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Formalizing the Informal Longitudinal Analysis of Socio Technical and Behavioural Sustainability of the Nitte Gram Panchayat Material Recovery Facility Model

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Abstract

This paper discusses socio-technical and behavioural sustainability of the Material Recovery Facility (MRF) model adopted in the Nitte Gram Panchayat, Karnataka, based on longitudinal and mixed-method approach. The study will evaluate operational efficiency, behavioural change in waste management practices and overall economic and social effects of a decentralized waste management system. Structured survey was used to gather primary data on 73 households and interviews, focus group discussions and field observations were used to gather both quantitative trend and qualitative information. Results show significant gains in the main solid waste management indicators in three implementation stages. There was a greater household waste segregation, as well as coverage of almost all households by collection and increased compliance on user fees. The participation in education and awareness became the determinants of behavioural change [7]. The model also proved to be economically viable by recovering costs and creating significant social impacts such as creating more jobs and involving more women via self-help groups. The paper reaffirms the importance of community involvement, institutional trust, and local governance in maintaining the decentralized systems [2, 16, 22]. Overall, the Nitte MRF model offers a good argument that community-based, integrated models can be effective in terms of environmental performance, financial viability and social inclusion in the scenario of rural waste management.

Objective

In rural regions of India, there are many challenges to managing solid waste in rural India [4], particularly regarding regular collection of waste and proper segregation at the household level. Although there are national programs like the Swachh Bharat Mission that promote decentralized systems of waste management at the Panchayat level, there is little empirical evidence regarding how these systems operate in rural settings [6, 16, 19]. This dataset was generated on the functioning of the Nitte Gram Panchayat Material Recovery Facility (MRF) in Udupi district (Karnataka - India) that operates via a public-private partnership model [18, 24, 25] and processes dry waste collected from surrounding Panchayats.

The dataset's primary goal is to account for operational and behavioral shifts resulting from the implementation of the Material Recovery Facility (MRF). Research methods include conducting surveys of households, interviews with various stakeholders and focus group discussions. This dataset creates opportunities for research into waste segregation behavior, collection coverage, user fee compliance and community awareness levels [10, 17, 22]. In addition, this dataset documents the role of panchayat leadership and women's self-help groups [14, 23] in the management of decentralized waste management systems. The dataset provides a foundation for continued research into rural waste governance, behavior change and the economic viability of community based recycling systems [9].

Data Description

The primary data for this study collected between January and March 2025 used quantitative and qualitative approaches. Quantitative data was collected using a structured questionnaire to measure the segregation of solid waste as a percentage of wet waste, dry waste, and rejected waste, the coverage of collection, as measured by accessibility of collection to households and the compliance to payment of a fee for service provision and to develop knowledge, attitude and practice indices about segregation. All of which were measured on 5- point Likert scales (knowledge, impact of waste; attitude, social norms and locus of control; practice, routine). The questionnaire was pre-tested with 10 households to ensure that the questions were clear and valid; the data was digitised to reduce data entry errors. The qualitative data was collected by semi-structured interviews (30–45 minutes) that were audio-

recorded, verbatim transcribed and translated, to explore enablers of and barriers to segregation of waste; via focus group discussions (60–90 minutes), to elicit group norms from participants; and through non-participant observations (20 occasions) using checklists to observe the degree of segregation of waste, the use of personal protective equipment, the efficiency of waste collection and the interaction of the community with collectors at the time of waste collection and at material recovery facilities. Secondary data sources included panchayat solid waste management reports, the Swachh Bharat Mission 2.0 guidelines [15], the Solid Waste (Management) Rules (2016), regulatory frameworks on waste management [8], and census data. Ethical consent for the collection of data was obtained from the appropriate institution; participants were assured anonymity through the International Council for Medical Research guidelines.

Data Type	Instrument	Sample	Key Measures	Reliability/Validity
Quantitative	Structured survey	73 households	Segregation (%), coverage (%), fees (%), KAP Likert	Cronbach α > 0.75; pilot-tested
Qualitative	Interviews (12)	Officials/SHGs/workers	Behavioral drivers, governance	Triangulated; verbatim
Qualitative	FGDs (4)	Workers/SHGs/residents/youth	Norms, inclusion	6–8 pp/group; thematic
Observational	Checklists	Collections/MRF	Practices/PPE/efficiency	Structured; n = 20

Data Analysis

Quantitative (R 4.3.2)

R software (version 4.3.2) was used to analyse the quantitative data. The key solid waste management indicators such as household waste segregation, coverage of collection, and compliance with user fees in various stages of implementation were summarised through descriptive statistics. Inferential statistical methods like correlation analysis and repeated-measures ANOVA were used to test the relationships between socio-demographic variables and behavioural outcomes, and to test changes over time. Cost-benefit approach was taken to consider the economic feasibility of the MRF model [14]. This involved an estimation of the operation costs (including labour, training and personal protective equipment) and the comparison with the revenue streams through the user fees and sale of recyclables. The fixed assets were recorded by the application of the conventional depreciation techniques to show the decreasing worth of the assets over time. All statistical tests were done at the right significance levels.

Qualitative (NVivo 14)

The coding from the transcripts yielded some common themes, such as "leadership," "trust," and "regular treatment [2, 22]." The use of word clouds or frequency trees highlighted particular words as appearing more often (waste, plastic, health); the use of converged triangulation allows for quantifying data (e.g., 81% segreg bag/health pick up and place narrative). These findings also support technological optimization approaches in solid waste systems [11].

Integration

Combined findings through joint displays (i.e., predictors of education + the theme of "awareness"). Meta-inferences tested Arfaee's factors [1] rural groups; tech has the greatest coverage gains.

Table 3
Key Analytical Elements

(Adapted from Arfaee SEM)

Element	Quantitative	Qualitative	Triangulation
Factors	CFA analogs (KAP, compliance)	Thematic (NVivo nodes)	Convergent (e.g., education→awareness)
Model Fit	ANOVA/Regression ($p < 0.001$, R^2)	Saturation (themes)	Joint displays
Software	R (stats), Excel (CBA)	NVivo (coding)	Excel matrices

Reliability and Validity

Survey pilot (n = 10) verified content validity; internal consistency $\alpha > 0.75$ for KAP/service scales. Inter-rater coded observations ($\kappa > 0.80$); member-checking validated transcripts. Triangulation reduced biases; purposive sampling increased transferability. Researcher positionality monitored using reflexivity journal.

Results

Phase 1: Quantitative Analysis

Respondent Profile

Respondents to the survey (n = 73) were an average of 44.8 years old (range 18–68 years), with the majority (38.4%) being aged 31–45 years. Respondents had completed secondary/higher secondary education (majority) or graduated (significant proportion). Most respondents were homemakers, followed by government employees and other informal occupations Outside the home, households ranged from 1 to 8 people, with the majority (4–8) being medium to large size. See Table 1 for detailed socio-demographics.

Table 1
Socio-Demographic Profile

Age Category	n	%
18–30	12	16.4
31–45	28	38.4
46–60	23	31.5
> 60	10	13.7

Behavioral Outcomes: SWM Indicators

There was an increase in segregation compliance over time: 18% compliance pre MRF, 45% transition, 81% post. Coverage for collection services increased from 52% to 98% (nearly all of the citizens), and payment of service fees grew from 28% to 84%. The average segregation index across all subjects was 73.5, and the post intervention data had low variability, indicating that segregation has become the norm. The trends are visually depicted in Table 2 and Fig. 1.

Table 2
SWM Indicators by Phase

Indicator	Pre	Transition	Post
Segregation %	18	45	81
Coverage %	52	-	98
Fees %	28	-	84
Segregation Score	-	-	73.5

Scale Reliability

The KAP, service satisfaction, and challenge scales all had high internal reliability (Cronbach's α > 0.75 for all), which supports the validity of our inferential analyses. See Table 3 for details.

Table 3
Reliability Measures

Scale	Cronbach's α
KAP	0.82
Service Satisfaction	0.78
Challenges	0.76

Socio-Demographic Predictors

For education, we found a positive correlation with both segregation ($r = 0.42$, $p < 0.01$) and fees ($r = 0.35$, $p < 0.05$). There was no correlation of significance observed for age/gender ($p > 0.05$). There was a weak correlation of income to fees.

Table 4
Socio-Demographic Correlations

Variable	Segregation	Fees
Education	0.42**	0.35*
Age	0.12	0.08
Gender	0.05	0.03
Income	0.18	0.22
*p < 0.05, **p < 0.01		

Time-Based Changes (ANOVA)

The repeated-measures ANOVA found significant improvements across all indicators ($p < 0.001$), with the largest gains shown pre→post in the post hoc tests. See Table 5 for the results.

Table 5
ANOVA Results

Indicator	F	p
Segregation	45.2	< 0.001
Coverage	62.1	< 0.001
Fees	38.7	< 0.001

Awareness Impact (Chi-Square)

Awareness of participation was a strong predictor of both segregation (χ^2=12.4, $p < 0.05$) and fees (χ^2=9.8, $p < 0.05$). To compare segregation levels among participants, 90% of participants had higher levels than 60% of non-participants.

Phase 2: Qualitative Themes (NVivo)

By using thematic analysis, five clusters emerged, such as operational efficiency, community engagement, health/environmental awareness, institutional trust and labor dignity [2, 3, 23]. The dominant terms were waste, plastic, health, collection, system, and respect. The narratives focused on formalizing dumping and giving credit for Panchayat leadership and SHG mobilization to replace informal dumping. Similar performance and challenges of decentralized waste systems have also been reported in earlier studies [12].

Economic & Social Outcomes

The increase in the number of jobs increased from 8 to 41 (4.1x increase), and the number of women in the workforce increased from 10% to 45% because of the formalization of SHGs [14, 22]. There was an increase in fee compliance (84%), and sales of recyclables allowed for revenue neutrality.

Summary of Key Findings

Three phases (before intervention/transition/after maturity 2023–2025) were systematically tracked over time for the Material Recovery Facility (MRF) of Nitte Gram Panchayat. The evaluation shows a sustained improvement in household segregation compliance (increased from 18% to 45% to 81%), as well as the near-universal collection coverage (98%), and the Revenue Neutralisation of Operations (84% of residents who paid fees). There is statistical significance between the three phases ($F = 45.2$; $p < 0.001$) according to repeated measures ANOVA. Education ($r = 0.42$; $p < 0.01$), and participation in awareness (X^2; $p < 0.05$) were two significant contributing factors to this statistical significance. Workforce formalisation/further formalisation resulted in the generation of 41 new jobs (an increase of 33 jobs) and an increase in female employment from 10% to 45% via Self-Help Group (SHG) integration. Overall MRF operation demonstrates comprehensive environmental, economic, and social sustainability with demonstrated stability over time.

Theoretical and Applied Contributions

As a longitudinal study, this study provides the first rural validation of integrated socio-technical frameworks [1, 5] through the Quantification of service reliability as behavioral infrastructure which mediates cognitive intent to sustained practice (KAP score 73.5, $\alpha > 0.75$ maintained throughout all phases). The temporal triangulation (phase-wise quantitative metrics, plus NVivo thematic progression) confirms the durability of the intervention absent in cross-sectional pilots. The case provides evidence for potential recovery of operational costs under high fee

compliance combined with stable recyclable market conditions [13, 24, 25]. Policy considerations relative to the results of this case study include standardized benchmarks for MRF capacity, formal mechanisms for inclusion of SHG workforce, and digital monitoring frameworks for compliance.

Limitations

1. 1. The Nitte Gram Panchayat was the only location where the study was done; therefore these results may not be generalizable to other rural areas or locations.
2. 2. Limited number of interviews and focus group sessions may not capture the full range of perspectives present in the community.
3. 3. Survey respondents only self-reported their answers to the questions in the survey. Therefore there may be bias due to self-reporting. Similar peri-rural waste behaviour trends have been observed in Karnataka-based studies [26].
4. 4. All of the data was collected over a short amount of time between the year 2025 so the data are not representative of long-term behaviour changes.

Recommendations for Future Research

Future studies need to include three strategic expansions that build on this longitudinal framework.

- **Comparative Multi-Site Longitudinal Studies**: Use temporal depth and concurrent comparisons of matched MRF interventions across distinct agro-climatic contexts [19, 20] (e.g., dry Rajasthan and coastal Andhra) to identify contextual scalability moderators.
- **Causal Pathway Modeling with Time Lags**: Apply structural equation models that include a temporal sequence of events [17]: investments in technologies (Year 1), improved reliability of services (Year 2), and increased economic viability (Year 3).
- **Gender-Disaggregated Panel Analysis**: Conduct multi-year assessments of the social return on investment (economic stability, health outcomes, and empowerment within family or household) for SHG women to evaluate how sustainable convergence will be when leveraging the NRLM framework.

Fidelity decay patterns across multiple replication sites can provide guidance for a more successful national rollout of implementation science. Stress-testing financial projections within ± 50% of actual recycle price [13, 24] will provide boundaries for accurate financial projections. Sustainable landfill reduction and resource recovery approaches also require further rural evaluation [21].

Nitte provides longitudinal evidence supporting decentralized municipal recycling facilities (MRF) successfully obtaining durable requirements of SBM Version 2.0. The evidence further demonstrates that decentralization of MRF systems in rural settings can be economically viable within appropriate governance and institutional contexts. Broader evaluation of scalability should be done through multiple empirical test sites rather than through macro-level estimates.

Abbreviations

1) FGD
Focus Group Discussion
2) KAP
Knowledge, Attitude and Practice

3) MRF
Material Recovery Facility
4) SHG
Self-Help Group
5) SBM
Swachh Bharat Mission
6) SWM
Solid Waste Management
7) PPP
Public-Private Partnership
8) CBA
Cost-Benefit Analysis
9) CFA
Confirmatory Factor Analysis

Declarations

Ethical Approval

The study was approved by the Institutional Review Board (IRB), Justice KS Hegde Institute of Management, Nitte (Deemed to be University), Karnataka, India. The research was conducted in accordance with the Indian Council of Medical Research (ICMR) National Ethical Guidelines for Biomedical and Health Research Involving Human Participants (2017).

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Author Contributions

Dr. Ashalatha K (Corresponding Author**):** Supervision, Framework validation, Writing review & editing, Academic guidance, Institutional ethics oversight.

Disha B: Conceptualization, Methodology design, Primary data collection (73 household surveys, 12 interviews, 4 FGDs), Data analysis (R statistical modeling, NVivo thematic coding), Writing-original draft (all sections), Visualization (charts and figures), Project administration.

Anusha: Literature review compilation, Data validation, Writing review (Methodology + Results sections).

Deeksha S Acharya: Policy recommendations development, Discussion section drafting, Citation formatting.

Amisha Shetty: Data entry and cleaning, Figure preparation support, Formatting and proofreading.

All authors read and approved the final manuscript.

Competing Interests

The authors declare that they have no competing interests.

Consent to Participate

Informed consent was obtained from all individual participants included in the study prior to data collection. Participation in the study was voluntary and respondents were informed about the objectives of the research, confidentiality of responses, and their right to withdraw from the study at any stage without any consequences. No participants under the age of 18 years were involved in the study.

Consent for Publication

Not Applicable. The study does not contain any identifiable images or personal data of participants.

Human or Animal Rights

Ethical standards and regulations have been adhered to by all methods employed in this research project (as determined through adherence to ICMR's and India's national ethics standards: human subjects).

Data Availability

The datasets generated and/or analysed during the current study are not publicly available due to confidentiality and privacy considerations involving participant responses. However, the data are available from the corresponding author on reasonable request.

Clinical trial number: Not applicable.

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Figures

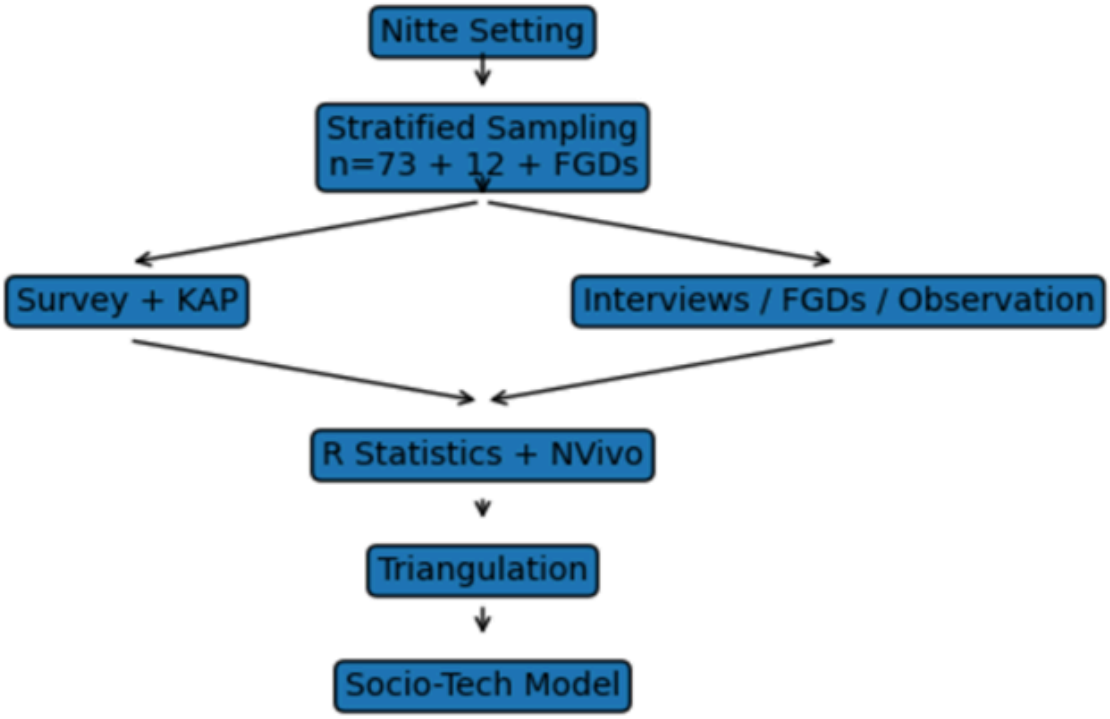


Figure 1

Research Flowchart

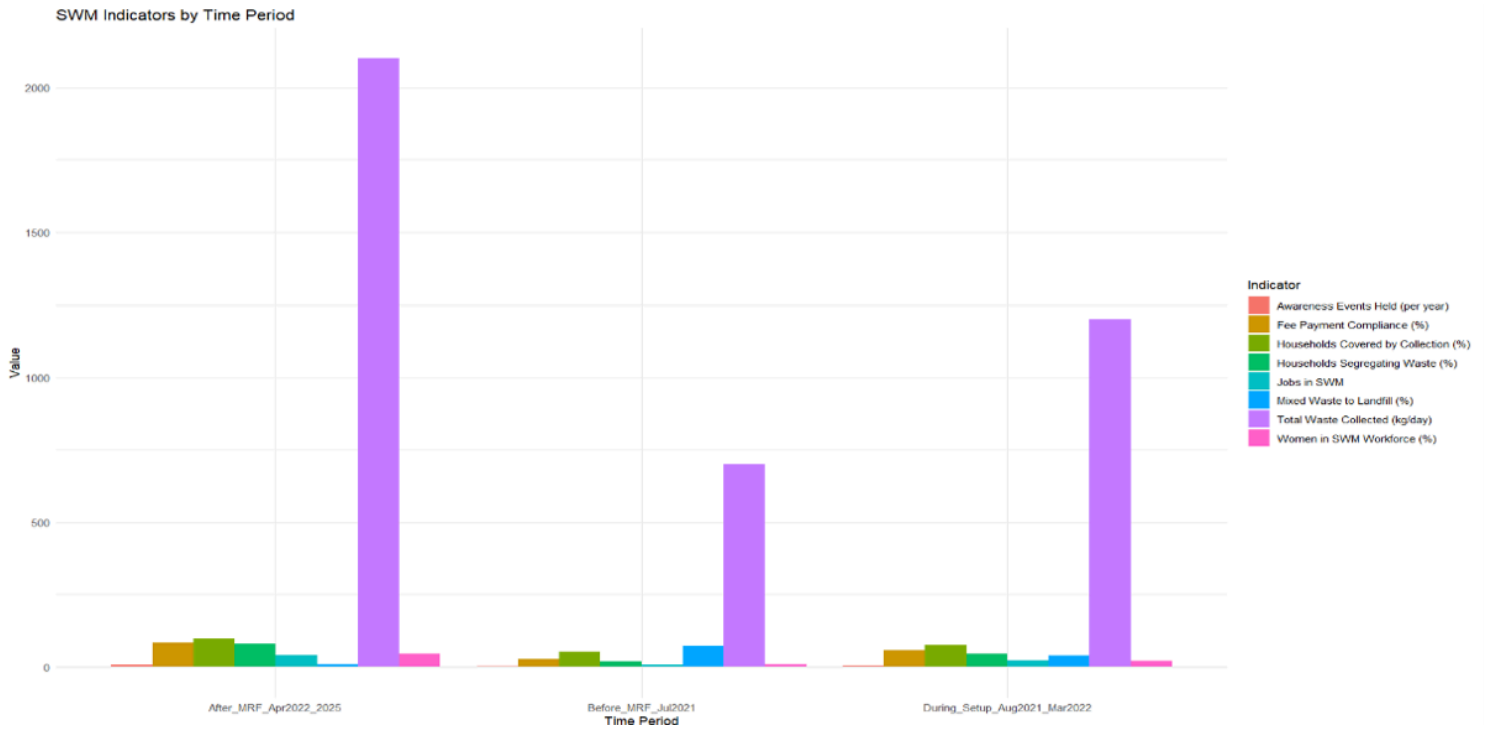


Figure 2

Fig. 1: Trends in Key SWM Indicators Over Intervention Phases

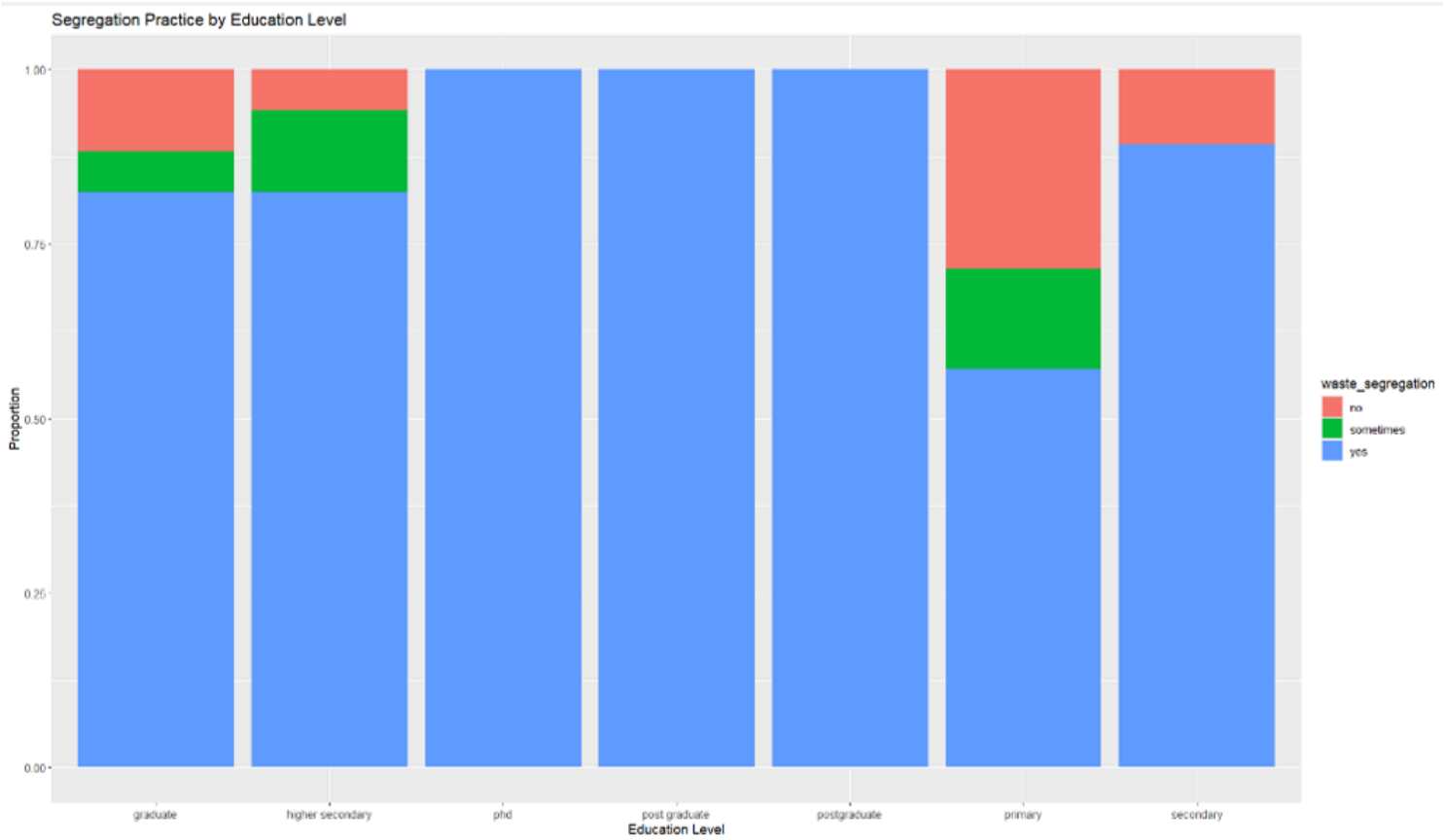


Figure 3

Fig. 2: Education levels vs segregation compliance

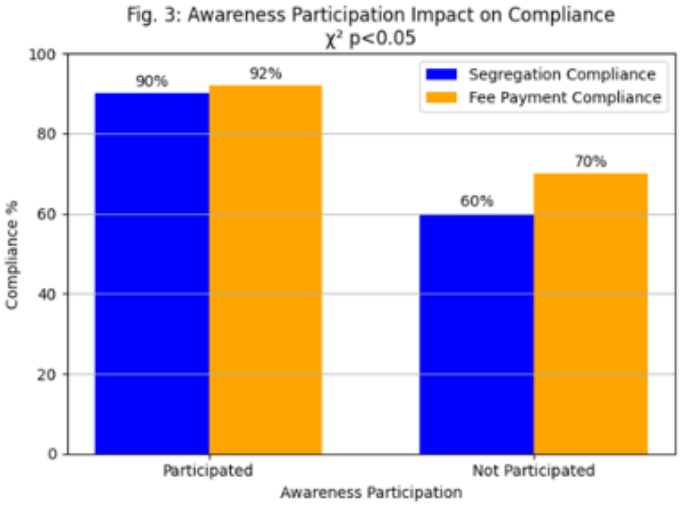


Figure 4

Fig. 3: Awareness Participation vs. Compliance



Figure 5

Fig. 4: NVivo Thematic Word Cloud

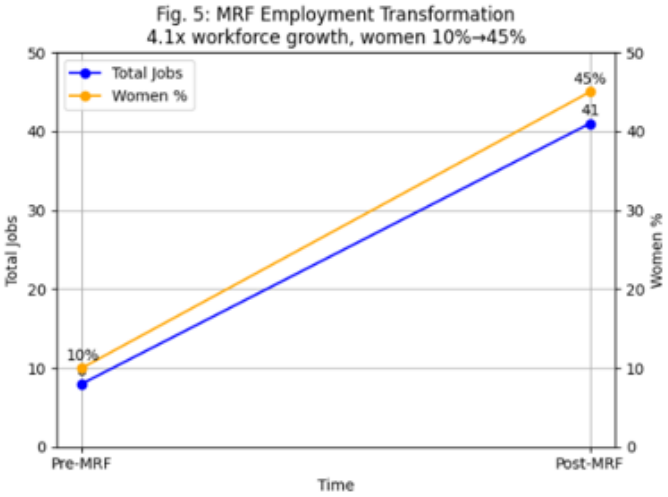


Figure 6

Fig. 5: Workforce Growth and Women Inclusion