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Evaluating landfill site operator competence and experience for sustainable waste management in the Upper Vaal Catchment Area

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Abstract

South Africa's solid waste management system is under increasing pressure from rising waste generation, limited municipal capacity and uneven operational performance at disposal facilities. Landfill sites remain necessary for residual waste disposal, but their environmental performance is closely linked to operator competence and experience. This study examined the education, work experience, training exposure and perceived capacity building needs of landfill site operators involved in sustainable waste management. A mixed-methods design combined structured questionnaire data with descriptive statistical analysis and qualitative content summarisation of open-ended responses. The personnel were predominantly male (87%), and the largest age group was 40–50 years (30%). Operator experience was moderate, with 35.5% of respondents reporting three to five years of service. Education and training were important indicators of competence: 48.8% had tertiary education and 71% attended waste management training. However, training duration was generally limited, with 39% having attended only one week courses and 32% having received no training. Training was mainly operational, with less attention paid to environmental law, landfill management, recycling and regulatory compliance. The study concludes that operator capacity is a key component of sustainable landfill site governance and that structured, accredited and continuous training is needed to align landfill site operations with environmental protection, circular economy objectives and regulatory requirements.

1. Introduction

South Africa's solid waste management system faces persistent challenges that affect sustainability objectives and service delivery. Waste generation continues to rise, while many municipalities operate with constrained technical and financial capacity [1, 2]. A substantial share of domestic waste remains outside formal collection and treatment systems, contributing to illegal dumping, pollution and unequal environmental burdens [2–4]. Recent South African studies show that poor monitoring, inadequate budget allocation, limited technical expertise and weak institutional coordination continue to impede the effective implementation of Integrated Waste Management Plans [1, 5]. These systemic and operational deficits create a gap between policy intent and practice.

Municipal waste governance is further complicated by rapid urbanisation and the growth of informal settlements. Limited access to waste collection services, poor infrastructure and population growth reduce service efficiency and increase uncollected waste and illegal dumping [2]. Comparable patterns are reported in other developing regions, where weak source separation, insufficient recycling infrastructure and heavy dependence on landfilling remain common challenges [2, 6, 7]. These conditions show that operator competence must be understood within a broader system of municipal capacity, infrastructure and policy implementation.

Globally, municipal solid waste systems are under pressure from urbanisation, consumption growth and climate change [7]. Poorly managed disposal systems contribute to pollution, greenhouse gas emissions and public-health risks, while waste generation is rising faster than many cities can manage [8]. This

global evidence is relevant to South Africa because many municipalities still rely heavily on landfilling, while diversion, recycling and resource-recovery systems remain uneven [1, 7]. Operator competence is therefore both a local operational issue and part of the international transition towards safer, lower-emission and more circular waste systems.

Recent research highlights the need for robust operational management and technically informed decision-making in sustainable landfill site management. In a European landfill efficiency study, Lair et al. [9] show that improved operational practices, gas management and policy alignment can contribute to greenhouse gas reduction. Evidence from Zimbabwe similarly indicates that safety, health and environmental quality systems depend on competent personnel to reduce operational and environmental risks [10]. These findings are relevant to South Africa, where operator training, site discipline and environmental compliance remain central to landfill site performance.

The changing role of landfill sites also requires operators to understand resource recovery and post-closure sustainability. Li and Liu [11] show that closed landfill sites can be transformed into sustainable public spaces when rehabilitation and long-term environmental management are integrated into planning. Kafle et al. (2025) further argue that municipal solid waste management should increasingly support valorisation pathways such as recycling, recovery and resource efficiency. Landfill site operators therefore require competencies that extend beyond routine disposal to include waste diversion, site rehabilitation, environmental monitoring, and circular economy principles.

Capacity building is therefore central to sustainable waste management. International training frameworks increasingly emphasize role-based competence, evidence of training, refresher learning, and practical assessment for waste resource personnel [12]. In South Africa, the need for structured training is reinforced by evidence that municipalities face financial, technical, and institutional barriers to effective waste-management planning [5]. This study responds to that need by examining whether landfill site operators possess the education, experience and training exposure required to support sustainable landfill site governance.

Landfill sites remain important components of integrated waste management systems because they provide the final disposal point for residual waste that cannot be recycled, composted or otherwise recovered [7]. When properly managed, landfill sites provide controlled containment that reduces the risk of soil contamination, groundwater pollution, methane emissions and other environmental harms [4, 7]. Modern landfill sites may include liners, leachate treatment, gas capture and post-closure rehabilitation, all of which require competent daily operation and monitoring [9, 11].

The role of landfill site operators has expanded beyond basic waste placement. Operators are expected to receive and categorise waste, manage working faces, apply daily cover, operate heavy equipment safely, identify unauthorized waste streams, support recycling or recovery where available, and respond to risks such as fires, odours, leachate and gas emissions [12]. These responsibilities are directly linked to regulatory compliance and environmental protection. Recent work on landfill efficiency and SHEQ

systems confirms the importance of trained and experienced personnel for effective landfill site operation [9, 10].

Operator competence is particularly important in South Africa because municipal landfill sites often operate under constrained financial and technical conditions. Where staff have limited training in environmental law, landfill engineering, waste classification and monitoring, the risk of non-compliance increases. Conversely, operators with adequate education, training and experience are better positioned to implement licence conditions, maintain site standards and recognise emerging environmental risks. Unlike much of the recent literature, which has focused on municipal systems, technology or environmental impacts, this study provides an operator-level assessment of landfill site competence and training needs in a South African context [4, 5, 16]. Its contribution is to connect employees capacity with sustainable landfill site governance and to identify where training pathways need to be strengthened.

This study is a useful addition to Discover Sustainability's emphasis on working towards Sustainability governance as it gives an operator level assessment of the competence of landfill sites in the Upper Vaal Catchment Area. It relates education, work experience, course duration, training priorities to regulatory compliance, environmental protection, circular economy practice and measurable landfill governance capacity instead of considering landfill sustainability as a technical infrastructure or pollution problem alone.

2. Materials and methods

2.1 Research design

Mixed-methods research design was used because landfill site operator competence required both numerical description and contextual explanation. Quantitative data were used to summarize demographic profile, working experience, education level, training attendance, course duration and training needs. Qualitative responses were used to explain why particular training areas were considered useful for improving landfill site standards. Mixed-methods designs are appropriate where structured results need to be supported by respondents' explanations and practical field context [13].

2.2 Study population and sampling

The Upper Vaal Catchment Area was chosen because it encompasses municipalities where the keeping of landfill sites, waste disposal and water-resource protection intersect. Where the name and operation of the sites was sensitive, the study centered on staff from accessible municipal landfill sites and did not identify sites, to protect the municipal staff and site operational information.

The study population included landfill site operators and employees who directly work with municipal landfill sites and waste management. The 31 respondents selected for the study were those having hands on experience in the activities at the landfill site and were able to provide relevant information about their work experience, education, training history and capacity building needs through purposive

sampling. The sample size was small and not designed to be nationally representative, but rather to be adequate for an exploratory mixed method study to describe the competence profile of practitioners in accessible municipal landfill sites [13].

2.3 Data collection instrument

Data were collected using a structured questionnaire that captured demographic information, work experience, education level, attendance of waste-management training, duration of courses attended, types of courses completed and training needs identified by respondents. The questionnaire included both closed-ended items, which generated frequency and percentage summaries, and open-ended items, which allowed respondents to explain how training could improve landfill site standards. This structure enabled the study to link operator background characteristics with perceived capacity-building needs.

2.4 Data analysis

Descriptive statistics were used to analyse quantitative data. Each answer category was counted, and percentages were calculated and displayed on tables and graphs. This was chosen since the study was intended to describe the profile and training exposure of landfill site operators rather than to test causal relationships. Qualitative content summarization was used for open-ended responses. Responses were collated and summarised under common themes, including environmental management, landfill site operations, uncertainty over training requirements, environmental law and recycling. The qualitative methods literature in the last few years has also confirmed the utility of manual content analysis in situations where meaning must be extracted and grouped by human interpretation from text-based responses [14, 15]. To examine the internal consistency of the closed-ended questionnaire details, the Cronbach's alpha was used ($\alpha = 0.76$), which was acceptable for an exploratory questionnaire. This questionnaire was pre-tested with five landfill-site supervisors and modifications were made because of the comments.

2.5 Ethical considerations

The study involved adult professional respondents and operational information related to landfill site management. Participation was from participants that gave and agreed to the informed consent, and this was voluntary and responses were reported in aggregate form to avoid identifying individual respondents or specific employees. The study was approved by the University of the Free State Research Ethics Committee (UFS-HSD2018/0123/2711). The study was approved for ethics in 2018 and was registered as a longitudinal programme of research data collection that was undertaken between 2022 and 2024, in line with the scope and timeframe of the original clearance. No photograph containing identifiable individuals was used. All data collection were performed in accordance with relevant guidelines and regulations as approved by University of Free State Research Ethics Committee.

3. Results and discussion

3.1 Demographic profile and work experience

The demographic profile showed that the respondents were predominantly male, with males accounting for 87% and females 13%. The largest age category was 40–50 years, representing 30% of respondents. Regarding work experience, 35.5% of respondents had three to five years of service, while the remaining respondents had shorter or other periods of experience. This mixed profile suggests that the landfill site employees included both moderately experienced and relatively new operators.

The dominance of male respondents is consistent with the practical and machinery oriented nature of many landfill site operations, but it also points to the need for more inclusive employee development. International training frameworks increasingly treat landfill operation as a professional competence area requiring formal learning, documentation and periodic refresher training rather than only physical site experience [12]. Gender, age and experience should therefore be considered when designing capacity building programmes for landfill site workers.

Table 1
Descriptive summary of demographic and experience profile (n = 31)

Indicator	Frequency (n)	Percentage (%)	Interpretation
Male respondents	27	87.0	Workforce dominated by men.
Female respondents	4	13.0	Low representation of women.
Largest age group: 40–50 years	9	30.0	Mid-career operators formed the largest age category.
Three to five years of experience	11	35.5	Moderate operational experience among a large group of respondents.
Note: Frequencies were rounded from the reported percentages where necessary.			

3.2 Education, training and operator competence

Education was important in understanding operator competence. Nearly half of respondents (48.8%) had tertiary qualifications, while 16.1% had secondary schooling and 16.1% had matric. Only 6.4% had primary education or no formal education. In addition, 71% had attended waste management training, while 29% had not attended any additional training. Although most respondents had some exposure to training, its duration was generally limited: 39% had attended one-week courses, 32% had received no training, 3% had attended training lasting from one month to one year and 7% had attended training for more than one year.

These results indicate a foundation of education and training, but uneven training depth. International practice increasingly requires competency-based landfill site and waste resource qualifications that include role-based assessment and refresher learning [12]. European landfill efficiency research further shows that environmental performance depends on operational knowledge of gas capture, site

management, diversion and monitoring [9]. Short courses may improve basic awareness, but sustained and accredited training is needed to support more complex landfill site governance.

Table 2
Education and training profile of landfill operators (n = 31)

Indicator	Frequency (n)	Percentage (%)	Interpretation
Tertiary qualification	15	48.8	Indicates a useful education base for technical training.
Secondary school qualification	5	16.1	Shows need for foundational and practical training.
Matric qualification	5	16.1	Provides basic entry-level education for further training.
Primary or no education	2	6.4	Requires targeted foundational support.
Attended waste-management training	22	71.0	Most respondents had some exposure to training.
No additional waste training	9	29.0	A notable training gap remains.
One-week training duration	12	39.0	Training was often short-term.

Note: Percentages are reported as presented in the study and rounded to one decimal point where applicable.

3.3 Courses attended and capacity-building priorities

Operational courses were the focus of training, as indicated in the types of courses attended by the respondents. The most common categories of courses were environmental management (16.1%), environmental law (9.7%) and landfill site management (9.7%) and waste handling (9.7%). Other training areas covered waste management (National Qualification Framework Level 4), waste groups, recycling and handling, storage and transportation of waste. The findings indicate that respondents' experience is with practical waste functions, and relative experiences with strategic and regulatory functions like environmental law, landfill site management and recycling [12] are comparatively low.

Respondents agreed that training would contribute to the standards at landfill sites. 40% said that environmental management training would enhance knowledge and standards at the landfill sites, and 30% said that landfill site operation training would help them to get new ideas and increase efficiency. Twenty per cent of employees were not sure of the courses that would be beneficial and this indicates that some employees require guidance on suitable professional development courses. Five per cent saw environmental law as useful area, as did 5 per cent with recycling and waste classification. This is consistent with other research from Zimbabwe and international landfill site practice that has found that

sustainable landfill site management needs to include safety systems, knowledge of the operation and environmental monitoring and compliance capacity (Chimuka, Mukwada and Kaseke, 2024; Lair et al., 2024).

Table 3
Types of courses attended by respondents

Course type	Percentage (%)
No course	32.3
Environmental management	16.1
Environmental law	9.7
Landfill management	9.7
Waste handling	9.7
Waste management	6.5
National qualifications framework level 4	6.5
Waste group	3.2
Recycling	3.2
Handling, storage and transportation of waste	3.2

Table 4
Training priorities identified by respondents

Requested training area	Percentage (%)	Capacity-building implication
Environmental management	40	Improve knowledge, compliance awareness, and landfill standards.
Landfill operations	30	Improve operational efficiency and introduce innovative ideas.
Unsure / did not know	20	Shows the need for structured career guidance and training pathways.
Environmental law, recycling and waste classification	5	Strengthen regulatory and resource-recovery competence.
Other / unspecified	5	Additional site-specific needs may require assessment.

3.4 Comparison with recent studies

The findings compare with recent South African studies showing that waste management performance is shaped by capacity, training, governance and institutional support. Mukwevho, Radzuma and Roos [5]

found that limited capacity and weak stakeholder coordination obstruct the implementation of Integrated Waste Management Plans in South African municipalities. Similarly, Kalina and Schenck [17] argue that municipal waste management challenges remain deeply rooted in uneven service delivery, resource constraints and governance gaps. The current study adds an operator level perspective by showing that even where staff have some training, the short duration and narrow focus of such training may limit practical sustainability outcomes.

International evidence also supports the need for advanced operator competence. Lair et al. [9] show that improved landfill site efficiency and greenhouse gas reduction require operational knowledge, policy alignment and effective site practices. Li and Liu [11] demonstrate that landfill site management should also consider long-term post-closure transformation and sustainable land reuse. These studies suggest that South African landfill site operators need broader training that includes landfill site engineering, environmental law, gas and leachate management, recycling, circular economy, monitoring, reporting and post-closure planning.

When compared with recent African evidence, the limited duration of training in the present study is a noteworthy concern. Nyathi [2] shows that informal settlements across Harare, Soweto, Cairo, Lagos, Accra and Kinshasa continue to experience poor waste collection, inadequate infrastructure and environmental health risks, partly because waste systems are not supported by sufficient technical and institutional capacity. This supports the present finding that landfill site operators require more than short operational exposure; they need continuous training that connects landfill site operations to public health protection, community safety and environmental governance.

The results are also compared with recent research on communities living near landfill sites. Gumede and Gumede [4] found that residents near a Durban landfill site perceived poor air quality and associated health risks as major concerns. This is important because operator competence directly affects daily cover application, litter control, fire prevention, odour management and gas awareness. Inadequate operator training may therefore increase not only regulatory non-compliance but also the everyday environmental burden experienced by nearby communities [4].

Internationally, landfill site and waste management practice is increasingly moving towards digital monitoring, traceability and evidence based decision making. Almelhem et al. [16] show that Industry 4.0 technologies, including digital tracking, data analytics and smart waste-collection systems, can support more efficient and sustainable reverse waste flows when combined with appropriate governance and stakeholder participation. For landfill site operators, this means that future competence should include basic digital literacy, waste-data recording, environmental reporting and the ability to use monitoring information for operational decisions [16].

The finding that some respondents were unsure which training courses would improve their competence is also important. It suggests that capacity building should not be left to individual choice only. Instead, municipalities and environmental authorities should develop structured training pathways that move from basic waste handling to advanced modules in environmental law, landfill operations, leachate and

gas management, occupational safety, recycling and circular economy practices [12]. This approach is consistent with international competency frameworks, which emphasize role-based training, documented assessment and refresher learning for waste-resource personnel [12].

3.5 Study limitations and practical implications

The study is exploratory and descriptive, and has a limited sample size of 31 respondents, the results should not be generalized as representing all landfill site operators in South Africa. Self reported training histories were used in part and audited landfill site performance outcomes (daily cover application, leachate control, gas management, fire incidents and compliance records) were not measured. This means that this study cannot conclude a causal relationship between operator competence and landfill site performance. It does, however, offer a valuable reference point to municipalities and regulators, as it highlights areas of training need which can be met through a structured programme of capacity building. Larger samples and correlating operator education, training and experience with measured indicators of site performance should be employed in future studies; inferential analysis should be used where suitable.

The practical implication is that operator training should not be considered as a non-formal, personnel problem but rather as a measurable part of landfill site governance. The results can help municipalities prioritise competency based training in environmental law, daily operation of the landfill site, management of leachate/gas; recycling; data reporting and digital records; as well as help regulators evaluate the operational readiness and need for support in complying with environmental laws.

4. Conclusion

The demographic profile shows that landfill site operators were predominantly male and mainly in the 40-50-year age group, with a moderate level of experience. This profile has implications for employee development because training programmes need to support both experienced and less experienced employees.

Education and training were important factors shaping operator competence. Nearly half of respondents had tertiary qualifications and most had attended some form of waste management training. However, training duration was often short, and key areas such as environmental law, landfill management, recycling and strategic sustainability received limited attention. This gap matters because sustainable landfill site management requires more than routine waste handling; it also requires regulatory knowledge, environmental monitoring, site control and resource-recovery competence.

The study concludes that structured, accredited and continuous training is necessary to strengthen landfill site operator competence in South Africa. Municipalities, environmental authorities and training institutions should develop role-based training pathways that combine practical landfill site operations, environmental law, equipment safety, leachate and gas control, recycling, data reporting and circular

economy principles. Such training would improve compliance, reduce environmental risk and align landfill operations with national and global sustainability goals [7, 12].

Compared with recent international literature, the findings show that landfill site operator competence should be treated as a core element of sustainable waste governance. Studies from Europe, Africa and Asia indicate that landfill site performance depends on the interaction between trained personnel, effective site systems, data-based monitoring, circular economy planning and regulatory enforcement [6, 7, 9]. The South African findings therefore reflect a broader global pattern: infrastructure alone is insufficient if operators do not have the knowledge and confidence to implement daily environmental controls.

Future operator training should be competency-based and continuous rather than limited to short once-off courses. Training should include formal assessment, refresher learning, practical site demonstrations and documentation of competence. This is consistent with recent waste-management training and technology literature, which shows that modern waste systems require operators who can combine practical machinery skills with environmental compliance, data handling and sustainability thinking [12, 16].

Future research should relate the operator competence with the measurable outcomes at the landfill sites, like application of daily cover, leachate control, gas management, fire incidents, waste recycling results, accuracy of waste records and community complaints. This would provide a greater scientific underpinning for municipal training programmes and enable the effectiveness of workers development in improving environmental performance in practice to be assessed. The findings of the present study must be interpreted at this time as an exploratory evaluation of operator competence and training needs, and not an indication that training is an effective way to improve the performance of landfill sites, until evidence is provided.

Declarations

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Author contributions

Malise Noe: conceptualisation, fieldwork, data collection and preparation of the initial draft.

Hester Roberts: methodological guidance and supervision.

Karabo Shale: oversight, manuscript revision and corresponding-author responsibilities. Machete Machete: manuscript review and academic guidance.

Ethical declaration

The study was approved by the University of the Free State Research Ethics Committee (UFS-HSD2018/0123/2711). Ethics approval was granted in 2018 as part of a longitudinal programme of research; data collection took place between 2022 and 2024, within the approved scope and timeframe of the original clearance. The research involved professional municipal respondents and did not include medical, clinical, or experimental human-subject research. Participation was from participants that gave and agreed to the informed consent, and this was voluntary and responses were reported in aggregate form to avoid identifying individual respondents or specific employees. All data collection were performed in accordance with relevant guidelines and regulations as approved by University of Free State Research Ethics Committee.

Consent participation declaration

The municipal representatives who completed the questionnaire and accompanied the researcher during field visits were informed about the purpose of the study and provided consent to participate.

Consent to publish declaration

Not applicable.

Declaration of conflicting interest

Not applicable.

Funding Declaration

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Data availability

The data underpinning the findings is not publicly available as it contains information at the municipal site level regarding operation.

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Figures

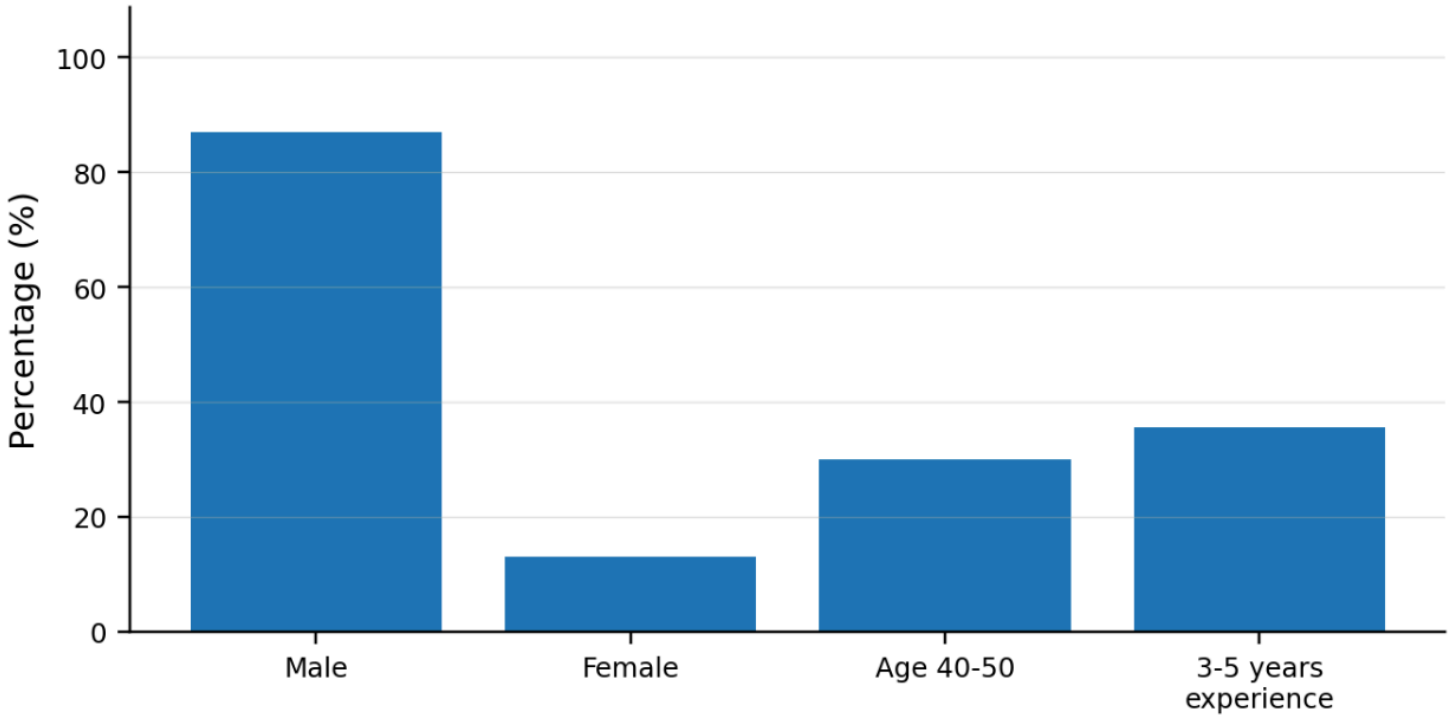


Figure 1

Demographic and experience profile of landfill operators

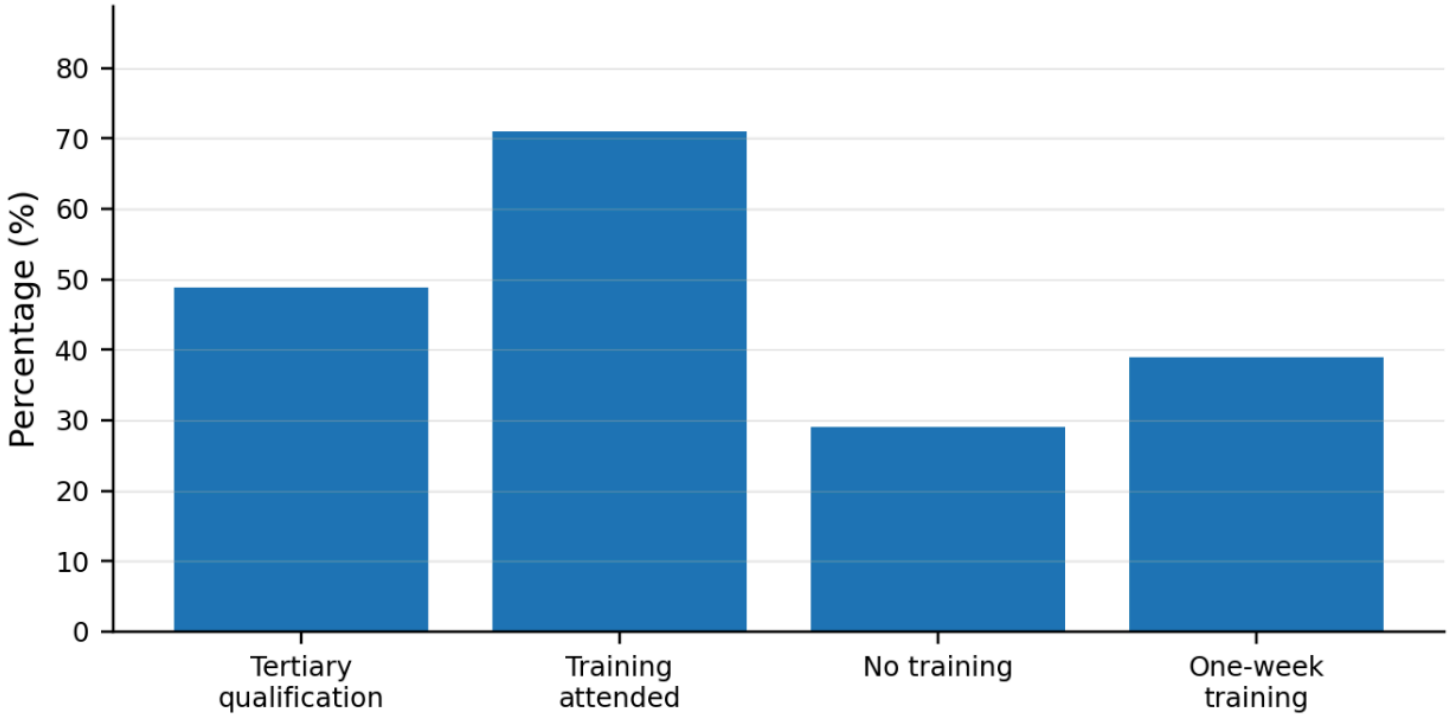


Figure 2

Education and training profile of respondents

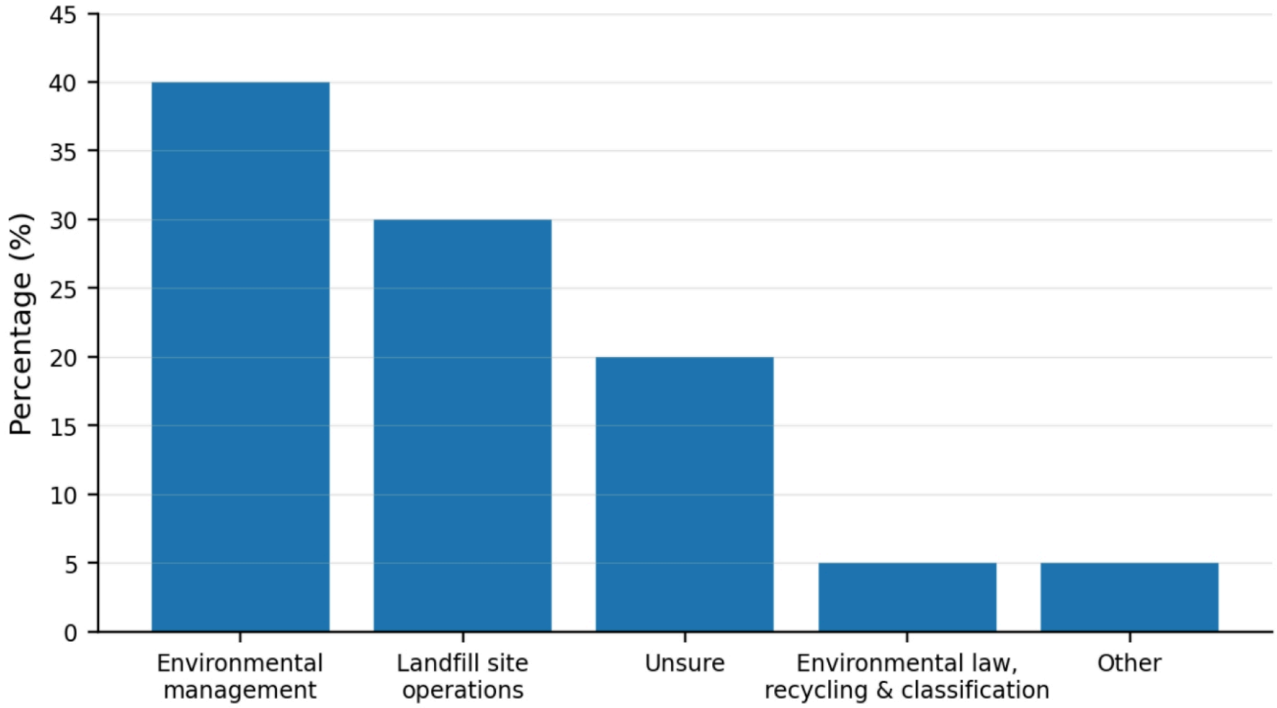


Figure 3

Training priorities identified by respondents