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Compliance Assessment of Republic Act 6969 in Air Navigation Service XI: A Sequential Explanatory Mixed-Method Analysis of E-Waste Management Practices in Key Airports of Southern Mindanao, Philippines

Laiza L. Limpin*, Elmer J. Alvarado

Information Technology and Physics Department, College of Natural Sciences and Mathematics, Mindanao State University – General Santos, Fatima, General Santos City 9500, Philippines

*Corresponding Author: laiza.limpin@msugensan.edu.ph

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Abstract

E-waste is a significant hazardous waste stream that poses environmental and health risks, prompting countries worldwide to implement legislation for its proper management. In the Philippines, Republic Act 6969 serves as the primary regulatory framework for handling toxic substances, hazardous waste, and nuclear waste. To assess if RA 6969 effectively addresses e-waste management, given its hazardous components, a pilot study was carried out in three airports in Southern Mindanao (i.e. Davao City International Airport, Cotabato City Airport, and General Santos City International Airport). Specifically, this study evaluated the compliance of Air Navigation Service Area XI with the requirements for waste generators and proper waste management as stipulated in Philippine laws. Using a sequential explanatory mixed-method approach and jointly utilizing qualitative and quantitative data collection protocols, this study assessed levels of compliance with RA 6969, triangulated survey findings, explored compliance challenges, and gathered recommendations for improving e-waste management. Findings revealed that ANS XI demonstrated moderate compliance with RA 6969, particularly its Implementing Rules and Regulations (IRR) under DAO 2013-22. Key challenges included lack of e-waste laws, weak enforcement, insufficient training and lack public of awareness. To enhance compliance, the study recommends proper training and stricter enforcement of regulations. Additionally, a dedicated legal framework specifically for e-waste management could further strengthen regulatory measures and improve overall compliance.

Keywords: *E-waste, RA 6969, compliance assessment, ANS XI, environmental regulations*

Electronic waste (e-waste), which refers to discarded electrical and electronic devices and components, has emerged as a pressing global concern. Rapid technological advancements and the short lifespan of these devices have significantly contributed to the increase in e-waste generation. Globally, the volume has increased from 34 million metric tons in 2010 to 62 million metric tons in 2022 and is projected to reach 82 million metric tons by 2030 [1]. This crisis presents environmental, health, and economic challenges [2, 3] that demand urgent and systemic responses from governments, industries, and institutions worldwide.

The Philippines is not exempt from this growing problem. In 2019 alone, the country generated approximately 3.9 kg of e-waste per capita [4]. More alarmingly, approximately 80% of this waste is processed through informal channels [5, 6], where rudimentary techniques like open burning, acid baths and cyanide treatment can lead to the release of hazardous substances such as dioxins, heavy metals (e.g., lead, cadmium, mercury) and volatile compounds into the environment [7, 8]. Further, studies indicate that these activities have been linked to elevated blood levels in nearby populations, often exceeding World Health Organization (WHO) safety thresholds by 3-5 times [9, 10]. This level of exposure is associated with a wide range of adverse health effects, including genotoxic damage (e.g., increased micronuclei in buccal cells) [11],

respiratory and cardiovascular issues [12], neurological and reproductive disorders such as stillbirths and premature births [8], and common symptoms like headaches, chest pain, and skin problems [12-14].

One of the key contributing factors to the ongoing problems in e-waste management is the absence of a robust legislative framework. Unlike developed nations with comprehensive e-waste management policies, the Philippines lacks specific legislation tailored to address electronic waste. The primary regulatory framework, Republic Act (RA) 6969, also known as the Toxic Substances and Hazardous and Nuclear Wastes Control Act of 1990, was enacted prior the emergence of the current e-waste landscape and does not adequately address the unique characteristics of electrical and electronic waste [15, 16]. Republic Act 6969 defines hazardous wastes as "*substances that are without any safe commercial, industrial, agricultural or economic usage and are shipped, transported or brought from the country of origin for dumping or disposal into or in transit any part of the territory of the Philippines. This shall also include those substances that by reason of their chemical reactivity or toxic, explosive, corrosive or other characteristics cause danger or are likely to cause danger to health or the environment*". Under this law, e-waste is broadly classified as hazardous waste, but it is not defined as a distinct category with its own regulatory framework. Consequently, there are no specific provisions assigning clear responsibilities to producers and consumers regarding the proper collection, treatment and disposal of electronic waste. This lack of targeted legislation has led to weak collection systems, improper disposal practices, and a continued dependence on informal recycling sectors [17].

Compounding these challenges is the complex nature of e-waste itself. Unlike conventional hazardous waste, e-waste presents a dual nature. On one hand, it contains hazardous materials including lead, cadmium, mercury and brominated flame retardants that pose serious environmental and health risks [18-20]. On the other hand, it contains valuable recoverable components such as gold, copper, rare earth elements that represent significant economic potential [21]. Efficient recycling processes can reclaim up to 60% of these valuable metals [22]. However, the Philippines currently lacks the infrastructure, investment and technical capacity to take advantage of this opportunity. This not only results in lost economic value but also perpetuates environmental degradation and health risks.

These systemic limitations are particularly evident in institutional sectors that heavily depend on electronic technologies but fall outside the scope of industrial regulation. Currently, the Environmental Management Bureau (EMB) under the Department of Environment and Natural Resources (DENR), as the implementing agency of RA 6969, focuses primarily on industrial chemicals and traditional pollutants rather than electronic waste [23, 24]. The rise of e-waste, particularly in non-industrial institutional settings like government offices and transport infrastructure, has outpaced the EMB's issuance of sector-specific guidelines and monitoring tools. This regulatory gap has left sectors such as the civil aviation, where large quantities of electronic equipment and hazardous components are procured, used, and discarded without formal e-waste strategies.

Among the overlooked but significant e-waste generators is the Air Navigation Service (ANS) under the Civil Aviation Authority of the Philippines (CAAP). The ANS relies heavily on critical electronic systems for navigation, communication, and safety that frequently require upgrading or replacement [25]. For instance, procurement records show ANS Manila alone purchased over 2,000 lead-acid batteries between 2018-2020, components that typically require replacement every 2-3 years [26]. These batteries are accumulating rapidly and have become a major contributor of ANS e-waste. Without proper disposal protocols in place, these batteries pose serious risks. They contain toxic metals such as lead, cadmium, mercury, and lithium, which can contaminate soil and harm both ecosystems and human health water [27-29]. Electrolyte leakage may cause burns and respiratory issues [30-32], while improper handling can lead to fires or explosions [33, 34].

Given these realities, this study focuses on Air Navigation Service (ANS) XI, which oversees air navigation systems in Region XI. ANS XI was selected due to its operational significance and the documented accumulation of obsolete navigational equipment and electronic components, many of which have remained in storage since their decommissioning in 2021. These conditions illustrate the practical challenges of e-waste management at the facility level and reveal systemic gaps in the implementation of Republic Act No. 6969. Specifically, this study investigates the extent of ANS XI's compliance with RA 6969 in managing electronic waste within its jurisdiction. It aims to evaluate current handling practices, identify barriers to effective implementation, and develop policy recommendations that address both regulatory shortcomings and the operational realities of managing e-waste in aviation infrastructure. By examining the case of ANS XI, the study contributes to the broader goal of enhancing institutional adherence to environmental

policies and strengthening the country's e-waste governance framework.

The findings will inform policy recommendations that address both regulatory shortcomings and operational realities, contributing to the Climate Change Commission's call for a national e-waste policy that addresses critical gaps in collection, segregation, and recycling systems [35]. Such policy development could draw from successful international models of Extended Producer Responsibility (EPR) that have proven effective in both reducing e-waste volumes and creating sustainable recycling economies [36, 37]. Furthermore, the CCC underscores the importance of establishing clearer mandates, sector-specific implementation guidelines, and adequate institutional capacity to manage e-waste safely, particularly in high-impact public sector facilities such as airports. These policy recommendations emphasize the need to strengthen RA 6060 through updated frameworks that better reflect the scale, complexity and evolving nature of e-waste challenges in the Philippines. Moreover, the study aligns with the United Nations Sustainable Development Goals (SDGs), particularly SDG 3 (Good Health and Well-being), SDG 6 (Clean Water and Sanitation), SDG 11 (Sustainable Cities and Communities), and SDG 12 (Responsible Consumption and Production). By promoting safe and accountable e-waste practices in Philippine aviation facilities, this research not only addresses a regulatory and environmental concern but also contributes to the pursuit of sustainable, health-conscious, and technologically resilient public infrastructure.

Materials and Methods

This study followed an explanatory sequential mixed-methods design, consisting of two phases [38]. The first phase involved a quantitative survey to assess the level of RA 6969 compliance among ANS XI personnel. This was followed by a qualitative phase, which aimed to further explore and explain the quantitative results, particularly the challenges encountered in adapting and implementing compliance measures. Figure 1 shows the sequential flow of methods used in this study.

The quantitative component offered measurable indicators of compliance across key regulatory dimensions. This provided a standardized basis for comparing practices among the three participating airports. However, quantitative data alone may fall short in explaining the underlying reasons for observed compliance levels [39]. Thus, qualitative data collection through focus group discussions was conducted to explore these underlying factors. The qualitative findings provided experiential insights from personnel directly engaged in hazardous waste management, including pollution control officers, facility safety officers, and facility heads.

The research was conducted in three ANS XI facilities: Davao City International Airport (DCIA), General Santos City International Airport

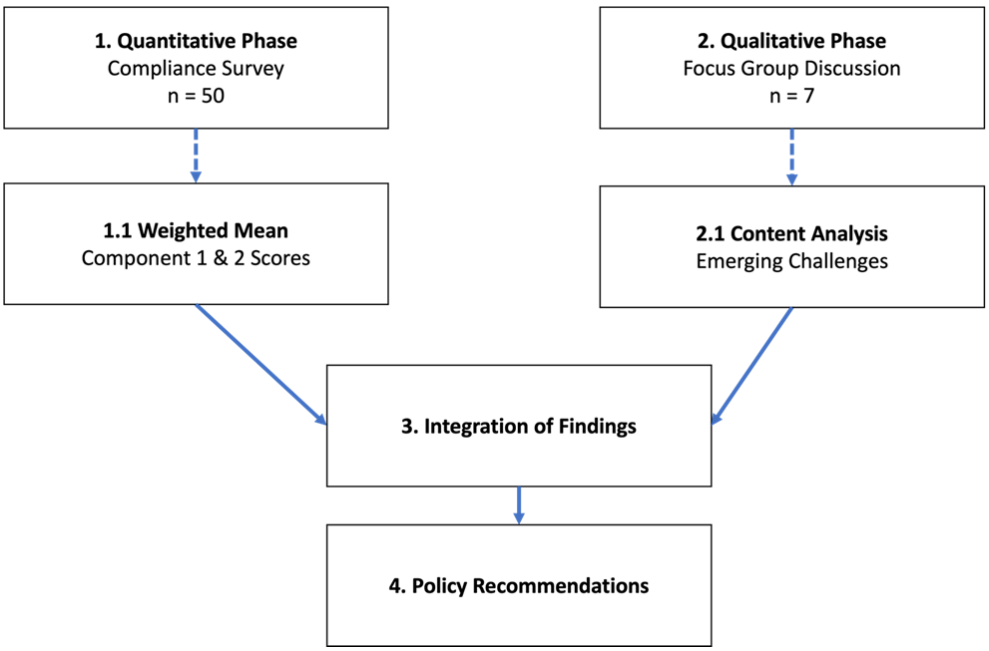

Figure 1. The procedural diagram illustrating the sequential flow of methods utilized in the study.

(GSCIA), and Cotabato City Airport (CCA). These airports were chosen for their strategic significance within the jurisdiction of ANS XI under CAAP. Both DCIA and GSCIA serve as major gateways in Southern Mindanao, handle substantial amount of air traffic and consequently generate large amounts of electronic waste. Meanwhile, the inclusion of CCA provided an opportunity to examine compliance within a facility undergoing a transition to the Bangsamoro Autonomous Region in Muslim Mindanao (BARMM), thus offering a unique institutional context for regulatory implementation.

A structured survey questionnaire was administered to assess the level of compliance of the selected ANS XI facilities with RA 6969. The survey instrument was based on the Implementing Rules and Regulations (IRR) of RA 6969, specifically the DENR Administrative Order (DAO) 2013-22. DAO 2013-22, also known as the Revised Procedures and Standards for the Management of Hazardous Wastes, serves as the primary regulatory framework for the classification, handling, storage, transport, and disposal of hazardous waste in the Philippines [40]. Guided by this administrative order, the study focused on evaluating compliance in two key areas: Component 1 - Requirements for Waste Generators and Component 2 - Proper Waste Management Practices. These components reflect core requirements of facilities in hazardous waste management, from registration and reporting to the implementation of safe treatment and disposal protocols. The survey questionnaire was reviewed and certified by two (2) environmental policy experts and pilot-tested with five (5) ANS personnel to ensure validity and reliability.

A total of 50 respondents participated in the survey, selected using Slovin's formula with a 95% confidence level and a 5% margin of error. The respondents consisted of Communication Navigation Surveillance Systems Officers (CNSSO) and Airfield Lighting Power Technicians (ALPT), whose roles involve direct handling, maintenance, and oversight of equipment that generates e-waste. These personnel were deemed most appropriate for evaluating compliance practices due to their operational responsibilities and familiarity with facility-level waste management procedures. The unit of analysis in this study is facility-level compliance with RA 6969, assessed through the perspectives of personnel responsible for hazardous waste management.

The survey was administered using a combination of online forms (Google Forms) and printed questionnaires to accommodate the availability and preferences of the respondents. Respondents rated compliance indicators on a 5-point Likert scale (e.g., 1 = Very Low, 2 = Low, 3 = Moderate, 4 = High, 5 = Very High), as shown in Table 1 [41]. The survey responses were then tabulated, encoded in Microsoft Excel 2019, and analyzed using IBM SPSS Statistics Version 23 (Statistical Package for the Social Sciences) [42]. The study employed descriptive statistics to analyze the survey data. Specifically, weighted mean analysis was used to determine compliance levels for each survey item and domain (Components 1 and 2). Data were then compared across three facilities using weighted mean scores per indicator, which were then categorized into qualitative labels based on Likert scale interpretation: Very Low (1.00 – 1.49), Low (1.50 – 2.49), Moderate (2.50 – 3.49), High (3.50 – 4.49), Very High (4.50 – 5.00). The categorization scheme was guided by standard interval scaling commonly used in social science research [43].

To validate the survey results and gain deeper insights into compliance practices, a focus group discussion (FGD) was conducted. Invitations for the FGD were sent to nine (9) participants from

Table 1. The five-Point Likert Scale used to assess ANS XI facilities' compliance with RA6969 and its guidelines. The scale ranges from 5 (Very High) indicating full compliance to 1 (Very Low) indicating non-compliance [41].

Scale	Descriptive Rating	Descriptive Meaning
5	Very High	This means that they are extremely compliant in the requirement/ activity
4	High	This means that they are highly compliant in the requirement/ activity
3	Moderate	This means that they are moderately compliant in the requirement/ activity
2	Low	This means that they are poorly compliant in the requirement/ activity
1	Very Low	This means that they are very poorly compliant in the requirement/ activity

the three ANS XI facilities. Selection criteria included their operational responsibilities and institutional knowledge of hazardous waste practices within their respective assignments. The invited participants consisted of six (6) facility safety officers (FSOs), two (2) pollution control officers (PCOs), and one (1) facility in-charge (FIC). Ultimately, six participants, along with the FIC were able to attend the FGD, while three invitees were unable to participate due to unspecified reasons.

Participants were formally invited through official communications and were provided with detailed information about the study, including its objectives, the voluntary nature of participation, assurances of confidentiality, and the right to withdraw at any time. Informed consent was obtained from all attendees prior to the session. The FGD was conducted virtually via Google Meet to ensure accessibility across sites and was recorded with the participants' permission for transcription and analysis.

The qualitative data were analysed using conventional content analysis approach, which is appropriate when the aim is to describe a phenomenon directly from participants' perspectives [44]. In this study, the analysis aimed to provide deeper insight into the compliance levels observed in the preceding quantitative survey. The process began with the researcher scrutinizing the data to gain a comprehensive understanding of compliance challenges encountered by airport personnel. The FGD transcripts were read line by line and relevant statements were highlighted. Open coding was conducted to capture initial impressions and assign labels to significant segments of the text. These labels were then grouped into categories based on their relationships and patterns. Quirkos 2.0 software was used in organizing and visualizing the coded data. Figure 2 presents a sample of the initial categories generated using the software. The final step involved describing the categories and developing themes from the data, which were supported by direct

Figure 2. This visual output from Quirkos 2.0 shows the emergent themes derived from qualitative data analysis. Each bubble represents a distinct category coded from the transcript, with the size of each bubble indicating the relative frequency or emphasis of that issue across participants' responses.

quotes to illustrate the findings [45]. These qualitative insights provided contextual explanations that helped interpret quantitative results and identify key challenges that shaped compliance outcomes across the ANS XI facilities.

To ensure the trustworthiness of the analysis, a member checking process was conducted. Selected participants were engaged in a follow-up interview, during which the preliminary findings and representative themes were presented for validation. Participants were asked whether the interpretations accurately reflected their views and experiences, and were also invited to clarify, agree, or contest specific codes.

Confidentiality and anonymity were strictly maintained during this process. The researcher limited discussions to the derived codes only, refraining from disclosing any personally identifiable or sensitive information [46]. This step was essential in preserving participants' privacy while allowing them to refine or elaborate on interpretations.

The qualitative findings from the FGD were used to verify and explain the survey

results by comparing participants' insights with the quantitative compliance scores. This cross-validation process ensured that the survey findings were contextually grounded in the actual experiences and challenges faced by personnel involved in hazardous waste management [47].

The study protocol, including instruments, was approved by the Mindanao State University – General Santos Research Ethics Committee.

Results and Discussion

This section presents the findings from the quantitative survey and focus group discussion. The first part examines the level of compliance of the three facilities with the two components of RA 6969 and its Implementing Rules and Regulations (DAO 2013-22). The second part explores the challenges encountered in e-waste management, including barriers to compliance. The final part provides policy recommendations to improve e-waste regulation and management practices.

ANS XI Level of Compliance with RA 6969

Table 2 presents the level of compliance of the three facilities with Component 1 of Republic Act 6969, specifically in relation to the requirements for waste generators. This provides a comparative assessment of their adherence to key regulatory obligations, including the designation of a Pollution Control Officer (PCO), registration as a

Table 2. Comparative assessment of compliance with RA 6969 Component 1. This shows the ANS XI facilities' compliance levels with key indicators such as PCO designation, generator registration, SMR submission, waste management practices, e-waste ownership, and manifest system use.

Statement	DCIA		GSCIA		CCA	
	Weighted Mean	Description	Weighted Mean	Description	Weighted Mean	Description
Accredited Pollution Control Officer on a full-time basis (PCO) has been designated	3.17	Moderate	3.10	Moderate	1.80	Low
Has been registered as waste generator in EMB Region & Office having jurisdiction	3.21	Moderate	3.00	Moderate	1.80	Low
Submitted Quarterly Self-Monitoring Report (SMR)	2.96	Moderate	3.29	Moderate	1.60	Low
Adopted effective waste management practices from the time wastes are generated until they are rendered non-hazardous	3.42	Moderate	3.19	Moderate	2.20	Low
Continued to own and be responsible for the e-wastes generated	3.38	Moderate	3.29	Moderate	2.20	Low
Followed the hazardous waste transport manifest system	3.17	Moderate	3.10	Moderate	2.20	Low
Submitted to EMB a thorough emergency planning and response program	3.00	Moderate	2.95	Moderate	1.80	Low
Have orientation of personnel about the dangers of handling hazardous materials	3.17	Moderate	2.90	Moderate	2.20	Low
Develop capability to implement the emergency preparedness and response programs and continually train core personnel on the effective implementation of such programs	3.04	Moderate	2.86	Moderate	2.20	Low
Overall Mean	3.17	Moderate	3.07	Moderate	2.00	Low

Legend: 4.50-5.00 Very High, 3.50-4.49 High, 2.50-3.49 Moderate, 1.50-2.49 Low, 1.00-1.49 Very Low

waste generator, submission of self-monitoring reports (SMRs), and implementation of hazardous waste management practices.

The results show that both DCIA and GSCIA demonstrate a Moderate Compliance with Component 1 (3.17 and 3.07, respectively), consistently scoring above 3.00 in most indicators. DCIA scored 3.42 in adopting effective waste management practices and 3.38 in maintaining responsibility over generated e-waste, which reflects the presence of structured systems and designated personnel. DCIA's relatively stronger performance can be attributed to its role as a regional office under CAAP ANS XI, which handles a higher volume of e-waste due to its administrative and operational scope. The presence of a dedicated Waste Disposal Team at DCIA also reinforces this structured approach. GSCIA, the second-largest airport in ANS XI, maintains accountability of its e-waste and ensures regular submissions of Self Monitoring Reports (SMR) (3.29). These findings align with Vélez – Ramirez et al., who emphasized that e-waste management efficiency is often linked to institutional capacity, governance structures and resource availability [47]. Larger or more structured institutions tend to have better e-waste management performance due to higher level of awareness, compliance mechanisms and dedicated personnel, as seen in both DCIA and GSCIA [48-51].

In contrast, CCA demonstrates a significantly Low Compliance, with an average rating of 2.00, falling under the "Low" category across all indicators. Specific gaps include the absence of a PCO (1.80), failure to submit SMRs (1.60), and limited adoption of effective waste practices (2.0). These values clearly illustrate the facility's systemic deficiencies in meeting baseline regulatory requirements under DAO 2013-22.

Several factors may explain CCA's low compliance. First, CCA's jurisdictional transition from EMB Region 12 to BARMM may have disrupted regulatory alignment and created monitoring inconsistencies. As BARMM enforces its own evolving policies, there is a risk that harmonization with national standards under RA 6969 has been compromised. This fragmentation is not uncommon. Doremus highlights how regulatory overlaps and unclear mandates often lead to enforcement gaps, reduced accountability, and delays in compliance [52]. Second, the significantly lower workforce at CCA, representing only 10% of ANS XI personnel compared to the 48.5% at both DCIA and GSCIA, has likely impacted its ability to implement and monitor hazardous waste protocols. With insufficient staffing, activities such as report submission, personnel orientation, and emergency preparedness remain underprioritized. For instance, CCA consistently scored 2.20 on orientation and training -related items, which reflects the limited opportunities for continuous capacity building.

Table 3 presents the compliance status of the three facilities with Component 2 of RA 6969, which outlines the requirements for proper hazardous waste management. According to regulatory guidelines, waste generators are responsible for managing hazardous waste from the

Table 3. Comparative assessment of compliance with RA 6969 Component 2. This shows the ANS XI facilities' compliance levels with waste storage standards, pre-transport procedures, use of registered transporters and TSD facilities, and adoption of the online manifest system.

Statement	DCIA		GSCIA		CCA	
	Weighted Mean	Description	Weighted Mean	Description	Weighted Mean	Description
Requirements for waste storage facility	3.29	Moderate	3.10	Moderate	2.43	Low
Pre-transport requirements	3.03	Moderate	2.79	Moderate	2.20	Low
Use of registered waste transporters and TSD facilities	3.00	Moderate	2.86	Moderate	1.80	Low
Use of the online hazardous waste manifest	2.96	Moderate	2.81	Moderate	1.80	Low
System in transporting hazardous waste for offsite treatment, storage and disposal confirmation of treatment or disposal completion	3.04	Moderate	2.86	Moderate	1.80	Low
Overall Mean	3.06	Moderate	2.88	Moderate	2.01	Low

Legend: 4.50-5.00 Very High, 3.50-4.49 High, 2.50-3.49 Moderate, 1.50-2.49 Low, 1.00-1.49 Very Low

moment of generation to its final treatment disposal by an EMB-registered transporter or treatment, storage, and disposal (TSD) facility.

The findings indicate that DCIA achieved the highest overall compliance score of 3.06, categorized as "Moderate Compliance". This reflects consistent adherence to the regulatory requirements, with scores ranging from 2.96 to 3.29 across all five indicators. DCIA's highest rating was in the requirements for waste storage facility (3.29), followed by system in transporting hazardous waste for offsite treatment (3.04) and pre -transport requirements (3.03). These scores indicate that DCIA maintains a functioning hazardous waste management system supported by storage infrastructure and procedures for compliant handling, transport and documentation.

Similarly, GSCIA achieved a Moderate Compliance score of 2.88, with most indicators falling between 2.79 and 3.10. While slightly lower than DCIA, GSCIA still demonstrated consistent implementation of required practices. Its scores of 3.10 for storage facility requirements suggests adequate infrastructure is in place. However, slightly lower scores in pre-transport requirements (2.79) and online manifest use (2.81) point to areas for improvement, particularly in documentation and tracking of waste movement.

The moderate compliance levels at both DCIA and GSCIA can be attributed to the presence of temporary storage facilities, which allow for proper segregation and short-term containment of hazardous e-waste before final treatment. The presence of designated PCOs in these facilities also contributes significantly to compliance performance. As Awasthi et al. argue, the existence of dedicated environmental officers or regulatory compliance personnel significantly improves hazardous waste management practices by ensuring that proper protocols are followed and that regulatory reporting and monitoring requirements are met [53]. Facilities with structured waste management programs, including designated storage areas and compliance officers, tend to exhibit better adherence to hazardous waste regulations compared to those lacking such infrastructure and personnel [54].

In contrast, CCA demonstrates Low Compliance, with an overall mean score of 2.01, with uniformly low scores across all indicators. CCA scored lowest in use of registered transporters and TSD facilities (1.80) and use of the online hazardous waste manifest (1.80). These scores reflect a lack of engagement with formal hazardous waste disposal systems and limited use of compliance tools mandated by EMB. Moreover, its score of 2.43 for storage facility requirements remains below the moderate threshold which suggests a deficiency in physical infrastructure for waste containment.

The performance gap between DCIA and CCA underscores the influence of institutional capacity and infrastructure on compliance outcomes. DCIA benefits from being the regional hub, with dedicated personnel and established systems, whereas CCA, which operates with fewer staff and recently transitioned under BARMM jurisdictions, faces constraints in both resource allocation and regulatory continuity. Unlike DCIA and GSCIA, which have temporary storage facilities for hazardous waste, CCA lacks the necessary storage space, equipment, and logistical support to effectively manage hazardous materials from the point of generation to treatment or disposal. The absence of well-defined storage and disposal systems, coupled with inadequate engagement with accredited waste handlers, substantially hinders effective e-waste management [55]. The case of CCA exemplifies this risk, highlighting how logistical, administrative and structural gaps converge to create persistent compliance challenges.

Compliance Challenges

The Low to Moderate Compliance of the three ANS XI facilities Component 2 can be attributed to several systemic and structural challenges. These include the absence of formal mechanisms, weak enforcement of regulations, insufficient training, and lack of public engagement and awareness. These obstacles are not unique to ANS XI but are widely observed in developing countries, where e-waste management systems often lack formal mechanisms for collection, recycling and disposal. For instance, India and Indonesia face similar compliance issues due to the absence of a structured e-waste recycling mechanism, which leads to heavy reliance on informal waste management sectors [56, 57]. In these countries, a large portion of e-waste is processed by small-scale informal collectors, who often lack the technical expertise, proper equipment, and regulatory oversight necessary for safe and efficient e-waste handling. These informal recycling methods, including open burning and acid baths, pose serious environmental and health risks. The release of toxic substances such as heavy metals (e.g., lead, mercury, cadmium) from improper processing contaminates soil and water sources and contributes to air pollution [58-60].

Despite the Philippines' existing hazardous waste regulations under RA 6969, the country lacks a specific, well-defined framework for e-waste management [61]. While RA 6969 provides general guidelines for hazardous waste control, it does not establish clear, standardized protocols for the

collection, treatment, and disposal of e-waste. This regulatory gap leads to fragmented and inconsistent implementation across the country [62]. In the absence of such mechanisms in the Philippines, many facilities are forced to rely on localized and improvised approaches, which many not always align with internationally recognized best practices. However, this challenge is not unique in the Philippines. Many developing countries also lack dedicated policies for e-waste management and instead rely on generic hazardous waste laws, which are often inadequate to address the complex lifecycle of e-waste [63].

In contrast, countries such as Japan and South Korea have implemented robust, well-defined legal frameworks that assign clear roles and responsibilities to producers, retailers, and consumers. For example, Japan and South Korea operate under Extended Producer Responsibility (EPR) systems that mandate manufacturers and retailers to take back and recycle waste electrical and electronic equipment (WEEE). These systems transfer end-of-life management responsibilities to producers, which results to a highly structured collection and recycling processes that ensures traceability [64-66]. Furthermore, these countries implement recycling fee systems where consumers are charged at the point of purchase to cover future recycling costs [65].

Another key element in successful e-waste regulations is the use of public-private partnerships (PPPs). These partnerships bring in both technical and managerial expertise, as well as financial resources that public institutions may lack [67, 68]. For instance, In India, integrating informal and formal sectors through PPPs has enhanced e-waste management systems by leveraging the innovations and experiences of small and medium enterprises (SMEs) [69]. However, the presence of legislation alone is not enough. Weak implementation remains a critical challenge, even in contexts where e-waste policies exist. In Africa, for example, enforcement mechanisms remain weak, resulting in limited formal recycling and a heavy dependence on informal processing systems [68]. A similar situation is observed in ANS XI, where implementation challenges persist. According to FSO1, proper e-waste management practices receive little attention and its implementation is deprioritized due to the presence of numerous and sometimes conflicting laws and standards. For instance, respondent PCO1 indicated, "*we're concentrating on complying with the provisions of the Clean Air Act with regard to the operation of generators and disposal of batteries and oil"*. This regulatory failure exacerbates the growing waste crisis, particularly in countries with limited infrastructure for formal e-waste collection and recycling [70, 71]. A notable example is the Canada-Philippines waste dispute, where illegal waste shipments from Canada to the Philippines highlighted broader concerns about weak enforcement of waste regulations, loopholes in international waste trade policies, and the exploitation of developing nations as dumping grounds [72, 73].

The lack of training on proper e-waste management across facilities is also evident, with low to moderate compliance in personnel orientation and capacity-building initiatives related to hazardous materials handling (as shown in Table 1). Under the Implementing Rules and Regulations of RA 6969, waste generators are required to conduct personnel training for accreditation. However, most Pollution Control Officers (PCOs) have only undergone initial training and lack access to continuous education and capacity-building programs, particularly on recent compliance processes and requirements under RA 6969. As FSO4 stated, "*We lack the necessary training… although we were trained on generator oil and batteries, we were not trained on their proper disposal.*" Additionally, efforts to continuously upskill core personnel in hazardous waste management remain limited. PCO2 added, "*While there are trainings, they are not updated to the current processes and requirements… if you're not trained, you will not be accredited by the EMB*." The absence of updated training on compliance requirements and emerging waste management processes may hinder effective hazardous waste management and regulatory adherence. Although training programs for PCOs exist, they primarily cover broader hazardous waste topics rather than focusing specifically on e-waste management. This gap can be attributed to RA 6969's broad scope, which encompasses all hazardous chemicals, including nuclear waste, rather than providing targeted guidelines for e-waste disposal. Consequently, the lack of specialized training on e-waste treatment, disposal, and recycling contributes to compliance gaps and improper handling practices within facilities. Moreover, the lack of public engagement and awareness significantly contributes to the challenges in e-waste management, as stakeholders may not fully grasp the risks associated with improper disposal. FSO4 related that Filipinos, in general, lack awareness and consciousness regarding proper e-waste disposal. This issue is not unique to the Philippines. Studies have identified a significant gap in public awareness about e-waste disposal in other developing countries such as India and Indonesia [74, 75]. Many individuals remain unaware of appropriate disposal practices and the environmental and health risks associated

with improper e-waste handling. Hasan underscores the critical role of public participation in hazardous e-waste management and notes that increased awareness can significantly enhance waste segregation, promote responsible disposal, and improve recycling outcomes [76]. When consumers understand the importance of proper e-waste disposal, they are more likely to utilize formal recycling programs rather than resort to informal or illegal disposal methods. Additionally, businesses and manufacturers play a key role in promoting Extended Producer Responsibility (EPR) programs, which encourage take-back schemes and sustainable product lifecycle management [77].

Finally, knowledge gaps are also evident among those directly involved in e-waste handling. As FSO1 admitted, it was her first time hearing about RA 6969, despite being part of the organization. Studies have also highlighted informal e-waste handlers remains unaware of the health risks and proper disposal methods [78-80]. In many developing countries, informal recyclers play a major role in e-waste collection and dismantling, yet they often operate in hazardous conditions without protective gear or access to safer processing technologies [80, 81]. For instance, in Ghana, many e-waste workers are aware of environmental risks but do not adopt safer practices due to inefficiencies in available alternatives [81].

These challenges present a clear and compelling explanation for the low to moderate compliance with RA 6969 observed among ANS XI facilities. Moving forward, the following recommendations are proposed to address critical gaps in e-waste regulation, enforcement, and operational processes not only within the aviation sector but also across other industries that generate electronic waste in the Philippines.

Recommendations

Drawing from the findings of this study and a critical review of Republic Act 6969 and its Implementing Rules and Regulations (DAO 2013-22), the following recommendations are proposed to address the legal, institutional, and operational gaps in e-waste management in the Philippines:

1. **Establish a dedicated legal framework for e-waste management**

There is an urgent need for a dedicated national policy specifically addressing e-waste. While Republic Act 6969 and its Implementing Rules and Regulations (DAO 2013-22) provide a general framework for the regulation for hazardous substances, they do not sufficiently address the unique characteristics, lifecycle stages, and environmental risks associated with e-waste. Similarly, Republic Act 9003 (Ecological Solid Waste Management Act of 2000) primarily covers biodegradable and non-biodegradable waste but does not define clear protocols for e-waste collection, storage or treatment [82]. As a result, e-waste in the Philippines is often managed through fragmented and inconsistent approaches, with institutions and local government units improvising methods that may not align with international standards or scientific best practices.

A dedicated e-waste law would enable the government to clearly define and classify different types of electronic waste and set standardized procedures for its collection, transport, treatment, recycling and disposal. It would also establish clear mandates for enforcement agencies, set accountability for mechanisms for violators, and outline the responsibilities of stakeholders, including producers, importers, retailers, consumers and recyclers. The law should also integrate key principles such as the polluter pays and extended producer responsibility (EPR), which have been proven effective in countries such as Japan, South Korea and European Union [6, 83, 84].

Furthermore, the new legal framework should include provisions for formalizing the informal recycling sector, which currently handles the majority of e-waste in the country but often operates without adequate safety standards or environmental controls. Similar to India, these informal sectors can be integrated into the formal system by providing adequate trainings, incentives and regulatory support that can enhance compliance and ensure safer and more efficient processing of e-waste [53, 67].

2. Implement evidence-based and contextualized policy approaches

To effectively formulate and implement e-waste regulations, systematic and well-structured policy approaches must be developed [85]. Policies should be based on interdisciplinary research, integrating environmental science, public health, economics and policy studies to provide a holistic understanding of e-waste's impacts. By leveraging evidence-based policymaking, authorities can address both the short-term and long-term consequences of e-waste accumulation, including environmental degradation and occupational health hazards for informal recyclers [86]. According, to the Global E-Waste Monitor, countries with well-informed, data driven strategies show significantly higher rates of formal e-waste collection and recycling [1]. In the Philippine context, this means using empirical data to map waste flows, understand informal sector dynamics, and design interventions that are both achievable and measurable.

Moreover, policies should be tailored to the Philippine waste management landscape, considering infrastructure limitations, local government capacities, and the cultural norms surrounding waste disposal. Merely adopting models from more advanced countries may prove ineffective without localized adaptation. However, best practices such as product lifecycle tracking, eco-labeling, and formal e-waste take-back systems can be localized to guide national policy development and enforcement [56, 77].

3. Strengthen institutional capacity and technical training

Another critical recommendation is the need to enhance institutional capacity, particularly among frontline implementers such as Pollution Control Officers (PCOs), local government units (LGUs) and relevant staff within the Environment Management Bureau (EMB). Findings from the study revealed that most PCOs have only undergone basic accreditation training, with limited access to continuous professional development on evolving compliance procedures, updated regulatory tools, or technological advancements in e-waste treatment. Although DAO 2013-22 mandates PCOs undergo refresher or continuous training every three years, compliance with this requirement remains limited among ANS XI facility PCOs. This is primarily due to constraints such as limited budgets, the infrequent availability of training programs, and insufficient personnel on site to allow for staff release. This mirrors observations in other developing countries, where lack of training and capacity has been cited as a barrier to effective waste management [86]. To address this, the government should institutionalize regular, updated and modular training programs focused on e-waste classification, risk assessment, handling, documentation, and compliance monitoring.

4. Promote public awareness and behavior change campaigns

Public awareness is crucial for effective e-waste management. The study highlights a significant gap in knowledge and engagement among the general public regarding proper disposal practices and the environmental and health risks associated with the improper handling of electronic waste.

To address this, the government should launch nationwide information and education campaigns (IECs) tailored to different stakeholder groups, such as consumers, schools, businesses, and barangays. Campaigns should focus on the hazards of e-waste, the benefits of proper recycling, and available formal collection systems. This should be delivered through both digital platforms and community-based outreach programs. Successful initiatives in Ghana and China show that combining education with incentives can increase participation in formal recycling channels [88].

Conclusion and Future Directions

This study assessed the compliance of ANS XI with Republic Act 6969 in relation to e-waste management. The findings revealed low to moderate compliance levels across the three airports. The compliance was hindered by several key challenges, including the lack of a formal e-waste mechanism, weak policy enforcement, insufficient personnel training, and low public awareness and engagement. These issues reflect a broader issue in the Philippines, where regulatory understanding and consciousness remain underdeveloped, largely due to insufficient education, poor information dissemination, and weak advocacy efforts.

One of the most critical gaps is the lack of a dedicated legal framework for e-waste, as RA 6969 broadly addresses hazardous substances but does not offer targeted provisions specific to the collection, treatment, and disposal of e-waste. To address this, the development of a comprehensive national e-waste policy is essential, one that clearly defines protocols for collection, treatment, and disposal, and supports localized, context-specific enforcement mechanisms. Improving compliance also requires stronger institutional support. Targeted training programs for personnel handling hazardous waste must be prioritized and adequately funded. Strengthening the role and capacity of Pollution Control Officers (PCOs) is equally critical to ensure sustained and informed compliance within operational facilities.

To strengthen and expand the scope of this study, future research could explore several key areas. First, future comparative research involving other ANS facilities could provide a more comprehensive view of compliance patterns, operational practices, and challenges across the country. Second, the study can be expanded to other sectors beyond the aviation sector would help identify broader compliance gaps and best practices. Third, the integration of digital innovations such as blockchain, QR code systems, or geotagging could be investigated to enhance the traceability, transparency, and accuracy of e-waste documentation from generation to final disposal. Lastly, conducting economic and environmental impact assessments would help quantify the true costs of inadequate e-waste practices, strengthen the evidence base for policymaking, and justify investments in long-term solutions such as formal recycling systems and EPR programs.

Author's Contribution

LLL was responsible for writing the manuscript, including refining the analysis, synthesizing the findings, and structuring the discussion. EJA conducted data gathering, performed the statistical analysis, and prepared the initial draft of the manuscript.

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