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Regulatory Non-Implementation in Infectious Waste Management: Procedural Failures, Stakeholder's Fragmented Coordination, and Context-Specific Solutions in Punjab, Pakistan

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Abstract

Pakistani Healthcare Waste Management is regulated on the national and provincial level, but unsafe segregation, storage, transportation, treatment, disposition, lack of documentation, informal recycling, and inconsistent enforcement are prevalent issues. This conceptual paper explores the reasons for the lack of uniform implementation of regulations, despite the presence of formal regulations in healthcare facilities in Punjab. The study, which employs an integrative review of academic literature, regulatory documents and policy reports, consolidates evidence of the procedural inefficiencies, coordination among stakeholders, institutional capacity, governance and contextual differences between public and private hospitals and between metropolitan and suburban settings. The principal difficulty, according to the review, is that while there are regulations, there is a lack of coordination along the healthcare waste supply chain, including among hospitals, contractors, transporters, treatment operators, regulators and informal players. Drawing lessons from these concepts, Supply Chain Risk Management, stakeholder coordination, contingency thinking, and the idea of "antifragile", the paper introduces a conceptual framework that is context-sensitive, focusing on: responsibility mapping; risk-based governance; competency development; decentralized treatment options; and digital traceability, including RFID, IoT, AI and blockchain. The proposed framework offers a foundation to enhance the implementation of regulations and sustainable healthcare waste management and propositions for future empirical testing in Pakistan and similar developing-country contexts.

Keywords: Infectious Waste Management; Regulatory Implementation; ; Hospital Waste; Stakeholder's Fragmented Coordination; Healthcare Compliance; Environmental Governance.

Introduction

The type of waste produced by healthcare facilities vary significantly in nature and level of hazards. The majority of healthcare waste can be similar to normal household waste but some proportion could include infectious substances, sharps, pathological waste, pharmaceuticals, chemicals and other waste which needs careful handling. If hazardous and non-hazardous streams are combined, the amount of water that will need the

specialized treatment will increase, the costs will rise and waste workers, communities, the environment, and hospital staff will be at risk. (WHO, 2014) and the International Committee of the Red Cross (ICRC, 2011), emphasized that children are more likely to suffer due to infectious waste risks being incapacitated, malnutrition, low birth weight, and stunted growth. Final disposal is not the only area of concern in medical-waste management. It is a constant process starting from the point of waste generation and labeling of waste, collection, storage, means of transport, treatment and the last mile disposal. All the phases rely upon the performance of both preceding and succeeding actors. Even a well segregated container can render hazardous if mixed out during collection or if kept beyond safe limits or if no documentation is provided for it during transport or if diverted to informal recycling. (Windfeld & Brooks, 2015; Attrah et al., 2022). An additional leading source of environmental degradation is the healthcare sector, which utilizes resources, emissions and produces items that are eventually thrown away, generates chemicals, and produces trash. Unsafe disposal can lead to the contamination of soil and water, risk exposure for the waste pickers to infectious substances or sharp objects, as well as release of harmful emissions when burning the waste. Thus, medical-waste governance is a question of health-care quality and an environment-protection responsibility. (Lenzen et al., 2020; Karliner et al., 2020; Singh et al., 2022). Regulatory measures have been enacted in Pakistan, which govern hospital waste management. There are formal expectations in the Hospital Waste Management Rules, 2005 and Punjab Hospital Waste Management Rules, 2014 regarding responsibilities and procedures of waste-management. These instruments do show that there is no blanket explanation of the medical-waste issues in Pakistan by looking at the lack of legislations. The more salient issue relates to the lack of a consistent transfer of formal requirements into everyday use. (Government of Pakistan, Ministry of Environment, 2005; Government of Punjab, Environmental Protection Agency, 2014). Research is being conducted in Pakistan, where waste-segregation, documentation, protection of occupation, storage, transporting, treating, training and monitoring have been repeatedly identified as gaps. There are inter-hospital differences that indicate a dependence upon institutional leadership, available resources, staff capability, and contractor performances and local enforcement conditions. There are also some variations in practices of public hospitals versus private clinics and between urban settings. (Ali et al., 2016; Ashraf et al., 2016; Khan et al., 2019; Panezai et al., 2023). These were exacerbated by the Covid-19 pandemic that has led to the inclined uses of items such as masks, gloves, syringes, testing materials, packaging and disposable clinical items. The surge in waste put further strain on the segregation, storage, collection, and treatment capacities. The crisis of COVID-19 demonstrated that the waste management systems, which are almost at their limits of operation, can become unsafe when both the number of wastes and the risk of infection increase vehemently. (World Health Organization,2020; Rahayu et al. (2021). Regulatory compliance is often viewed as a pass/ fail proposition – a facility is either compliant or not. This renders the chain of implementation hidden. There may be a situation whereby a hospital may be in compliance at the point of segregation and not at temporary storage. Waste can be picked up by a contractor on a scheduled basis but moved with incomplete tracing. A treatment facility may accept waste, but then cannot confirm the quality of the treatment. It is therefore important to consider not only individual compliance indicators, but the whole waste flow in effective regulation. This article explores non-implementation as a systemic / relational issue. It suggests that medical-waste regulations can't possibly succeed if multiple departments are responsible, monitoring is disperse and infrequent, and no record of the waste can be kept from its creation to actual final disposal. It also suggests the factors that underlie non-compliance vary by metropolitan versus sub-urban location, and also by public versus private hospital.

The article tackles three interrelated goals.

- *Firstly*, it is a diagnosis tool to pinpoint inefficiencies in hospital waste management processes.
- *Secondly*, it assesses the influence that a stakeholder constellation and regulatory issues have on implementation.
- *Thirdly*, it outlines solutions that can be applied to certain context specific issues such as decentralized treatment, digital documentation, AI-based segregation, and RFID for transportation monitoring.

Procedures, organizational, regulations, and technological issues are interdependent, and they impact medical-waste management in resource-constrained healthcare systems. Problems with segregation can lead to greater volumes of hazardous wastes; and deficiencies in internal collection, storage, transport, treatment and final disposal can put workers, patients, communities and ecosystems at avoidable risk. The various technical issues cannot simply be viewed as isolated technical failure issues, since the flows of hospital waste have multiple departments, external contractors, treatment operators, regulators and in some cases informal waste actors. This interdependency will be explored in the present article in a supply-chain perspective. It aims to find out if traditional Supply Chain Risk Management and resilience methods can be applied to create an antifragile system that uses disruption to learn and increase its effectiveness in the future. The special focus on decentralisation, real-time information, post-shock learning and the context-sensitive adoption of new technologies. The study has accordingly the whole-contextual approach to the following research questions:

Q1. What are the inefficiencies in the flow of hospital waste in the metros and sub-urban areas in Punjab?

Q2. What impacts do we see on effectiveness and implementation of existing medical-waste practices with regard to stakeholder dynamics, institutional responsibilities, and regulatory constraints?

Q3. What are the different implementation barriers between public and private hospitals and between metropolitan and sub-urban hospital setting?

Q4. Can Supply Chain Risk Management (SCRM) be the basis to create an “antifragile” medical-waste system?

Q5. What steps can resource limited health systems take to implement these principles of antifragility such as decentralization, real time data, and post shock learning?

Q6. Which of the operational, regulatory, organizational and technological interventions can help in better management of medical waste?

Q7. What comparative advantages can decentralized processing units provide under different geographical and institutional conditions?

The questions emphasize the linkage between procedural diagnosis and theoretical development and practical intervention. However, believing a single organizational or technology is the cure-all remedy for medical waste is inaccurate, and the article examines whether a different solution is better suited to different hospitals based on size, ownership, geographical location, waste levels, levels of infrastructural readiness, digital readiness, capacity of stakeholders and regulatory enforcement. The medical waste management in Pakistan is regulated by national and provincial regulatory frameworks, which define the roles and procedures for the segregation, collection, storage, transportation, and processing of medical waste. The fact that these rules do exist, however, shows that the lack of regulation is not always the biggest problem. However, implementation will rely on legal provisions being backed up by sufficient funding, trained staff, infrastructure, monitoring mechanisms, institutional responsibility, and coordination between health, environment and local-government institutions.

The regulatory environment has a direct link to how an antifragile medical-waste system is able to be developed. When responsibilities are not clearly defined, information is unavailable to make informed decisions about the system's operation or conditions, or responsibility stops when the waste moves to another player, then a system cannot learn from disruption or make decisions that raise the performance level. Regulation should therefore be viewed not just as a collection of laws, but as an institutionalisation of information, responsibilities, corrective actions, and learning. Pakistan Hospital Waste Management Rules, 2005, give formal support for delegating the responsibilities of waste-management in health care premises. The regulations acknowledge that hospital waste needs to be segregated, collected, transported, treated, and disposed of systematically and not be collected in ordinary municipal-waste collections. They make medical-waste management a legal requirement and an integral part of healthcare administration. In 2005, the Government of Pakistan, Ministry of Environment, issued the following:

While important, the operational capability is not guaranteed by the existence of national rules alone but is the result of formal legislation. Healthcare facilities must have adequate containers, secure storage areas, trained workers, collection procedures, transportation mechanisms, access to treatment, documentation and supervisory mechanisms. While these resources exist and, in some cases, are also available, in others they may exist but not be consistently available, and in some cases, regulations may lead to nominal or documentary compliance, lacking of any actual improvement in actual waste practices. There are also some national environmental institutions and policy guidance in Pakistan that is included in the overall regulatory environment. But, where there is overlap of different institutional mandates and where the implementation capacity is not equal, there may be uncertainty on aspects of monitoring, inspection, reporting and enforcement. The primary reporting agencies could be health-sector authorities in the case of hospitals, and transportation, treatment emissions, environmental contamination, and end disposal might be under environmental or local-government agencies. (Pak-EPA, 2020)

Antifragility concept suggests that there should be ways to be sure of operational failures, report them, analyse them, and make them into better operating procedures. An inspection-based regulatory regime can detect non-compliance when it is apparent, but is not effective to achieve institutional learning or ongoing improvement in performance. The Government of Punjab has introduced province specific rules for Hospital Waste Management in 2014, to translate National Principles into Provincial Responsibilities and Implementation Requirements. These rules will give the desired legal backbone to the regulation of waste practices in the rather heterogenous health system including the large teaching hospitals, hospitals at the district level, private hospitals, clinics and health institutions which are spread all over the country. (Gov't of Punjab, EPD, 2014)

The diversity in healthcare places in Punjab is putting an impact on the implementation challenge. Hazardous waste management and the services involved can be complicated for large metropolitan hospitals, which can be expected to produce significant amounts of hazardous waste. In smaller, or sub-urban, facilities, the amounts may be smaller but with fewer treatment plants and qualified contractors, less digital computer systems, and less frequent regulatory inspection. These differences suggest that for the same regulatory purpose it is advisable to choose different modes of operation.

A continuity of accountability is also a provincial problem. In a clinical department, healthcare workers might generate waste which is separated, collected by support workers and taken to temporary storage, transported to a contractor, treated by an external facility and disposed of by another authority. Each transition opens a potential opportunity for information and accountability gaps. Without documentation and

verification of these stages, it will be hard to prove the level of compliance. A hospital can claim its responsibility has been fulfilled if waste is delivered to waste collector, but there is no definite proof that the waste has arrived at a meant facility or properly treated. Likewise, regulators may audit hospital records, but will not be able to audit the complete flow downstream. This discontinuity corroborates the need for a supply-chain model where a flow and circulation of physical waste, operational information, and accountability are fostered. Despite the potential of other technologies to help optimize this continuity, such as use of RFID, electronic manifests, Internet of Things (IoT) monitoring, and shared digital records, responsibilities, data expectations, and enforcement methodology must be defined.

International guidance focuses on separation and segregation at source; colour-coded and transparent containers; safe handling of sharp items; safe temporary storage; correct treatment; occupational safety; and documentation systems. It also emphasises the importance of minimising waste, and the need to choose a treatment technology based on the waste's composition, the size of the plant, the nature of the existing infrastructure, available local technical skills/expertise, and environmental results. (World Health Organisation, 2019; ICRC, 2011).

It is at this point that the principles mentioned in this article can be used to support the contingency argument. While outcomes requirements are determined by international standards, the strategy to meet them would take into account local conditions. Depending on the size of the metropolitan hospital, it might be able to accommodate on-site treatment, have the ability to send off some advanced processing to others, be mobile for collection and/or treatment, or be grouped in clusters to share. Recent international guidance identifies the services for water and sanitation; hygiene; environmental cleaning; electricity and healthcare-waste as interlinked cornerstones to safe healthcare services. Poor medical-waste management, however, should not be considered to be a stand-alone environmental issue. It can be a sign of more extensive issues with infection control, building structural safety infrastructures, staff safety, and institutional management. (World Health Organization, 2014; United Nations Children’s Fund, 2024; World Health Organization, 2023)

International guidance may also be valuable for determining if current local (Pakistan & Punjab) rules and regulations are matched in practice. Without taking into account local limitations of resources, however, interventions based on transferring of international models can yield solutions that are inappropriate or unsustainable. Thus, the concept of an antifragile framework proposed is based on international principles of safety, and contextual diagnosis, decentralized capacity, real-time information and institutional learning. The research questions define the procedural, organizational and technological conditions influencing the implementation of the safe management of medical wastes while the regulatory environment sets the minimum requirements for safe medical-waste management. In combination, these are essential for considering how medical-waste systems can be moved from being vulnerable to resilient to being anti-fragile.

Regulatory compliance, the performance of the supply chain and digital technologies are not viewed as unique fields. Treats them as the elements of a single medical-waste system that work together. Regulations set the goals, arrangements in the supply chain dictate the flow of waste and information, while technological solutions can enhance visibility and control. It is when these elements enable the system to sense failure, reconfigure, and bring about learning from the disruption that antifragility emerges.

Literature Review

Medical-Waste Management in Developing Countries

In developing countries, medical-waste management systems are typically hampered by lack of budget, infrastructure, staff training, waste segregation, treatment, and

enforcement. For lack of specialized services or due to cost, or geographical location, facilities may employ incorrect storage or disposal methods. (Ali et al., 2017; Zamani et al., 2021). The repercussions of bad management will not stay confined to the hospital. Sharps workers and informal recyclers are at risk for sharps injuries, risks of infection, chemical exposure, and unsafe working conditions. However, communities close to dumping or burning sites sometimes are exposed to environment and public-health risks. (Gautam et al., 2024; Singh et al., 2022)

Often, technologies are spoken of as a solution to the problem, but it is a complex issue to select a technology. The various techniques include incineration, autoclaving, chemical treatment, shredding, plasma gasification and many others which vary with regard to cost, size, emissions, maintenance and suitability for specific waste types. Installed without trained personnel, power supply, maintenance or an appropriate waste segregation process, a technology will fail. (Attrah et al., 2022; Erdogan & Yilmazoglu, 2021; Çelik et al., 2022)

Evidence from Pakistan

In Pakistan, the gaps identified in the segregation, storage, treatment, transport, protective practices, awareness and institutional monitoring have been documented. Hospital personnel may have some understanding of the general categories of waste but don't have regular hands-on training, oversight, or materials. (Ali et al., 2016; Riaz et al., 2023). Both public and private facilities could have strong and weak points. Private hospitals may have a more flexibly procurement and close managerial control, but on the other hand, they may have visible compliance or cost-cutting. Formal committees and larger infrastructures may be present in public hospitals, however, this is accompanied by a reduction of efficiency due to bureaucracy, limited budgets, staff changes, and lack of responsivity. These patterns are not pan-al and should not be assumed. (Ashraf et al., 2016; Panezai et al., 2023).

In the province of Punjab, a public hospital assessment has been undertaken showing the ongoing relevance of systematic waste planning, public hospital level capacity, monitoring and implementation support. That type of evidence suggests that regulations mandate institutional structures to offer a way for formal obligations to be transformed into practices. According to Punjab Health Sector Reforms Support Project (2013), there are 90 government hospitals with an available bed capacity of 10,024. Literature review of hospital-waste execution in Pakistan further indicates that there are environmental issues due to poor treatment and disposal. Unsafe recycling is also very relevant as a discarded product of medical nature can re-enter the commercial circuit, making the consumers and the informal workers responsible for the risks. (Shakira Mukhtar et al., 2018; Chand et al., 2019)

The Regulation–Implementation Gap

Regulation sets out standards implementation is a matter of coordinated action. Although some statutes or other legal rules may provide that waste materials are to be separated, hospitals need proper containers, educational programs, and supervision, as well as cleaning, scheduled in-house waste collection and penalties for mixing. There may be gaps in implementation where institutional responsibilities are spread across departments and there is no clear departmental ownership for the institutional responsibility. Clinical safety may be controlled by infection-control personnel, administration by contract administrators, environmental regulators by treatment or disposal facilities inspections, or by cleaning personnel by waste transportation. Without integration these functions, problems can be passed on from one actor to another. Implementation research in the field of health policies has highlighted that evidence and a formal policy need to be built into the day-to-day work of decision-making and its structures. In absence of authority, resources, incentives, information, or institutional support, it is unlikely that rules will result in consistent change. Another

gap regarding written and operational compliance is in the documentation. Paper records can be incomplete or retrospective, or even not related to the actual waste movement. Administrators will have no reliable information to track what contractors are doing and regulators won't be able to trace the chain of failures or inadequacies. (Koon et al., 2016)

Procedural Inefficiencies Across the Waste Flow

Segregation

The greatest risk occurs at the source of the waste generation, where the waste is not yet segregated. Segregation at this stage is the most important. If sharps and infectious material are placed in the same container, the entire container may be classed as hazardous waste. Failure to segregate waste into bins is commonly due to lack of the container, lack of understanding of bin labelling, poor bin location, staff work load, lack of orientation, inconsistent colour coding or the possibility of a cleaner working out the problem later. (World Health Organization, 2014; Riaz et al., 2023)

Internal Collection

Waste can be picked up via inappropriate collections, open-ware containers, or inadequately secured trolleys. Collection schedules may not align with amount of waste collected, resulting in waste overflows or build-up of waste. Cleaners and handlers are usually in a low status position in their organizations and do high-risk jobs. Safe implementation is therefore dependent on co-ordination to ensure their knowledge, protective equipment, vaccination, supervision and access to incident reporting.

Temporary Storage

Storage areas might lack security, ventilation, accessibility to unauthorized personnel, or proximity to patient areas or food-service areas. The separation of waste categories is just as important as the correct segregation in clinical source. It is important also of holding power, or storage. Delaying collection will lead to odour and risk of infection for containers, container damage and strain on limited container storage capacity.

Transportation

Schools often experience responsibility gaps in their transport. Waste might depart the hospital without full documentation of how much, what kind, when collected, who who, where and what happened/confirmed. Poor monitoring may allow for changes in route, transfer, mixing or informal diversion, where a contractor works in more than one facility. Manual signatures do not necessarily supply reliable chain of custody evidence.

Treatment and Final Disposal

Treatment failure can be due to equipment break-down, lack of capacity, incorrect functioning of equipment, electricity problems, insufficient maintenance or incorrect equipment technology chosen. Untreated wastes could be stored or pass through unsafe means if backup arrangements are not available. For hospital administrators, the last step is the least known one, being the disposal of waste. Facilities might not have any good information on what happened after the collection if there is no treatment certificate or verification of disposal or regulatory information integration.

Stakeholder Fragmentation

Multiple internal and external stakeholders are involved in the hospital-waste management. In the clinic, clinical workers, nurses and lab, infection-control, waste-management committees, procurement, administration and cleaners influence performance. Transport contractors and treatment operators, regulators, municipalities, recyclers, and communities have influences on outcomes from the outside. Fragmentation is a situation where everybody does just a bit and nobody takes responsibility for anything. Clinical/treatment staff may think the need to bring it to the disposal site is the responsibility of the cleaners, the cleaners think treatment is the responsibility of the receiving facility, the receiving facility thinks treatment is the responsibility of the contractor, etc. Based on research in literature about the supply

chain it might be inferred that for coordination to be involved successful, there must be integrated management of materials, information and relationships. In case of trans-institutional waste, medical-waste governance is absent, and information and accountability aren't even close. The informal contribute to the complexities in the system. Market value for disposed recycling can still be realized and unsafe recycling may occur despite the possible safe recycling. When it is difficult to enforce the prohibition of informal recovery and individuals are reliant on it as a livelihood, formalization on its own cannot prevent informal recovery from taking place. The offerings of solutions thus should take into account economic motivations, controlled recycling of appropriate and safe materials as well as protection of vulnerable workers. (Cooper et al., 1997; Craighead et al., 2007)

Public–Private Variation

The governance and resource of public and private hospitals is variable. It is possible to have formal administrative processes, centralized purchasing and several lines of accountability for public facilities. They can help the standardisation process, but they can slow equipment change or changing contractors or staff recruitment. Private hospital may make quick purchase and managerial decisions, but the level of regulatory performance may differ according to the size of the hospital, the ownership's preferences, the pressure and attitude to be accredited, and the cost of the treatment as well. Therefore, be careful about making comparisons that are assumed to be superior from one of the sectors. How do governance systems affect staffing, accountability, documentation, monitoring of contractors and investing in waste systems?

Metropolitan–Sub-Urban Variation

Larger hospital resources will be available at the metropolitan hospitals in terms of regulators, contractors, treatment facilities and expertise. They are also more likely to produce more waste, have to wait for jobs/overloaded with jobs, to use advanced network of contractors and to experience delays in transport due to traffic congestion. The sub-urban hospitals can have a greater distance between the hospitals and the treatment facilities, a lower density of qualified contractors to supervise services, less technical support, a lower level of inspection coverage, and a higher level of informal disposal services contact. These differences would give impetus to the implementation of a Contingency Approach. The process for achieving safety outcomes that we desire has the same ultimate goal of safety outcomes, however, changes in process may be geographically different or depend on size and capacity of a facility. (Lawrence & Lorsch, 1967; Donaldson, 2001)

Decentralized Solutions

Waste movement can be made visible with the help of the use of digital technology, which increases the effectiveness of implementation. Parameters that can be monitored with IoT sensors include the fill level or the temperature of a storage tank or treatment equipment, or the duration and temperature of a treatment process. The application of RFID helps to link a waste container with its origin, type of waste, time for collection, waste collection vehicle, final destination and final treatment. (Mohamed et al., 2023). AI is potentially able to support image-based sorting, identifying bad pictures returned or predicting waste volumes. It will be practical based on the data quality, training, maintenance, connectivity, and the performance of basic segregation systems. (Mohamed et al., 2024).

Blockchain can make it possible to share the record among hospitals, contractors, treatment facilities, and even regulators. But it cemented the issue when the data it was based upon were incorrect or there was an ambiguity as to which persons were accountable to whom. Digital traceability is thus not a governance tool, but an accountability tool. (Le et al., 2022). If the treatment is decentralised, then transport may be less far and storage time possible may be less and only need one treatment plant.

Centralized treatment services may not be available on a consistent basis which may allow for on-site, cluster, modular or mobile treatment to be possible. A decentralized system, however, does require technical skills and the keeping up of the equipment, control over the environment, and sufficient waste to be worth maintaining.

Analytical Framework

The analytical framework looks at the regulatory implementation by five interlinked dimensions: operational capacity, stakeholder coordination, monitoring and enforcement, legal clarity and contextual fit. The role and responsibilities are clearly described by laws: for waste generation, transportation, treatment and managing failure. Operating ability includes facilities, staff properly trained, protective equipment, documentation and financing. Stakeholder collaboration connects hospitals, contractors, treatment operators and regulators, sharing information and a shared responsibility. Monitoring is a combination of inspections, reporting, chain of custody records, treatment confirmation and evidence of incidents. Contextual fit is a principle of implementation that sees fit as dependent upon the size, location, quantity of waste, infrastructure, and information technology readiness of the hospital, as well as the consistency of public health, occupational safety, and environmental protection results.

Theoretical Framework

The present study is based on Regulatory Implementation Theory, Stakeholder Theory, and Contingency Theory while adopting the framework for Supply Chain Risk Management (SCRM) and understanding the Antifragility concept for non-implementation of regulatory frameworks on infectious waste management in the province of Punjab, Pakistan. The three theories served as the main theoretical underpinnings of the analysis of implementation behaviour, the relationship between stakeholders and the context-specific reactions by actors at the organizational level. These perspectives are complemented by the process oriented approach of the SCRM framework for risk and disruption analysis of healthcare waste management chains, and the Antifragility concept can be used as a lens to understand how a healthcare waste system can develop further, beyond also being resilient, by learning from disruptions and continuously improving the operational performance. Both of these perspectives, in the form of theory and concepts, form a full framework for examining the institutional, operational, organizational and contextual determinants of the successful application of the regulations for infectious waste management.

Regulatory Implementation Theory

One of the core principles to grasp is the difference between formal regulations and the 'real world' practices and attitudes of everyone involved with the service.The primary concept in understanding this is Regulatory Implementation Theory. While Pakistan's countrywide and provincial laws and policies have introduced various regulations for healthcare waste management such as the Hospital Waste Management Rules, 2005 and the Punjab Hospital Waste Management Rules, 2014, the presence of legislation does not suffice to ensure effective implementation. This demands adequate institutional capacity, adequately trained staff, financial resources, infrastructure, monitoring systems, procedures on documentation, and defined responsibilities. Therefore, it is argued that the formal compliance of the healthcare facilities to regulations may exist while unsafe segregation, storage, transportation, treatment and disposal of waste occur in day-to-day activities.

Stakeholder Theory

Stakeholder Theory helps to understand the interconnection between the various players in infectious waste management. The healthcare waste stream is not limited to hospitals, but includes clinicians and nurses, laboratory workers, waste workers, cleaners, waste-management committees, contractors, transport carriers, facility/treatment workers, environmental regulators, local governments and, in certain

situations, informal waste collectors. Coordination between jurisdictions, and even within each district, is often less than ideal due to divided responsibilities by the various stakeholders for distinct activities within the waste-management system, poor communication and conflict between jurisdictions and different institutional priorities. This theoretical approach is therefore suitable to explain why there is a lack of implementation of the regulations.

Supply Chain Risk Management (SCRM) Framework

In addition to the theoretical perspectives, the Supply Chain Risk Management (SCRM) framework is presented, which conceptualises the whole process of infectious waste management as one supply chain, from segregation and from the waste to temporary storage, transportation, treatment and final disposal. The different operational phases are closely intertwined with each other so that failures in one process may be passed on and result in a failure in the next. Accordingly, key principles of systematic risk identification, tracking the chain of custody, oversight of contractors, sharing of information, treatment verification, and continuity of accountability across organizational boundaries are highlighted in the SCRM framework. This systems perspective is used to analyze the failure in the procedures as well as to recognize opportunities to bolster the reliability of the healthcare waste supply chain throughout the systems.

Antifragility Concept

The study also introduces the Antifragility concept from author Taleb (2012) as an additional conceptual framework, but not as an actual theory. Antifragility is distinctly different from resilience, which is about resistance to disruption, but it is another facet of vulnerability toward uncertainty, variability and operational stress, in which systems get better, if not bigger. Unlike resilience, which is about resisting disruptions, antifragility is the adaptability in a system, in which systems get better, if not bigger, from uncertainty, variability and operational stress. In infectious waste management, the focus is on institutional learning, continuous improvement, reporting, corrective action, and governance. Digital technologies can contribute to the principle of antifragility: RFID devices, Internet of Things (IoT) sensors, artificial intelligence (AI), electronic manifests, and integrated monitoring systems can aid in the traceability, transparency and data-informed decision-making processes. Technology alone, however, is neither sufficient nor necessary for being antifragile if it is not backed by capable staff, the ability to learn from mistakes and experiences, weak governance, and weak regulation.

Contingency Theory

Hence, it is obvious that the Contingency Theory seeks to resolve issues why a single implementation strategy is found inadequate in addressing the diversity of healthcare facilities that exists within the province of Punjab. Public and private hospital governance mechanisms, financial resources, managerial autonomy, regulatory pressures and organizational capacity are very different. Similarly, the hospitals in metros and sub-urban areas have all different coefficients of waste generation, availability of treatment sources, freewheeling transportation network, availability of contractor services, readiness for digitization implementation, and regulatory inspection coverage. Therefore, though the objective of the regulation must stay the same, the implementation of the regulation needs to be tailored with regard to the specific characteristics of the organization and environment. This view lends itself to interventions that are locally based: decentralised treatment facilities, cluster-based treatment models, mobile treatment applications and scalable digital monitoring systems in the context of local institutional capacity.

Integrated Theoretical Perspective

Based on these complimentary viewpoints, the study claims that five interrelated dimensions legal clarity, operational capacity, stakeholder coordination, monitoring, and enforcement, and contextual fit—are impacting the setting up of the regulations in the field of infectious waste management. Regulatory Implementation Theory gives insights to the role of institutional capacity in complying with regulations; Stakeholder Theory provides explanations on the role of multiple actors in coordinating the process; SCRM framework analyses procedural risks in the waste-management chain; Antifragility concept explains the benefit of adaptive learning and continuous improvement; and Contingency Theory justifies context-specific solutions for regulatory implementation across different health care contexts. Thus, effective infectious waste governance demands a lot more than the presence of regulations. However, the sustainable implementation requires coordination among institutional responsibilities, the availability of reliable information systems, effective monitoring and enforcement, organizational learning, and strategies for implementation that suitably address local operational realities. This framework is based on theories that already exist and is supplemented by complementary management and conceptual perspectives, offering a holistic approach to understanding the institutional, operational, technological and contextual factors driving the implementation of those regulations in infectious waste management.

Theoretical Relationship

Legality, capacity, stakeholder coordination, monitoring and enforcement, and contextual fit have an impact on the way the regulatory implementation takes place. All these dimensions have an impact on the performances of waste segregation, pickup, storage, transportation, treatment and final disposal. Flaws in any of these areas heighten risk of regulatory non-implementation. In the opposite direction, with appropriate coordination among stakeholders, good risk management, institutional learning, digital tracking, and the sensitivity of their implementation, healthcare waste systems are made more resilient and, then, continuously learn and adapt to become antifragile.

Research Methodology

Research Design

The study uses conceptual design with the help of an integrative literature survey to analyze the non-implementation of regulatory body on infectious waste management in Punjab, Pakistan to mitigate the issue. This study takes an integrative literature survey approach with a conceptual design to identify the issue as non-implementation of regulatory non-implementation on infectious waste management in Punjab, Pakistan. The study does not create new empirical evidence, but adopts a systematic evidence synthesis approach summarizing and integrating evidence from peer-reviewed academic publications, regulatory documents, government guidelines, organizational protocols, and theoretically identified evidence to build a unique sense of the factors affecting regulatory implementation. The integrative review approach is especially suited to synthesizing findings derived from patchy “disciplinary” information to uncover common barriers for implementation, stakeholder relationships, inefficiencies, governance difficulties, and local solutions.

Data Sources

The study relies on several sources of secondary data: peer-reviewed Journal articles, Government regulations, Policy reports, institutional guidelines and International best-practice documents. Important sources include the Pakistan Hospital Waste Management Rules 2005, the Pakistan Punjab Hospital Waste Management Rules 2014, World Health Organization (WHO) publications, the International Committee of the Red Cross (ICRC) publications, along with recently published literature in the field related to healthcare waste management, regulations implementation, supply chain

management, environmental governance and organizational resilience. The emphasis of the review is on evidence provided for waste segregation, internal collection, temporary storage, transportation, treatment, final disposal, regulatory compliance, stakeholder coordination, institutional capacity, monitoring and enforcement, public–private differences, metropolitan–suburban differences, and technological readiness.

Literature Analysis and Synthesis

Thematic synthesis approach for critically analysing selected literature. An overview of the operational limitations, institutional restrictions, governance issues and technological opportunities encountered was identified and contrasted between the studies. This information was then analysed to determine the level of consistency in implementation and identify differences which will relevant to the context in Punjab in relation to infectious waste management. The synthesis allowed for establishing an integrated view of the relationships among the regulatory complexities, stakeholders' reactions, institutional capability, operating processes and environmental conditions.

Conceptual Framework Development

The findings from the thematic research were then used to structure a conceptual framework to understand the non-implementation of regulation for infectious waste management in a context-specific manner. This framework is based on Regulatory Implementation Theory, Stakeholder Theory and Contingency Theory and draws from the principles of the Supply Chain Risk Management (SCRM) framework and the Antifragility concept. All three form together a picture of the factors that interact legal clearness, coordination of the stakeholders, capability of operations, monitoring and enforcement, contextual adaptation, and learning interacting with each other in explaining regulatory implementation. Based on this, the type of the research in this study is theory building not theory testing. Current literature is reviewed and synthesis is done to elucidate the interconnections between legal clarity, institutional capacities, stakeholder coordination, the ability to build infrastructure, staff competency, accountability, risk-based monitoring, decentralized treatment systems, digital traceability and adaptive governance. The conceptual framework thus developed is used here to develop the theoretical basis for understanding the factors responsible for the different implementation outcomes in various healthcare institutions (regardless of their ownership structure), across geographical areas and regulatory and operational contexts in Punjab.

Future Empirical Validation

The proposed conceptual framework will direct the future empirical investigations. With an objective of the validation of the framework, a subsequent quantitative cross sectional study can be made to gather data; public and private healthcare facilities working at metropolitan and sub-urban settings in the Punjab. These proposed constructs may be assessed through structured questionnaires, standardized observational checklists and/or institutional or performance indicators. If there is an appropriate sampling frame available, probability-based sampling methods can be used to increase representativeness. To empirically analyze the relationships proposed, descriptive statistical analysis can be combined with inferential statistical analysis like correlation analysis, multiple regression, Structural Equation Modelling (SEM), or Partial Least Squares Structural Equation Modelling (PLS-SEM).

Ethical Considerations

This research is a conceptual study and does not involve human participants nor primary data collection, it does not need institutional ethical approval. However, future empirical research built on the proposed framework must follow internationally accepted guidelines for research that include voluntary participation, informed consent, confidentiality, anonymity and adherence to the rights of participants throughout the

research process (Morgan, 2007; Creswell & Plano Clark, 2018; World Medical Association, 2013).

Diagnostic Propositions

The study suggests that the regulatory non-implementation in medical-waste management is an integrated causal effect of fragmented coordination of stakeholders, learning limitations in the procedures, poor information consistency and institutional contexts. These possible "hot spots" of poor segregation, collection, storage, documentation, transportation, and treatment can happen if there are lapses along the waste chain, and can create larger environmental and public health risks. It is also hoped that implementation will be different depending on the hospital where it is being used, who owns it, controls it, has access to its tools, and how staffed it is. While digital technologies and decentralized processing offer the potential for better compliance, traceability, and operational efficiency, the effectiveness of their use will require institutional readiness, staff capability, infrastructure, regulatory support, and the unique circumstances of each health care application.

Available Solutions

Medical waste management can be made better by seamlessly translating regulatory requirements into clear operational roles and responsibilities through comprehensive waste-management committees, training: by-titles/ by-functions, infrastructure for segregation, and improved contractor oversight. Where institutional capacity and basic infrastructure are adequate, there should be standardised digital manifests, RFID-based transport tracking, selective IoT monitoring and segregation facilitated by electric current intelligence. Cluster or mobile treatment options help minimize risk of storage and transportation hazards when central options are at a distance or are inaccessible. A risk based inspection process with built-in health and environmental data must exist and evidence of treatment and final disposal must be verified. Safe recycling should be managed with the formal participation of worker protection and through exclusion of hazardous materials. Reporting incidents and near misses should not only be used as an instrument for punishment, but for corrective action, institutional learning and continuing system improvement.

Context-Specific Implementation Model

The priorities for implementation should be adjusted based on the size, ownership, location and infrastructure of the hospital and access to treatment. Department level monitoring, dedicated waste team, digital manifest, RFID tracking, review of contractors' performance, regular audits and backup treatment capacity are essential in large metropolitan public hospitals. Contractual responsibility, e-reporting, competency of staff, integration of accreditation and verified treatment records are key factors that should be highlighted in a metropolitan private hospital. Sub-urban public hospitals require reliable containers, basic training, secure storage, scheduled transport, streamlined documentation, cluster-based or mobile treatment as well as increased provincial support. Shared transport and shared treatment contracts, collection schedule uniformity, low cost digital records, regulatory verification, periodic training and minimised storage may be worthwhile options for smaller private facilities.

Discussion

Regulatory Non-Implementation as a Systemic Outcome

This is the reason why it has been predicted that the findings of this framework of medical-waste non-compliance will be systemic effects of non-compliance and not individual errors by front line workers. The level of errors in segregation, storage, documentation, transportation and treatment are influenced by the interplay of infrastructure, workload, institution purpose, supervision, staff capacity and inter-institutional coordination. When the system is not capable of identifying and fixing the causes of individual mistakes, places the responsibility on a particular person to correct

them, and/or does not provide ways to prevent them from happening again, they become entrenched. Therefore, regulatory implementation needs to be evaluated throughout the full extent of the waste chain. You can't make up for failure by success in another stage. The benefit of correct segregation is lost if it is later mixed, moved without documentation or sent to an unknown treatment plant. The proper measure of analysis is thus the uninterruptedness of the safe movement of material, the dependability of information, and the continuity of institutional responsibility from birth to final disposal.

Beyond Organizational Boundaries Accountability

One of the main issues in medical-waste management is when waste is transferred between departments and/or organizations, accountability becomes fragmented. The handoff, or transfer, is often considered the end of responsibility, whereas environmental and public-health risks persist outside of the hospital. This results in a governance vacuum between the generation, transport, treatment and disposal of waste. There needs to be a sense of duty to keep implementation going through such changes as the custody of the operation and hands-on implementation. Link hospitals, contractors, treatment operators and regulators, via verifiable records and obligations. This is not to say that all of these activities need have been carried out by the same institution; rather it is to say that each actor must be able to show that its part was done and the subsequent step taken when it was needed. Thus, there is a need for coordinated accountability instead of individual compliance of the organizations, before the regulators can exercise effectiveness.

Bringing Legislation to a State of Sufficiency and Power to Implement.

Even with legislations at the national and provincial levels it shows the national and/or provincial situations, that the absence of laws is not always the problem encountered. Adding more regulations without helping in implementation capacity can lead to growing administrative burden without changing the material practices. A more critical question is whether legal requirements are met by the infrastructure, funding, people, monitoring, enforcement, and institutional coordination. Legislative revision may still be required where there are ambiguities of responsibility, changes in technologies, or a dispersion of enforcement authority. However, evidence that points to where and why there is a need for reform should be the basis for reform. Therefore, emphasis of policy should be changed from rule production to implementation management, clear operation, measurable performance, correction follow-up.

Contextual and Technological Fit

Healthcare facilities need common safety and environmental practices, but are not expected to use the same approaches to operations. The arrangements that can be implemented depend on hospital size, ownership, geographic location, volume of waste, distance of transport, access to treatment services and digital capacity. Consequently, while standardisation should cover any necessary outcome, essential documentation and occupational protection and any practices that are not allowed, flexibility should be afforded in the configuration of treatments, monitoring systems, staffing and arrangements for collecting. Digital technologies could have a supportive effect on implementation aimed at increasing the visibility, traceability and support for decisions, but cannot compensate basic institutional capacities. Their impact is contingent upon good quality data sources, training of users, infrastructure, upkeep, and regulated utilization of data produced. The implementation of technology should thus not reflect a general notion of modernization, but needs to be seen as a reaction to a clearly identified failure in the process. The article concludes overall that sustainable improvement efforts demand a coordinated effort in terms of regulation, organizational capacities, joint work by stakeholders and surrounding conditions. Accountability through the chain of command, resources sufficient to implement medical-waste

systems, and technology that does not supplant good medical-waste operations is fundamental to effective systems.

Conclusion

Nevertheless, the reason for the medical-waste mismanagement in Punjab isn't only due to the absence of regulation. What is already available in the form of formal rules but is unevenly implemented in Pakistan and the Punjab is that legal responsibilities are not always translated to resourced, coordinated and measurable legal processes. The higher risk weak points are all along the waste chain during segregation, in internal collection, in the storage, during transport, during treatment, in documentation and at final disposal. Failure adds up – this is through the transfer of accountability and the failure is not verified. Fragmentation of stakeholders is thus at the heart of the issue. There is interdependency between all these actors, including hospitals, regulators, contractors, treatment operators, transporters and informal actors, who have some role in determining outcomes, but responsibilities and information systems are not linked. The obvious public–private and metro – sub-urban differences are even more telling of the need for a one size fits none solution. Geographic positioning, size and institutional capacity, access to treatment and readiness to digital tools should all be taken into account in the design of operational arrangements, but in line with common safety principles. This includes responsibility mapping, competency-based training, advanced waste committees, control of contractors, inspection based on risks, electronic manifests, tracking vehicles by RFID, use of Selective applications of AI and IoT and cluster or decentral treatment. It's not about technology for the sake of technology. Technology should be leveraged to create clear procedures, reliable data, accountability and enforcement. It is important for Punjab to move from the issuance of rules to implementing the medical-waste governance. This includes making regulation 'visible' in process controls, connecting information to the flow of waste and ensuring there is confirmed responsibility for waste with each waste transfer.

Recommendations

Integrated Chain of Accountability Framework (ICAF)

A single accountability system for the medical-waste chain from generation to segregation, transport to treatment, and disposal should be introduced in Punjab. To develop the Responsibility Matrix for every activity, for each healthcare facility, a list of Responsible Department, Officer, Records required, Method for verification and Escalation System must be developed. But, responsibility shouldn't stop when waste is turned over to a contractor; hospitals still have a responsibility to ensure responsible conveyance, treatment and disposal. The regulators should demand that there be documented evidence that waste has gone through the whole approved process. This would minimize the possibility of “passing the buck” and decrease the scope for omission of action both horizontally and vertically, and point to somewhere and someone to see if a failure to act has occurred. Diverse agencies with overlapping, though complementary, roles and responsibilities in health, environmental regulator/control, hospitals, contractors, and treatment operators should be formally clarified to avoid regulatory overlap and institutional ambiguity. (Government of Pakistan, Ministry of Environment, 2005; Government of Punjab, Environmental Protection Department, 2014).

More Specific and Tiered Conformity Requirements

Medical-waste rules should hold consistent results for safety and the environment, but offer varied routes to those results, depending on hospital size, ownership, location, volume of waste and accessibility of treatment plant. While in the large metropolitan hospitals it is possible that they need dedicated waste teams, digital tracking, on-site waste treatment and frequent audits, in smaller sub-urban hospitals it could involve shared waste transport, cluster based treatment, simplified electronic reporting and

enhanced provincial support. There should be some level of compliance, instead a level to which a smaller hospital is not required to operate and the same basic requirements will hold segregation, worker protection, secure storage and authorized disposal. Context-sensitive regulation would make it more feasible, promote realistic compliance and reduce reliance on symbolic documentation that may not reflect capacity. (Lawrence & Lorsch, 1967; Donaldson, 2001; Punjab Health Sector Reforms Support Project, 2013)

Explore the conceptualization of an Integrated Digital Traceability System

A unified digital system for waste-manifestation for hospitals, transporters, treatment facilities and regulators in Punjab should be introduced. Generating department, waste category, amounts, collection time, storage time, transporter, vehicle, destination, treatment and confirmation of final disposal should be registered in the system. RFID can be implemented to help identify containers and validate chain of custody transfers, and IoT could be used for storage conditions and container fill level, vehicle movement and treatment-equipment performance. When a lot of different actors need access to a common, hard-to-tamper record, a blockchain can be taken into account. But digitalization need to be done gradually from reliable records, verified data entry and so. Technology must complement existing duties and is not a substitute for inspection, training and management supervision. (Le et al., 2022; Mohamed et al., 2023, 2024; Rahayu et al., 2021)

Institutionalize Competency Based Training and Worker Protection

Training by attendance: Healthcare facilities should be identified as one of the areas where the focus on attendance should be shifted to competency-based education with tailoring to the roles of the different clinicians and nurses, and laboratory, cleaning staff, administrators and healthcare transport personnel. Training should be provided on the following areas: Segregation, Colour coding, Sharps handling, Internal collections, Emergency response, Documentation, Occupational exposure and Incident reporting. Evaluation of competency should be made by observing, practicing, performing brief assessments and periodical refresher evaluations. The need of particular attention is for cleaners and for handlers/transport workers, who are exposed to the virus directly and often lack institutional authority. Hospitals should provide regular availability of personal protective equipment, vaccination as needed, post-exposure protocols and means to report sensitive injuries. In order to promote training as a means of continuous improvement and not simply a formality in reporting to administration, training records must be coupled with observations of performance and iterative misconduct. Low birth weight, maternal low and high weight conditions, stillbirths, and large-for-gestational-age neonates are among the obstetric and delivery complications associated with these infections. Obstetric and delivery complications caused by these infections include low birth weight, low weight, and high weight for neonates, as well as stillbirths.

Develop Regional Cluster Based Treatment and Backup capacity

Punjab should carry out geographical assessment for waste generation, distance of waste transportation, road accessibility and availability of treatment for identifying the suitable treatment option centralized/ decentralized/ cluster-based treatment. This could be the use of systems on-site in large hospitals with the necessary technical and financial infrastructure, or regulated cluster-treatment centres for neighbouring smaller and medium scale hospitals. A mobile or modular unit may be used for remote or sub-urban locations in areas where transport is limited. Additionally, each hospital should have an approved contingency plan for cases of equipment failure, waste storage or collection failure, or sudden increases in waste, such as by emergency. In addition to the purchase price, the composition of waste; the capacity, maintenance needs, energy supply, emissions, competence of the operator and long-term cost should all be taken into consideration when choosing what technology to select. Regional treatment

planning can help decrease storage time, transport risk and reliance on a single facility and also provide technical oversight. (World Health Organization, 2019; Attrah et al., 2022; Çelik et al., 2022)

Implement Risk-Based Enforcement, Institutional Learning

Routine checklist inspections are outdated and regulatory agencies should adopt a risk-based monitoring approach that identifies facilities that have had multiple segregation failures, incomplete records, longer storage times, no verification of treatment, equipment failure, complaint by the contractor and/or history of dumping. Relationship between inspection results and deadline, corrective-action plan, follow-up checks and enforce with proportions. It is important for the regulators to make a difference between the deliberate actions and ones that those have not been committed because there is no infrastructure, or because their capacity was limited, and punish the intentional violation, while provide technology support if possible to the rest. Hospitals should have near miss, sharps and container leak, miss collection, unauthorized access and treatment failure reporting systems. These should be investigated to inform any changes to procedures, training, contracts and infrastructure, while also looking for systemic causes. Otherwise, regulation would shift from fault-finding to a process of ongoing risk reduction, accountability and learning at organizational level. (Koon et al., 2016; Fiksel et al., 2015; World Medical Association, 2013)

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