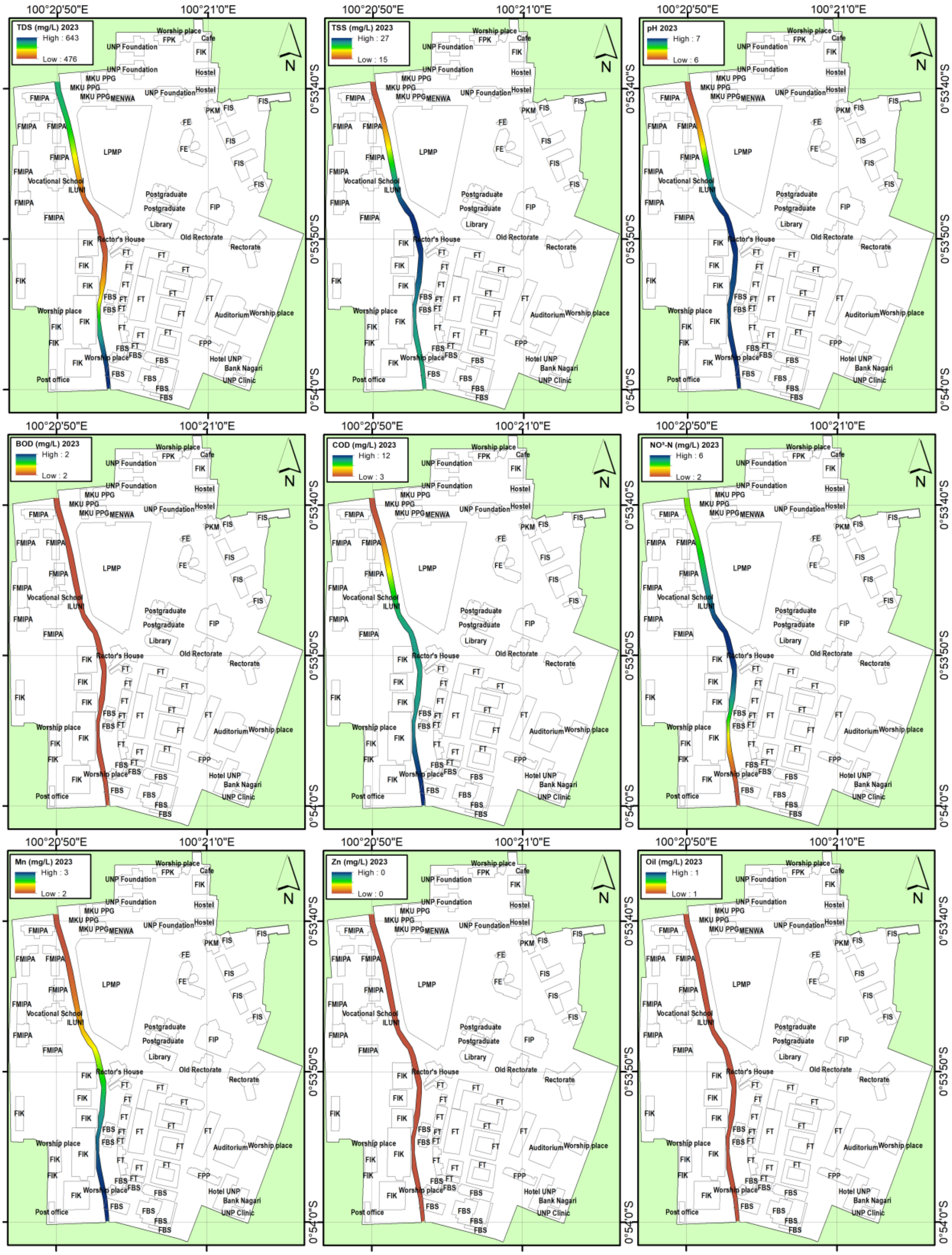

Fig. 5. Model of river water quality 2023 in the UNP area.

Inorganic waste, especially plastics (accounting for roughly 30% of daily waste), requires targeted intervention. A waste bank system is recommended to facilitate the sorting, collection, and sale of recyclable materials while fostering environmental awareness among students. Mwakalinga (2014) underscores the dual functionality of waste banks as recycling hubs and educational platforms, promoting long-term environmental stewardship.

Addressing water management, this study proposes an innovative recycling program to counter potential pollution risks in the campus river, particularly the rising nitrate concentrations downstream. The program incorporates sustainable, geography-sensitive technologies, such as natural biofilters using aquatic vegetation to remove pollutants and sediments. Additionally, rainwater harvesting systems are recommended to meet irrigation and sanitation needs, reducing reliance on external water sources and preserving the river's ecological balance.

In conclusion, the integrated waste and water management strategies proposed in this study present a comprehensive framework for sustainable campus management at UNP Air Tawar. Organic waste composting, plastic waste banks, and water recycling systems are key components of this approach, ensuring ecological resilience and advancing sustainability goals. These measures not only address immediate environmental challenges but also promote a culture of responsibility and environmental consciousness within the campus community.

3.2. Daily waste generation, quantity, and types of waste generated

Based on a seven-day sampling period, the UNP Air Tawar campus generates an average of approximately 3,026.34 Kg/day. As depicted in **Figure 6**, the distribution of waste generation across the week reveals significant variations. Monday records the highest volume of waste, peaking at 3,523.33 Kg. This elevated amount primarily results from the accumulation of uncollected waste from Sunday. Since Sundays are designated as public holidays with no waste collection services, the limited waste generated by reduced campus activities on that day is combined with Monday's waste management. This overlapping collection system leads to a substantial surge in waste volume at the beginning of the week. These findings underscore the critical need for optimized waste management systems on campus. The introduction of consistent waste collection schedules and the reorganization of temporary disposal sites would enhance waste handling efficiency. A structured and sustainable waste management framework would not only improve campus hygiene but also foster a more conducive environment for both students and staff.

Figure 5 highlights the results of waste sorting conducted during the study. The data reveal that organic waste, including food remnants and yard debris, constitutes the largest proportion of daily waste generated. This is followed by inorganic waste, with plastic packaging emerging as the predominant component within this category. Conversely, wooden waste accounts for the smallest fraction of the total waste volume. This clear classification of waste types underscores the necessity of implementing tailored management approaches to address the specific waste streams generated on campus. Waste management solutions must be adapted to the campus's physical and operational characteristics. For instance, implementing a composting program could substantially reduce the volume of organic waste while simultaneously enhancing the maintenance of green spaces within the campus. Similarly, establishing a waste bank system would provide a practical mechanism for managing inorganic waste, particularly plastic, by incentivizing recycling and reuse practices. These strategies not only mitigate immediate waste management challenges but also align with broader sustainability goals, promoting environmental stewardship among the campus community. **Figures 6** and **7** provide detailed visual representations of waste generation patterns and their implications for effective management strategies, offering a comprehensive basis for informed decision-making.

From the data presented in **Figure 6**, Monday exhibits the highest recorded waste volume, reaching 3,523.33 kg. This significant amount is attributed to the accumulation of waste from the weekend, particularly on Sunday, when waste collection services are suspended due to the holiday. However, as some students continue to engage in campus activities on Sundays, waste generation persists. The uncollected Sunday waste is then combined with Monday's waste, leading to a pronounced volume spike at the start of the week. To mitigate this issue, it is essential to reevaluate the weekend waste collection schedule or explore automated waste collection systems to operate during holidays, ensuring uninterrupted service. Additionally, increasing the frequency of waste collection on high-activity days can help prevent excessive waste buildup.

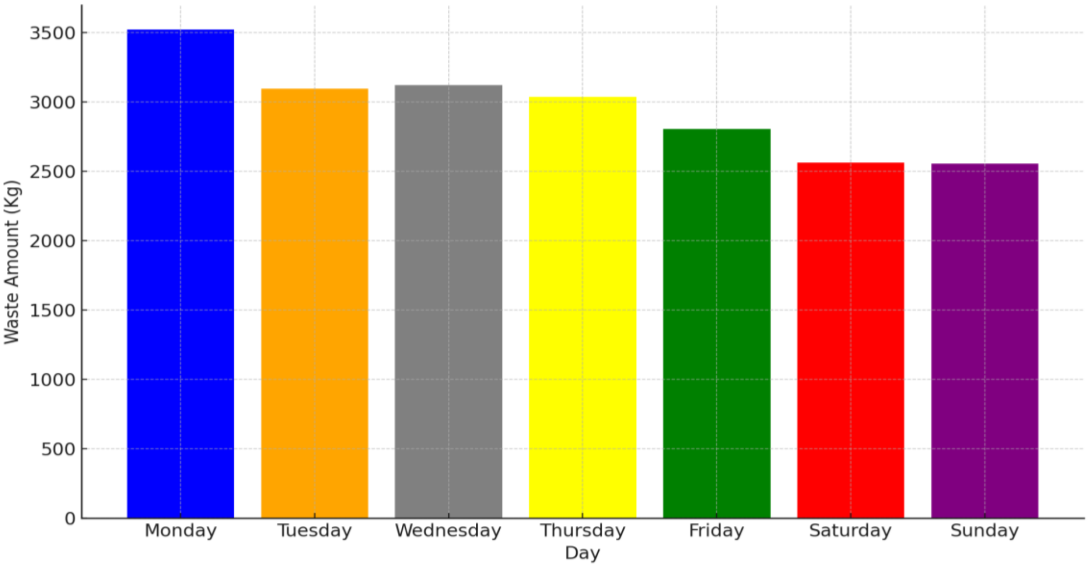

Fig. 6. Daily waste amount (Kg/day) at UNP Air Tawar campus.

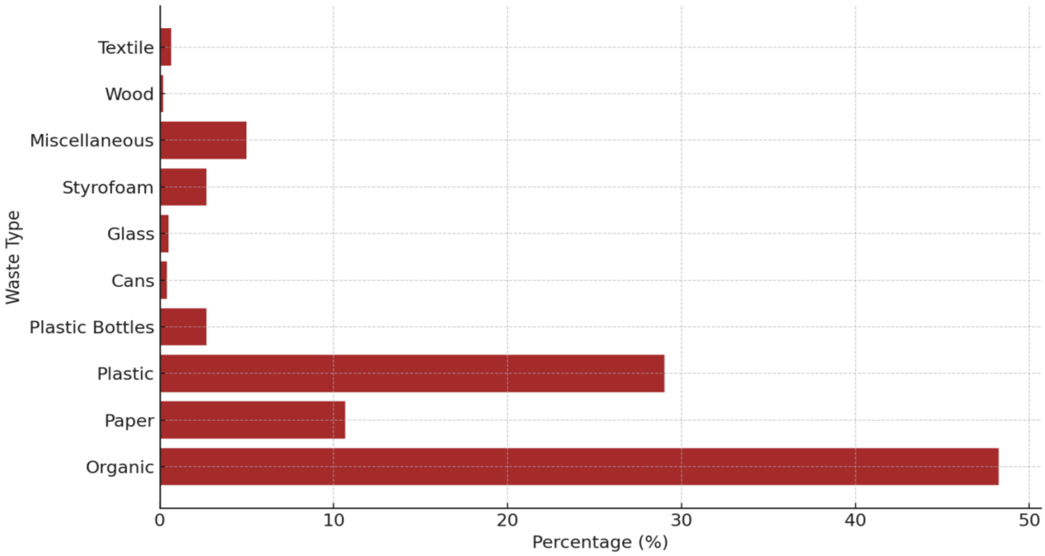

Fig. 7. Waste composition by Type (%) at UNP Air Tawar campus.

Figure 7 provides insights into the composition of campus waste, revealing that organic waste accounts for 48.24% of total daily waste. Plastic waste follows closely, contributing 29.02% to the total. These findings highlight the necessity of establishing a structured composting program. Composting can significantly reduce the organic waste volume, transforming nearly half of the daily waste into valuable compost for landscaping and campus greenery. A campus-wide composting initiative involving students and staff can promote a culture of environmental responsibility while enhancing the campus's aesthetic appeal.

In parallel, a waste bank system should be prioritized to manage inorganic waste, particularly plastics. With plastics constituting almost 30% of the waste, waste banks can act as collection, sorting, and recycling centers for recyclable materials. These programs can also serve as educational tools, fostering awareness about recycling and plastic waste reduction among students. Moreover, they can generate additional revenue to support campus operations or community-focused initiatives. For non-recyclable inorganic waste, small-scale technological solutions such as incinerators could be considered, provided they are equipped with proper emission control systems to minimize environmental impact. Sustainable waste management at the UNP Air Tawar campus requires a comprehensive approach that integrates education, awareness, and innovative utilization strategies. By reducing waste sent to landfills, the campus can create a cleaner, greener, and healthier environment.

Looking forward, waste management at UNP should adopt a circular economy framework based on the principles of Reduce, Reuse, Recycle, Repair, and Reject (5R). This approach ensures that all materials generated by the campus are reused or repurposed, effectively eliminating the concept of waste. In this framework, the waste bank can serve dual purposes: managing inorganic waste, including plastics and paper, while also distributing compost generated from organic waste. This dual role can enhance the economic value of organic waste and support both campus and community greening efforts. Further improvements in inorganic waste management can be achieved through advanced processing methods. For instance, separated plastic waste could be transformed into raw materials for recycling industries or converted into value-added products. Technologies like pyrolysis, which involves heating plastics in an oxygen-free environment to produce gas or fuel, could also be explored. Such initiatives would reduce the demand for new raw materials and conventional energy sources while aligning with broader sustainability goals.

Data collected over seven days reveal that the UNP Air Tawar campus generates an average of 3,026.34 kg of waste per day, with the highest volume recorded on Monday at 3,523.33 kg (**Figure 4**). According to Cointreau (2006), waste accumulation during non-working days can increase operational burdens during weekdays, emphasizing the need for robust waste management strategies. Routine waste transportation must be prioritized to prevent buildup, which poses health and environmental risks, especially in high-activity areas like campuses. Medina (2010) highlights that inadequate waste transportation systems exacerbate pollution risks, while Zaman & Lehmann (2011) argue that composting can reduce organic waste by up to 50% and provide organic fertilizer for greening initiatives. The optimization of the campus waste bank program is also crucial to effectively manage the 30% of daily waste composed of plastic. Mwakalinga (2014) identifies waste banks as not only collection points but also centers for educating communities on recycling and waste reduction. By minimizing plastic waste sent to landfills and raising environmental awareness among students, waste banks can contribute to sustainable waste management. Van Beukering & Bouman (2001) emphasize the role of continuous education in integrating environmentally friendly waste practices into educational institutions. As a living laboratory for sustainability principles, the campus can pioneer innovative waste management practices that promote a circular economy and environmental stewardship.

The waste management system at the UNP Air Tawar campus predominantly operates under a conventional collect-transport-dispose paradigm. Observations indicate that waste disposal bins are strategically placed across the campus to support waste management efforts. These bins, typically constructed from durable plastic materials, are categorized to accommodate specific waste types, including hazardous and toxic waste. This categorization system is intended to streamline the management and recycling of waste by aligning disposal practices with the unique characteristics of each waste type. While the presence of categorized bins reflects an effort to promote organized waste segregation, there remains significant room for improvement in the overall waste management system. For example, enhancing the design and accessibility of these bins could encourage higher compliance with proper waste disposal practices among campus users. Additionally, integrating advanced waste segregation technologies, such as sensor-enabled bins that automatically sort waste, could further optimize waste handling processes and reduce contamination of recyclable materials. Further details regarding the distribution and utilization of these bins, as well as their role in the campus's waste management system, are illustrated in **Figure 8** below.

Fig. 8. Waste disposal bins at UNP Air Tawar campus.

The transportation of waste from collection bins to the temporary disposal site at the UNP Air Tawar campus is conducted using three-wheeled bentor waste transport vehicles. Currently, the campus operates three bentor units for this purpose. Two of these vehicles are managed as assets by the Equipment Division under the General Affairs and Finance Bureau, while the third unit is owned and operated by PT. UNP Mandiri Berkarya, a campus-affiliated entity. Each bentor is assigned to specific zones within the campus to ensure equitable waste collection coverage across all areas. The temporary disposal site is located adjacent to the UNP twin dormitories. However, at the time of this study, its condition was found to be suboptimal. Significant piles of uncollected waste were observed at the site, awaiting transport to the final landfill in Air Dingin. These delays in waste transportation resulted in visible discomfort for campus users and heightened the risk of environmental pollution in the surrounding area. The uncollected waste not only emits foul odors but also has the potential to attract pests and contribute to the leaching of harmful substances into nearby soil and water resources.

Addressing these issues requires a more streamlined and efficient waste transportation schedule, alongside improvements in the management and maintenance of the temporary disposal site. Additionally, upgrading the temporary disposal site with proper containment structures and waste processing facilities, such as compaction or segregation units, would minimize its environmental impact. Details regarding the conditions of the transportation system and the temporary disposal site are presented in **Figures 9**, and **10** below.

Fig. 9. Current condition of the temporary disposal site at UNP Air Tawar campus.

Transportation of waste

Weighing of waste

Transportation of waste to landfill

Waste sorting

Fig. 10. The Process of waste collection, weighing, and sorting.

The waste management system at the UNP Air Tawar campus continues to rely on a traditional "collect-transport-dispose" approach. Observations reveal that waste disposal containers are strategically distributed across the campus, ensuring accessibility in multiple locations. These containers, primarily made of plastic, are categorized by waste type organic, inorganic, and hazardous and toxic waste to facilitate recycling and ensure safe handling of hazardous materials. According to Srinivasan et al. (2017), segregating waste at the source substantially improves management efficiency while minimizing environmental impacts. The types and placement of these containers are depicted in **Figure 8**. Waste collected from these containers is transported to a temporary disposal site using three-wheeled vehicles known as bentor. The campus operates three bentor units, two of which are managed by the General and Finance Bureau, while the third is operated by PT. UNP Mandiri Berkarya. Each bentor unit is assigned specific zones within the campus, ensuring comprehensive waste collection coverage. As Guerrero et al. (2013) note, an effective waste management system requires not only a robust transportation infrastructure but also a well-coordinated collection schedule to prevent inefficiencies.

However, the condition of the temporary disposal site during this study raised serious concerns. Uncollected waste had accumulated in significant quantities, causing discomfort for campus users and posing potential health and environmental risks. Hoornweg & Bhada-Tata (2012) assert that unmanaged waste piles can contribute to severe health hazards and environmental degradation, including soil and water contamination. Furthermore, Gomes et al. (2008) emphasize that limitations in transportation infrastructure, such as the low capacity of bentor vehicles, can hinder the overall efficiency of waste management operations. To address these challenges, several improvements are critical. First, upgrading the capacity and operational efficiency of the bentor units potentially through the introduction of larger or more technologically advanced vehicles could ensure timely waste transport. Second, increasing the frequency of waste transportation, especially during high-activity periods, would help prevent the temporary disposal site from becoming an unintended pollution hotspot. Finally, infrastructure enhancements at the temporary disposal site, such as proper containment, waste segregation, and processing facilities, could mitigate environmental hazards while supporting more sustainable waste management practices.

4. CONCLUSIONS

Based on the findings from a study on waste management and water quality at the UNP Air Tawar campus, several significant conclusions can be highlighted. Visually, the river traversing the campus exhibits turbidity, indicating sedimentation and potential sources of pollution. However, laboratory analyses confirm that most water quality parameters conform to the Class 2 Water Quality Standards. Despite this compliance, certain parameters warrant closer attention, such as the rising nitrate concentrations observed at downstream locations. This increase may trigger eutrophication, compromising aquatic ecosystems' stability and biodiversity. The notable reduction in TDS levels between 2015 and 2023 demonstrates a progressive improvement in water quality; however, consistent monitoring of dissolved solids remains essential for maintaining environmental equilibrium.

Furthermore, the declining trends in BOD and COD signify overall enhancements in the ecological health of the river system. Nevertheless, enhanced and sustainable water management practices are critical, particularly in mitigating domestic and agricultural waste pollution affecting downstream areas. GIS Kriging analysis further corroborates these findings by identifying spatial hotspots of pollution across the campus river system. The analysis reveals that sedimentation and TDS levels are concentrated near upstream discharge points, while nitrate and organic waste contamination intensify downstream, particularly near densely populated and agricultural areas. These spatial insights emphasize the need for localized interventions tailored to specific sources of pollution.

Presently, the campus operates under a traditional waste management paradigm that involves collecting, transporting, and disposing of waste. This approach is constrained by limited transportation infrastructure. The campus generates approximately 3,026.34 kg of waste daily, with the highest volumes recorded on Mondays due to the accumulation of weekend waste. Organic waste constitutes nearly 48% of this total, suggesting substantial potential for composting as a management solution. Inorganic waste, primarily plastics, accounts for approximately 30%, which can be effectively managed through waste bank initiatives.GIS-based spatial mapping also highlights inefficient waste disposal zones, where high volumes of unsegregated waste persist, particularly near food service areas and dormitories. This necessitates improved bin distribution and accessibility. To address these challenges, it is imperative to enhance the frequency of waste transportation and implement a structured waste management system.

Integrating campus-wide initiatives such as composting and recycling within a circular economy framework is essential. The adoption of the 5R principles (Refuse, Reduce, Reuse, Recycle, and Recover) offers a practical pathway to achieve sustainable waste management goals. GIS Kriging analysis suggests that implementing geographically tailored composting and recycling hubs at key waste generation points would significantly optimize resource utilization while reducing environmental impacts. These measures would not only optimize resource utilization but also ensure a systematic approach to minimizing environmental impacts.

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