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Circular Supply Chain Management for Resource Sustainability and Human Health in Water/Effluent Treatment Plants (WTP) of Nagpur SMEs

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ABSTRACT: Small and Medium Enterprises (SMEs) are the backbone of the industrial development in a belt of the Nagpur Maharashtra Industrial Development Corporation (MIDC) which encloses clusters like Butibori, Hingna, Kalmeshwar, Wadi and MIHAN-SEZ. These clusters produce significant amounts of process water, and trade effluent due to the textile, engineering, chemical, food processing and allied manufacturing. This paper explores the possibilities of incorporating the principles of circular economy into the supply chain management of Water/Effluent Treatment Plant (WETP) having SMEs as operators or as part of the supply chain in Nagpur, with the dual aim of resource sustainability and human health protection. The study adopts a conceptual approach based on literature to establish a closed-loop model for water in the industrial sector of Nagpur, connecting the raw water intake, industrial water production, effluent treatment, resource recovery, and industrial water re-use.In order to propose a closed loop model for industrial water in Nagpur for reuse, the study combines circular economy theory, Indian research on the sustainability of MSMEs, and secondary data on the existing water infrastructure. The paper highlights the main challenges for adoption, including financial constraints, technical capacity gaps, inadequate inter-firm coordination and high operating costs of treatment technology, and explains how a circular supply chain helps to lower freshwater withdrawal, reduce contamination of water bodies by discharges and limit occupational and community health risks due to untreated or inadequately treated discharges. The study ends with a set of managerial and policy recommendations for the water governance at the cluster level in the SME ecosystem of Nagpur.

1. INTRODUCTION

In most manufacturing processes and operations of small and medium enterprises (SMEs), water is both a raw material and a process medium and a discharge stream. Rapid industrialization, especially in regional economies like Nagpur, a tier-II city at the heart of central India, has been exerting pressure on local freshwater resources and effluent treatment facilities, as clusters of SMEs in textiles, metal fabrication, food processing, chemicals and engineering have emerged into the city. The traditional linear approach to water management in industry is abstract, uses water, discharges water, and puts many of the environmental and public health impacts of the process on the shoulders of the communities, agricultural lands and water bodies that receive the partially treated or untreated discharge.

Circular Supply Chain Management (CSCM) is an alternative paradigm. By rethinking the Water/Effluent Treatment Plant (WETP) as a node where value is recovered – reusable water, recoverable sludge, nutrients, and energy – is reintroduced to the production system or to neighboring economic activities, the value of wastewater is transformed from the traditional end-of-pipe liability. In the context of Nagpur SMEs, this reframing brings two interlaced benefits. First, it helps ensure the sustainability of the resource by minimising net freshwater withdrawal, maximising the useful life of limited water resources and minimising discharge volume and toxicity. Second, it safeguards human health – that of workers directly affected by the discharge into the industrial effluent, and also, that of the communities along drains, nullahs and water bodies which eventually discharge the effluent from MIDC clusters.

In this paper, the study is focused on the structure of the circular supply chain principles around the Nagpur's SME base and included the operation of WTP. Establishes a conceptual framework that links supply chain actors (raw material vendors, SME producers, common effluent treatment plant (CETP) operators and regulators) to the physical flow of water, effluent and recovered resources and looks at the implications for resource sustainability and public health that comes with transitioning from a linear to a circular approach. The paper is conceptual rather than primary field survey, it aims at giving a conceptual framework which can be further validated in specific Nagpur clusters by conducting primary field survey.

1.1 Significance of the Study

There are three levels of significance in this study. It takes the concept of circular supply chain to the academic level and moves beyond the largely explored manufacturing of materials and product recovery to the more under-researched area of industrial water and effluent management, specifically focusing on a regional MSME cluster and not the national level or case studies of large firms. At the practitioner level, the framework and recommendations are meant to be directly put to use by the SME owners, operators of CETP and industry association leaders who are considering upgrading shared treatment infrastructure in Nagpur. The study provides a policy-level framework for those charged with responsibility for water resource development in the industry (MIDC and MPCB), which may be coordinated by different departments in a disjointed way.

1.2 Structure of the Paper

The remainder of the paper is organised as follows. The literature review presented in section 2 summarizes the theory of CE, the concept of circular supply chain management, circular economy of water, adoption of CE by SMEs in India, effluent treatment infrastructure in Nagpur, and human health impact of industrial effluent. The research gap is identified and the research goals are stated in Section 3. The literature based conceptual methodology is explained in section 4. Table 1 summarises the industrial and institutional setup of the SMEs and WTPs in Nagpur and is characterised in Section 5. The conceptual framework presented in Section 6 is Figure 1. Section 7 addresses adoption barriers, with the help of Figure 2, and Section 8 provides an overview of the infrastructure for the cluster, in Table 2. The resource-sustainability and human-health consequences of the framework are explored in Sections 9 and 10, respectively, and a case vignette is provided in Section 10a. The findings are presented in Section 11, limitations of the study are indicated in Section 12, policy and managerial recommendations are given in Section 13 and conclusion is drawn in Section 14.

2. LITERATURE REVIEW

2.1 Circular Economy and Circular Supply Chain Management

The academic literature offers more than 100 different definitions of the concept of a circular economy (CE), but all of them tend to follow an approach of "reduction, reuse, recycling, regeneration": keeping finite resources in use for as long as possible. From the Ellen MacArthur Foundation's perspective, CE is a restorative or regenerative by design industrial system and from the European Environment Agency's perspective, it is applied explicitly to water, which is a resource that can be reduced, reused, recycled, and rethought within an economic system. If these CE principles are integrated into the management of supply chains, both forward (forward flow) and backward (reverse flow), the resulting paradigm is called Circular Supply Chain Management (CSCM) and differs from the green, sustainable, and closed loop supply chain paradigms as it explicitly addresses the multi-loop nature of resource flows instead of a one-way focus on mitigating environmental impacts.

2.2 Circular Economy of Water

Water holds a special status in CE scholarship, because it is a resource, product and a service. Conceptual works made in the past few years suggest that the three R concepts (reduce, reuse, recycle) of the circular economy should be complemented by the introduction of water-related concepts (replace, store). In India, various research institutions have pointed out that treated wastewater has a great untapped economic value, and the market worth of treated wastewater is expected to increase significantly in the coming decades, as the scarcity of water will rise and the capacity of treatment systems will grow. Concurrently, research into the urban water sector in India identifies ongoing infrastructure deficits, in which many cities lack sufficient capacity to manage wastewater before it is released to rivers, lakes and drains, and where downstream impacts on water quality and public health are known.

2.3 Circular Economy Adoption Among Indian SMEs

Many studies have focused on understanding the challenges in the adoption of the circular economy by MSMEs in India despite their high contribution to the national economy. Based on case studies of manufacturing SMEs from India, it is observed that the lack of knowledge of circularity in internal business process, lack of technical skills, weak digital infrastructure, and fragmented coordination between the various stakeholders in the supply chain limit the ability of manufacturing SMEs to be circular, while competitive pressure, environmental regulation, and customer demand for sustainable products promote the circularity of manufacturing SMEs. Similar research in other parts of India also suggests that smaller companies find it difficult to invest in circular infrastructure due to scarcity of resources and access to finance, and that they rely on external actors such as the buyers, industry associations or larger anchor companies, for the knowledge and capital required to embrace circular practices, such as the shared use of treatment infrastructure.

2.4 ETI in Industrial Clusters of Nagpur

Butibori, Hingna, Kalmeshwar and MIHAN–SEZ are the MIDC zones of Nagpur and contain a cross section of SMEs in various sectors such as textiles, engineering, chemicals, food processing, fabrications and effluent quantities of which are too low to justify dedicated treatment with high specifications on a standalone basis. Secondary information available suggests that Common Effluent Treatment Plant (CETPs) have been set up as special purpose vehicles, generally in the form of public-private partnerships between MIDC and industry associations, and specialised environmental engineering companies, to collect and treat effluent produced by clusters of SMEs, to comply with the norms of the Maharashtra Pollution Control Board (MPCB). Although a number of small-scale effluent treatment plants (ETPs) are still in use in the region, a Greenfield CETP based on membrane bio-reactor (MBR) technology has been reported for the growing Butibori industrial area, which reflects the transition of the region to more advanced, higher-recovery treatment technology.

2.5 Human Health Dimensions of Industrial Effluent

The literature and international guidance (such as the World Health Organization guidance on the safe use of wastewater) all show a link between inadequate treatment of industrial and municipal effluent and increased risk of waterborne diseases, heavy-metal exposure and long-term toxicological effects on exposed workers, on downstream agricultural communities and on populations dependent on affected water bodies. This body of evidence gives the rationale for human health protection to be a first order design concern for the circular WTP, not an incidental co-benefit.

2.6 Theoretical Lens: Resource-Based View and Industrial Ecology

The framework presented in this paper is based on two different theoretical frameworks. Adopting the RBV, as used in previous researches on SME adoption of the CE, posits that a firm's unique competencies and resources constitute a sustainable source of competitive advantage, which, in the context of CE management of WTPs, implies that a CE capability based on water re-use would render the firm with an enduring competitive advantage in terms of lower input costs and reduced exposure to regulatory risks compared to non-CE competitors. The second lens is that of "industrial ecology" which views an industrial cluster as a natural ecosystem where each process produces wastes as resources for another process. This is especially relevant for MIDC-style clusters where the shared CETP infrastructure provides a degree of physical intimacy, institutional linkage between by-products and water exchange between otherwise unrelated SMEs. The reading of Nagpur's industrial clusters through the prism of industrial-ecology, however, puts the CETP not only in the role of a compliance utility but also in the role of a seedbed of an eco-industrial park where recovered water, sludge and energy flow among the industrial clusters broadly in the same way as nutrients flow inside a biological ecosystem.

2.7 Synthesis and Positioning of the Present Study

As a whole, the literature reviewed above shows that there are three implications for the present study. There is a conceptual language for the circular economy and the circular supply chain which is well developed, and can be applied to the specific physical and institutional attributes of water and effluent management: reduce, reuse, recycle, recover, replace, store. Secondly, empirical studies of MSMEs in India have repeatedly found that various sectors share a set of common adoption barriers – access to finance, skills, lack of coordination, and enforcement of regulations, indicating that adoption barriers are structural factors of the MSME operating environment that are not specific to any given sector. Thirdly, there is enough descriptive secondary information available on Nagpur's CETP and ETP infrastructure, although from a vendor oriented perspective, quite a bit of it is descriptive. The present study is situated to fill exactly this synthesis gap and the regionally representative case study of Nagpur will be able to provide a concrete institutional and infrastructural foundation to the general literature on CE/CSCM in Indian MSMEs.

3. RESEARCH PROBLEM, AIM, OBJECTIVES AND HYPOTHESES

3.1 Statement of the Research Problem

Although the concept of circular economy (CE) and circular supply chain management (CSCM) with respect to MSMEs in India has gained considerable traction, the published research does not explicitly focus on water and effluent management. The literature specific to Nagpur also remains mostly descriptive and vendor-focused with little academic synthesis focusing on characteristics of the CETP/ETP infrastructure and relating to circular supply chain theory or to human-health outcomes. While there is therefore no integrated conceptual framework for the reorganisation of supply chain relationships between SMEs, WTP/CETP operators, regulators and downstream communities around the WTP as a circular resource-recovery node, nor how this reorganisation would be predicted to influence resource sustainability and human health concurrently. The lack of an integrative, testable framework presents the major research problem in this study.

3.2 Aim of the Study

This study aims to develop and frame a conceptual framework for the operations of Water/Effluent Treatment Plant (WTP) serving SME sector of Nagpur and to come up with a set of theoretically grounded propositions regarding the effects of WTP operations on the sustainability of resources and human health, as a base for further empirical validation.

3.3 Research Objectives

- To achieve this objective, the following specific objectives were used to guide the study:
- To study the theoretical literature on circular economy, circular supply chain management, and circular economy of water, and critically review and synthesise it as a conceptual basis for the study.
- To analyse the linear resource flow through which water is being utilised and effluent discharged by the SMEs in Nagpur and to compare it systematically with a circular supply chain (CSC) option.
- To create an integrative conceptual framework to connect the actors of the supply chain, the O3 infrastructure and resource-recovery loops of Nagpur's industrial clusters.
- To understand and summarise the main challenges that affect the implementation of circular WTP in Nagpur's SMEs.
- Build testable propositions to empirically test regarding links between circular WTP adoption and (a) resource-sustainability outcomes and (b) human-health outcomes.

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- To develop managerial and policy suggestions that can facilitate the implementation of circular supply chain at the cluster level in Nagpur.

3.4 Research Questions

The study will answer the following research questions:

1. How is the structural configuration of WTP operations in a circular supply chain different from that of linear supply chain configuration observed among Nagpur SMEs –RQ1.
2. What are the institutional, financial and technical challenges that limit the shift from linear to circular WTP management in the clusters of the city of Nagpur?
3. What is the theorised relationship between circular WTP adoption and outcomes of resource-sustainability (fresh water withdrawn, discharge volume, discharge toxicity, resource recovery)?
4. What is the hypothesized association of human-health outcomes (occupational exposure and downstream community exposure) to the uptake of circular WTPs?
5. What were the most likely cluster level managerial and policy interventions to enable the adoption of circular WTP among Nagpur SMEs?

3.5 Research Hypotheses

The following hypotheses are directional theoretical propositions that are based on the CE/CSCM literature reviewed in Section 2 that formulates the study's conceptual design. They are listed here as options that should be tested empirically, and they are not considered as results of this paper, which is why this is maintained in the discussion in Sections 9–11.

- The findings indicate that there is a positive relationship between implementation of circular supply chain practices in WTP operations and the decrease in the net freshwater withdrawal of the participating Nagpur SMEs.
- There is a positive correlation between the implementation of circular supply chains in the operation of WTPs and the recovery and reuse of resources (sludge, nutrients, energy) within the cluster.
- There is a negative relationship between the proportion of WTP operations using circular supply chain practices and the volume and toxicological load of residual discharge to receiving water bodies.
- Workers involved in effluent handling and treatment in WTPs are related to negative indicators of occupational health risk and the adoption of circular supply chain practices in WTPs.
- Indicators of downstream health risk in WTPs serving cluster drainage areas and receiving water bodies are negatively associated with the adoption of circular supply chain practices.
- The results show that the financing constraints, technical capacity gaps, and weak cluster level coordination, are each negatively related to the likelihood of circular WTP adoption of SMEs in Nagpur irrespective of firm size or sector.

3.6 Scope and Delimitations

The study is set up in three ways. Geographically, it emphasizes on SME clusters in the industrial areas notified by MIDC of the City of Nagpur, mainly Butibori, Hingna, Kalmeshwar, Wadi/Hingna Road belt, and MIHAN/SEZ with the assumption that results may not be generalized without adaptation to other industrial areas. Thematically, the study is limited to water and effluent treatment as part of the larger circular economy and does not include the other themes of the circular economy, such as solid-waste, packaging or product-level circularity, unless they form part of a direct resource recovery process related to WTP (e.g., sludge valorisation). In methodology, it is conceptual-literature, as mentioned in Section 4, it develops and justifies the hypotheses above, and does not statistically analyze primary field data, which is discussed in Section 12.

4. RESEARCH METHODOLOGY

The research design used in this study is qualitative, conceptual and literature based rather than primary empirical survey based. There are four steps in the methodology. First, a systematic literature review (SLR) of academic and institutional literature covering the theory of circular economy, circular supply chain management, and the adoption of circular economy by micro, small and medium-sized enterprises (MSMEs) in India was undertaken, utilizing peer-reviewed journal articles, bibliometric reviews, and policy landscape papers. Second, effluent treatment plants (ETPs) and industrial clusters (ICs) data and information from various sources such as document of clearance for projects by MIDC, operators disclosure, and directory of the industrial unit was reviewed to characterize the effluent treatment infrastructure available in the principal industrial clusters across Nagpur. Thirdly, the results of these two flows were integrated in a conceptual framework (Figure 1) that visualised the circular flows of resources around the WTP node of the SME supply chain. Fourth, barriers that emerged from the literature reviewed were qualitatively coded thematically and presented as a relative-emphasis overview (Figure 2) as a means of discussing adoption challenges.

The study is based on the secondary evidences and literature and not the original field survey of the operator of Nagpur SMEs, so the results of the study should be interpreted as a conceptual framework and a diagnosis of the situation and not as the primary data of a survey. The hypotheses are here presented as theoretical propositions that suggest interdependencies stemming from the literature synthesis and are not presented as statistically testable relationships; this scope limitation is explicitly stated in Section 12 of the paper, and is considered the next logical step in the research agenda, in which H1–H6 can be statistically tested, with primary empirical testing recommended through primary empirical validation, which includes surveying of firms, sampling of effluent quality, and, where possible, health indicators of workers and communities.

5. INDUSTRIAL AND INSTITUTIONAL CONTEXT: SMES AND WTP INFRASTRUCTURE IN NAGPUR

The industrial base of Nagpur is primarily based on the estates notified by the MIDC, some of which house light and medium industry SMEs with shared infrastructure for utilities, roads and environmental services. Among the larger units, the MIDC area of Butibori has steel, engineering, agro-processing and chemical units while Hingna and Kalmeshwar are home to a higher density of smaller units of manufacturing and processing SMEs and MIHAN-SEZ is a blend of export-oriented manufacturing with logistics operations. Effluent qualities are different in each of these clusters, with textile and dyeing emitting high colour and high organic load effluent which is relatively difficult to treat, and engineering and fabrication producing effluent that is mainly comprised of oils, greases and suspended solids.

In Maharashtra's MIDC region Nagpur, the individual effluent from each SME is often too small to warrant dedicated advanced treatment, thus making the CETP model as the institutional approach the most prevalent. In this arrangement, MIDC acts as a facilitator, MPCB as an authority for monitoring, and a special purpose vehicle (usually jointly owned by an environmental engineering company and the local industry association) as an operator of the plant. This is a great way to make the WTP a shared supply chain asset as opposed to a firm-specific cost centre, thereby creating a pre-condition for circular strategies that rely on aggregated, higher quality treated water streams to be made available for coordinated reuse by multiple SME users.

In addition to CETPs, a second tier of smaller effluent treatment plants (ETPs), typically with simpler physico-chemical and activated-sludge treatment, exist within individual SME buildings in individual clusters like Kalmeshwar and the Wadi/Hingna Road belt. The dual structure (small cluster of large-scale CETPs, and large cluster of small-scale ETPs) has implications for circular supply chain design: cluster-wide reuse loops and resource-recovery investment naturally occur at the CETP level, while re-use in washing or gardening in a single unit's own premises are more suited to on-site re-use. To this end, a cluster-level circular strategy for Nagpur is likely to include reuse measures at smaller scale, which are facilitated by ETPs, as well as loops, which are enabled by CETPs, and are multi-firm in nature rather than relying on one or the other option alone.

Table 1. Linear versus Circular Supply Chain Approaches in Industrial Water/Effluent Management

Dimension	Linear (Take-Make-Dispose) Approach	Circular Supply Chain Approach in WTP
Water sourcing	Continuous extraction of fresh groundwater/municipal water for each production cycle	Treated/recycled water reused within process, cooling, and utility loops before fresh intake
Effluent handling	Effluent treated (or under-treated) once, then discharged to drain/river as waste	Effluent treated and re-circulated as a resource input; discharge is a last-resort residual
Sludge & by-products	Sludge sent to landfill or dumped informally	Sludge valorised for compost, brick-making, or biogas feedstock
Supplier relationships	Transactional, one-way procurement of raw material and chemicals	Collaborative network with CETP operators, chemical suppliers, and recyclers for closed loops
Cost structure	Rising cost of fresh water, effluent cess, and compliance penalties	Reduced fresh-water and disposal costs; potential revenue from recovered resources
Regulatory posture	Reactive compliance to avoid penalties from MPCB/CPCB norms	Proactive compliance embedded in design, enabling eco-labelling and market access
Health outcome	Elevated exposure risk for workers and downstream communities from untreated discharge	Reduced exposure risk through consistent treatment and closed-loop handling of contaminants

6. CONCEPTUAL FRAMEWORK FOR CIRCULAR SUPPLY CHAIN MANAGEMENT AROUND WTP

Figure 1 is a conceptual framework that was developed in this study. The framework also differentiates the conventional linear nature of the supply chain (raw material and freshwater intake, SME production, effluent generation and treatment) from the circular loops that can be established by having a WTP as a node rather than an end point for the effluent. Three parallel pathways are indicated coming out of the treatment stage: water-reuse pathway that returns treated water to functions within the same or neighbouring SME units as water; waste-recovery pathway that involves the recovery of sludge, nutrients, and biogas for use in agricultural, energy, or construction-materials value chains; compliant-pathway discharge pathway that is retained as a residual pathway for water discharged from the treatment pathway that cannot be recovered or reused at an economically viable rate.

The framework recognises four groups of supporting actors in the supply chain: (1) upstream vendors and cluster level SME networks; (2) regulatory and institutional actors like MPCB, CPCB, MIDC; (3) technology providers for treatment and green finance and (4) the surrounding community whose health outcomes are directly influenced by the effectiveness of the loop. It is designed as a closed loop or a system, not just a linear pipe, because keeping materials, water and value in the loop makes for a sustainable and resilient system in accordance with the CSCM principle.

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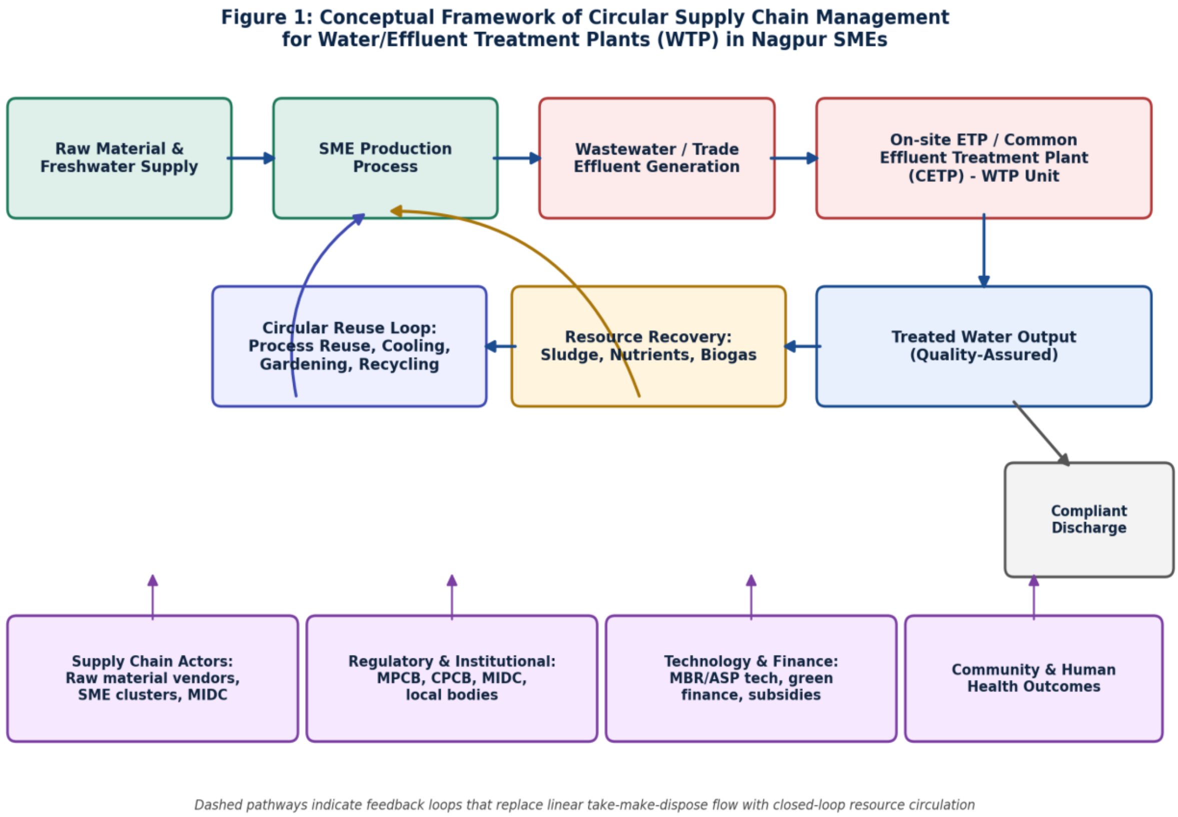

Figure 1. Conceptual framework of circular supply chain management for WTP operations serving Nagpur SMEs.

7. ANALYSIS OF THE CHALLENGES IN IMPLEMENTING WTP IN NAGPUR'S SMES

There are barriers that repeatedly appear in the CE and CSCM literature reviewed for this study which limit the ability to implement the framework in Figure 1. As these barriers are not a direct survey result but a qualitative summary, synthesised from the literature, they are arranged in the following order according to the relative emphasis placed on them in the reviewed sources, as summarised in Figure 2.

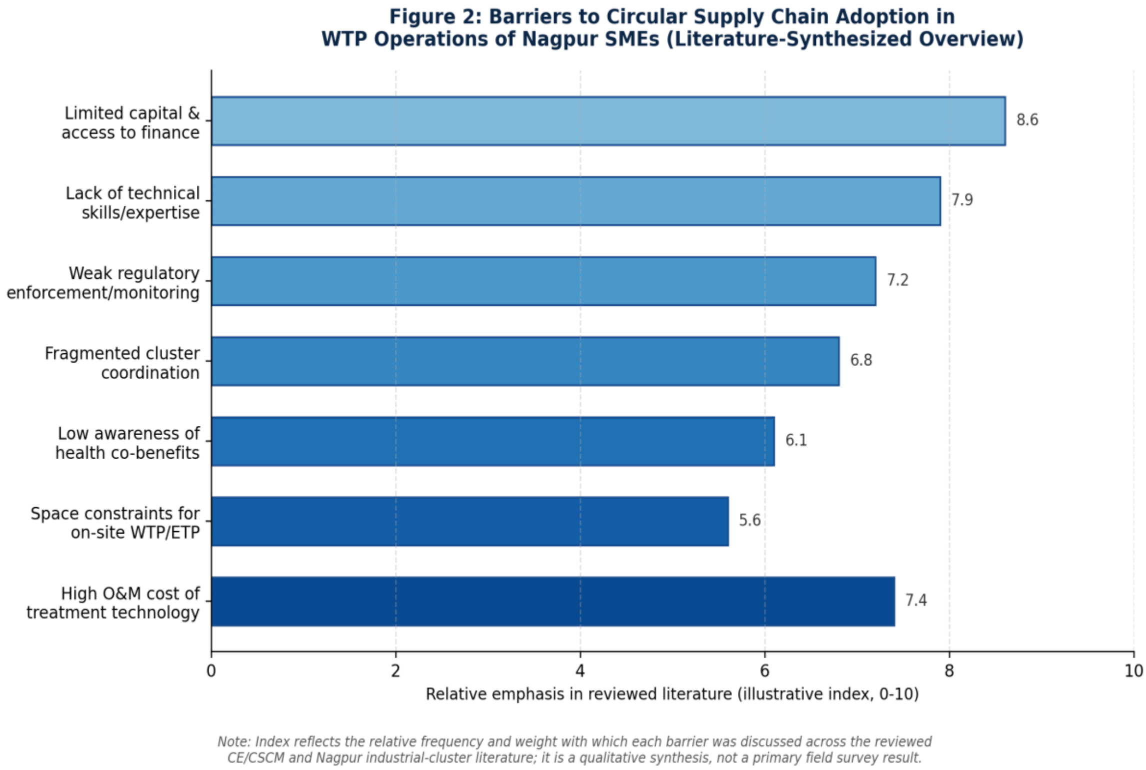

Figure 2. Barriers to circular supply chain adoption in WTP operations of Nagpur SMEs, synthesised from the reviewed literature.

Financing is always the top limiting factor cited: Membrane-based or tertiary treatment technology that yields reuse-grade water is costly to implement, and the potential payback is far out. High recurring operation and maintenance is another closely related cost that can be a barrier to those who can afford initial investment – even for advanced treatment technology. These limitations are exacerbated by a lack of technical sophistication on the inside, as the circular water management needs continuous process monitoring, quality testing and adaptive maintenance, many smaller units are not equipped to conduct. Weak regulation and monitoring limits the competitiveness of staying in a linear, discharge posture, decreasing the need for voluntary circular investment. Lack of awareness within SME clusters of the direct connection between effluent quality and community health, combined with fragmented coordination, hinders the ability to pool effluent volumes and capital for making CETP-based circularity economically feasible, and creates a social and reputational cost for individual firms to invest in upgrading their effluent treatment. Thirdly, on-site reuse loops are restricted by the physical constraints of the older, densely developed MIDC plots, which require extra treatment and or storage capacity.

8. OVERVIEW OF TREATMENT INFRASTRUCTURE IN ALL SME CLUSTERS IN NAGPUR.

The overall nature of the SME activity, and associated water/effluent treatment infrastructure, documented at a cluster level is summarised in Table 2, across the main MIDC areas in Nagpur. The table is sourced from secondary information from institutions and industries and is meant to be representative of the variation in infrastructure across the clusters rather than an inventory.

Table 2

Industrial Cluster / Area (Nagpur District)	Nature of Units	Water/Effluent Treatment Infrastructure
Butibori MIDC	Steel, engineering, chemical, agro-processing SMEs	Common Effluent Treatment Plant (CETP), including a Greenfield MBR-based facility serving Butibori and Hingna clusters
Hingna MIDC	Fabrication, casting, and general engineering SMEs	Predominantly on-site ETPs; several units linked to the Butibori CETP network
Kalmeshwar MIDC	Light manufacturing and processing units	Individual ETP/effluent treatment set-ups operated by private vendors
Wadi / Hingna Road belt	Textile, food processing, and small chemical units	Mix of package ETPs and STPs; wastewater partly reused for gardening/utility use
MIHAN-SEZ	Export-oriented manufacturing and logistics SMEs	Centralised STP/ETP with tertiary treatment for landscaping and non-potable reuse

Source: Compiled by the authors from MIDC environmental clearance documentation, CETP operator disclosures, and industrial directory listings referenced in Section 2.4.

This overview has two patterns of interest. First, the technical challenges in circular treatment are different for each sector, shaped by the sectoral mix of each cluster: the comparatively more difficult oil-and-grease dominated effluent from engineering/fabrication clusters is expected to be less likely to reach a reuse grade compared to the relatively more complex effluent with high colour and high organic load in textile/dyeing clusters. Second, there is evidence that export-oriented or larger anchor units, like MIHAN-SEZ, tend to have more centralised and higher specification treatment infrastructure in place, partly because of the 'buyer-driven' sustainability requirements in export supply chains, which indicates that export linkages could be an additional, market-based driver of circular WTP adoption beyond regulatory and institutional drivers discussed in Section 2.3.

9. RESOURCE SUSTAINABILITY IMPLICATIONS

The WTP operations form the core of a circular supply chain, which directly tackles three pressures on the resources of Nagpur's SME base. Firstly, it lowers the consumption of net freshwater by replacing fresh water with treated water in other non-potable uses like cooling, washing, gardening and some process steps, relieving the pressure on water (both groundwater and municipal) which is already under strain during summer in Nagpur area. Second, it also minimises the quantity and quality of effluent which eventually needs to be discharged, thus decreasing the assimilative pressures on local drains, nullahs and receiving water bodies. Third, it transforms a pure waste stream (sludge, particularly) into an input that can be recovered to be used in agriculture, energy production or construction materials production – the circular economy principle of keeping material within the economy for as long as possible.

This is the effect of these effects at the cluster level. If all of the SMEs can move towards the use of tertiary treatment for re-use grade effluent, the shared treatment plant can be a shared asset for the circular economy as a whole, as it is able to produce reuse grade water on a scale that individual SMEs may not be able to do on their own. This level of circularity at the cluster also brings down the total capital cost for the cluster, as opposed to each SME opting for more advanced treatment on-site.

An additional aspect of resource sustainability that is not always considered is energy. An energy-intensive effluent treatment method using conventional aeration is used; this energy is dissipated just to make effluent safe for discharge without any benefit in terms of return of a resource. If anaerobic digestion or biogas-recovery steps are included in the treatment train, a portion of the plant's operating energy can be recovered from the plant's organic load, thus enhancing the net energy benefit of the plant treatment process. This energy recovery potential could be significant for wastewaters from sectors with high energy value, such as food processing and some chemical industries, which are typically wastewater with a relatively high organic content, ideal for anaerobic treatment, in Nagpur's SME base. Incorporating energy recovery into the circular economy therefore not only helps to promote water's sustainability but also, that of energy.

10. HUMAN HEALTH IMPLICATIONS

There are two case paths involving human health related to circular WTP management: The first is occupational, and in such cases when effluent treatment infrastructure is under capacity or poorly maintained, workers directly involved in effluent handling, treatment plant operations and maintenance are at increased risk of exposure to chemical contaminants, pathogens and process hazards. A circular design approach which sees the WTP as a value generation project, not just a compliance “tick box” project, provides a greater economic incentive for regular operation, maintenance and monitoring, leading to safer working conditions.

An indirect route of transmission of health impacts is via the labour market. In the future, clusters of SMEs that cause a poor local environmental reputation (which is clearly visible in nearby water bodies or drains) may struggle to recruit and keep employees as local employees increasingly become aware of the risks to their health from the company's environmental footprint. In this regard, investment in circular WTP infrastructure also has an indirect (secondary) human capital benefit, besides its direct health protection function, in the form of strengthening the cluster's attractiveness and safety as a place to work.

The second level of exposure is at the community level, where downstream communities dependent on drains or nullahs, or agricultural land irrigated using either river water or groundwater that is contaminated by industrial effluent, are at risk of exposure to industrial effluent pathogens, heavy metals and organic pollutants if the effluent is not sufficiently treated prior to discharge. Guidance from around the world for safe application of wastewater in agriculture emphasizes that treatment quality—not just its presence—is what matters for the protection of public health when reusing wastewater, or releasing it. A circular supply chain framework explicitly recognizes treated water as a reusable product, which will provide a clear incentive to keep the water treated to a high enough standard to be re-used for processes or utilities, since poor-quality treated water will not be economic to re-use for processes or utilities. In this way, incentives for the sustainability of resources and protection of human health are complementary, and do not compete for investment priority.

10.1 Illustrative Case Vignette: A Cluster-Level Circular Loop

For the purpose of making the conceptual framework more concrete, let's take a stylised, illustrative vignette and make it up from the items of secondary infrastructure evidence that were reviewed in Section 2.4 and presented in Table 2, instead of taking it from one documented case, to see how a circular loop would work across a cluster like Butibori. A cluster of small scale dyeing units, food processing units and light engineering units release trade effluents into a common collection system that takes the effluents to the cluster's CETP. In a linear posture, this CETP does a minimum treatment of the effluent to ensure that it is discharged into the receiving water body safely, and the treated stream is not reused. The circular alternative shown in Figure 1 is an upgrade of the same CETP with additional tertiary and membrane polishing steps to provide a certain percentage of the CETP's output that can be reused. That water is then "returned" to the member units as a make-up to the cooling towers, equipment washing or horticulture in the industrial estate, thus minimizing each unit's need for fresh groundwater or municipal water. The sludge produced at the CETP is dewatered and handed over to a local off-taker such as an agricultural farm or brick factory (for reuse), instead of landfilling. The industry association of the cluster helps in coordinating with the other member SMEs for metering and cost allocation and MIDC and MPCB continue to perform their existing roles as regulator and facilitator. This vignette shows that the transformation from a linear to a circular posture doesn't have to follow the construction of new institutions from scratch, but simply has to be the re-direction and incremental upgrading of infrastructure and contractual arrangements already in place in a familiar form in the MIDC clusters of Nagpur.

11. DISCUSSION

Small size of the SMEs does not pose a challenge to the concept of circular supply chain management for WTP operations in Nagpur, but rather opens up new avenues for it. In the absence of an economically viable advanced treatment technology, the existing CETP model already outlines governance and institutional frameworks (clustered volumes, shared ownership, and a regulatory facilitated governance system) to support circular investment at a cluster level. The key challenge for supply chain managers, cluster associations and policy makers, then, is not to create new institutions, but to reorient existing CETP and ETP infrastructure to produce re-use grade output and resources to recover, instead of compliance grade discharge.

Meanwhile, Section 7 reveals that the barriers discussed indicate that this redirection will not be automatic. Blended financing schemes, green subsidy schemes, and shared technical-support schemes co-ordinated by industry associations are identified as some important enabling factors for the adoption of the CE in India's MSMEs as suggested by the reviewed studies, especially due to the financing constraints and technical capacity gaps. The relative lack of focus on health-outcome awareness in the literature reviewed, particularly in relation to the case for circularity, also suggests an opportunity: A public-health intervention approach to WTP investment, as opposed to just an environmental-compliance or cost-saving investment, may expand the circle of stakeholders willing to support cluster-level circular water infrastructure, including local health authorities and community groups.

On a managerial level, the framework suggests that there is a change in the way that the owners of SMEs and cluster associations should consider expenditure on the WTP. The circular approach is not a one-way thinking that simply views effluent treatment cost as a cost element that needs to be minimised, but rather the treatment investment needs to be assessed in the context of the value of the fresh water that will be saved, the cost or value of the effluent that won't be disposed of, or the revenue or cost offset generated by the recovered sludge and by-products. This is not to say that the true constraints on small capital has been removed; it does change the nature of the investment decision though, and it provides a better platform for making investment decisions as part of a joint and collective investment case which an individual SME may not have been able to build up the last time they went to a lender, MIDC or a state industry department for investment funds.

12. DIRECTIONS FOR FURTHER RESEARCH AND LIMITATIONS

This study is conceptual and literature based and no primary field data pertaining to effluent quality, water reuse quantities etc. is presented for the SME clusters in Nagpur, while barrier ranking in Figure 2 is based on the focus mentioned in the literature surveyed, it is not an average of the responses of firms surveyed. Hypotheses H1–H6 (Section 3.5) have been developed, but not statistically tested in this paper and therefore should be interpreted as a research agenda, not as conclusions. The proposed framework should be validated and extended in future using primary field work by conducting structured surveys of the SME operators for testing H1–H3, sampling of the effluent quality at the CETP inlet and outlet points to operationalise the resource-sustainability constructs in H1–H3 and epidemiological/exposure based assessment of health outcomes amongst the workers and downstream communities to test H4 and H5. Comparative case studies of other water management models for circular management in Indian industrial clusters would enhance evidence base on the policy recommendations put forward in Section 13.

13. POLICY AND MANAGERIAL RECOMMENDATIONS

- Upgrade shared CETP infrastructure to tertiary/MBR treatment where the effluent volume of the cluster is such that the investment is justified for re-use as opposed to only meeting minimum compliance requirements.
- Implement agreements at the cluster level to recycle water for the needs of other member SMEs for cooling, washing and non-potable processes, rather than to the watercourse.

- To reduce the capital cost for SME contribution towards shared treatment improvements/upgrades through the creation of blended financing/green subsidy windows through MIDC and industry associations.
- Improve technical-support and training programmes, provided by cluster associations, to counteract the lack of skills for the day-to-day circular operation and maintenance of treatment assets.
- •Develop sludge and by-product valorisation routes formally (compost, brick-making, biogas feedstock) with partnerships with off-takers/agricultural and construction material.
- Enhance regulatory oversight and public reporting of the performance of CETPs/ETPs to raise the reputational and compliance catalyst for delivering quality of treatment.
- Incorporate community-based communication and public-health messaging into cluster water-governance communication including a clear connection between treatment quality and downstream exposure risk.

14. CONCLUSION

Circular supply chain management provides a coherent and institutionally viable solution to the improvement of the sustainability of resources and the human health outcomes related to the operations of Water/Effluent Treatment Plant (WWTF/ETP) serving SME sector of Nagpur. Rather than simply a 'treatment fee' cost centre focused on compliance, SME clusters can use a WTP as a 'resource-recovery' node in a closed-loop supply chain, to reduce the amount of freshwater that is withdrawn, the amount and toxicity of discharge, the value of sludge and by-products recovered, and the economic incentive for always producing high quality treatments that protect workers and downstream communities. The current CETP programme in some clusters like Butibori, Hingna and MIHAN already has some institutional support for this transition; the only challenges that remain are financial, technical and coordination at the cluster level, which can all be overcome by the policy and managerial measures outlined in this paper. The conceptual framework developed in this work could be further strengthened with empirical research in the future that validates the framework.

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