Chapter: 2

Review of literature- Gap Identification, Objectives Setting, and Thesis Structure

2.1. Introduction to the chapter:

As discussed in the previous chapter, the waste issue is escalating, necessitating the remediation of existing dumpsites. Proper disposal and stabilization of retrieved fines are crucial before disposal or engineering utilization. In the previous chapter, facts based on studies by researchers are presented. In this chapter, key studies will be synthesized to analyse the gaps and objectives of the study. Based on this, the thesis will also have a structure.

2.2. Study's Objectives:

The objectives of this study are, given as below (Ref Mind-map Figure 9)

MSWF Characterization with Depth of Dumpsite-Mining: To conduct an in-depth investigation of the geotechnical and chemical characteristics of MSW and MSWF retrieved from studied dumpsites, with a focus on its applicability in various civil engineering and geotechnical scenarios.

I. **Assessment of Biopolymers in Soil Stabilization:** To evaluate the role and effectiveness of biopolymers in enhancing the mechanical/geotechnical and chemical stability of MSWF obtained from MSW mining.

II. **Long-term durability:** To evaluate the long-term durability of biopolymers in soil stabilization is essential to ensure that the benefits of using these environmentally friendly materials are sustained over time.

III. **Exploring the Real-life Application of Treated and Non-Treated MSWF:** This aspect focuses on investigating the practical uses of both treated and untreated MSWF in diverse real-world scenarios, particularly in civil engineering and related fields.

IV. **Environmental Sustainability and Circular Economy Alignment:** To assess the environmental sustainability of the bioremediation and bio stabilization process and its financial viability as well as alignment with the principles of circular economy, ESG, and sustainable development goals.

2.3. Literature Review:

Based on objectives the literature review is divided into three parts, the shcheme is shown using the mind map given in Figure 8:

2.2.1. Characterization of MSW and Retrieved Fines

A rigorous synthesis of existing literature will be conducted on the characterization of fresh and aged Municipal Solid Waste (MSW), legacy waste, and retrieved fines after bioremediation. This includes examining studies on the sustainable utilization of these materials.

2.2.2. Utilization of Additives for Stabilization

The second part will review literature on the use of additives for stabilizing contaminants and enhancing the mechanical properties of these materials for engineering applications. The focus will be on the use of biopolymers and other biomaterials to understand their long-term stability and durability.

2.2.3. Practical Application and Sustainability:

The final section will focus on the practical applications of stabilized materials. This includes their use in real-world scenarios and an analysis of their sustainability and alignment with circular economy principles. Each section will systematically analyze existing research to identify gaps and refine the study's objectives.

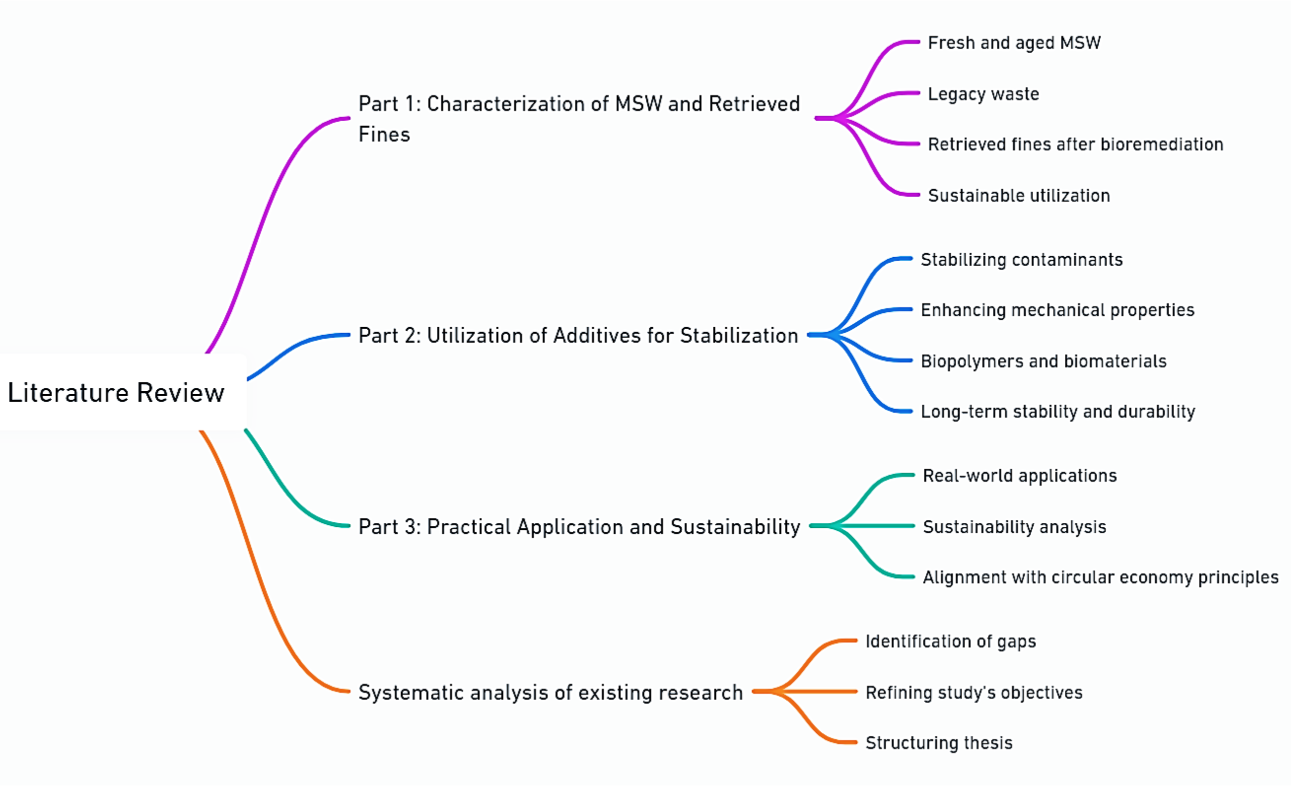

Figure 8: Scheme for literature review

Figure 9: Schematic map for the research gap and objective

Table 2: Characterization of MSW and Retrieved Fines

Part 1: Characterization of MSW and Retrieved Fines

SN	Study Details	Objective, material, and methodology	Observations and Results
1	Characterization and phytotoxicity assessment of organic pollutants in old and fresh municipal solid wastes at open dump site: A case study (Sharma and Kumar 2021)	▪ The study aimed to characterize organic pollutants in old and fresh municipal solid wastes at an open dump site. ▪ Methods included SEM, FT-IR, and GC-MS analysis to identify compounds and assess phytotoxicity using Phaseolus aureus L. seeds.	▪ Fresh MSW had high concentrations of metals, polymers, and co-pollutants. ▪ Phytotoxicity assessment showed more than 80% inhibition in seed germination.
2	The effect of aging on the compressibility behavior and the physical properties of municipal solid wastes: a case study of Kahrizak landfill, Tehran (Mokhtari et al. 2019)	▪ Objective: Determine the effect of aging on physical properties and compressibility of municipal solid wastes from Kahrizak landfill. ▪ Method: Tested fresh and aged samples using a large-scale oedometer. ▪ Material: Samples included fresh, 5.5-, 14-, and 21-year-old municipal solid wastes.	▪ Waste compressibility decreases significantly with age, one-third of fresh. ▪ Aging increases specific gravity and inert components in municipal waste.
3	Laboratory investigation of compaction characteristics of fresh and degraded municipal solid waste (Endait and Patil 2020)	▪ The study aimed to investigate the compaction characteristics of fresh and aged municipal solid waste (MSW). ▪ Materials included fresh MSW, windrows sample, and MSW aged 5, 10, and 15 years collected from a solid waste management site in India. ▪ The compaction was conducted under different energy levels to analyze the maximum dry density and optimum moisture content of the samples.	▪ Maximum dry density less in fresh sample at standard compactive effort. ▪ Dry density increases with age due to biodegradation completion.

4	Municipal Solid Waste Characterization as a Measure towards Sustainable Waste Management in Abuja, Nigeria (Aderoju Olaide and Guerner Dias 2020)	▪ The study aimed to characterize Municipal Solid Waste (MSW) in Abuja, Nigeria to enable sustainable waste management. ▪ Methodology involved using American Standard Test Method to analyze dumpsite waste and segregating household waste into colored bags. ▪ Results indicated food waste/organics and plastic waste as predominant MSW categories in Abuja.	▪ Food waste/organics and plastic waste are predominant MSW categories. ▪ Level of income significantly influences constituents of MSW generated.
5	Characterization of Municipal Solid Waste and Its Role in Sustainable Waste Management Practices (Zargar et al. 2023)	▪ The study aimed to assess the potential of municipal solid waste (MSW) for refuse-derived fuel (RDF) valorization. ▪ The method involved characterizing the residual/reject fractions of MSW for energy purposes. ▪ Materials studied included combustible mixed materials such as plastics, paper, and wood.	▪ The study found that the residual fractions of municipal solid waste (MSW) in Ghana have the potential to be used as refuse-derived fuel (RDF). ▪ The RDF produced from combustible mixed materials such as plastics, paper, and wood had a significant increase in lower heating value.
6	Characterization of municipal solid waste for waste to energy feedstock in Jakarta (Wahyono et al. 2022)	▪ Objectives: Determine waste characteristics from various sources in Jakarta, analyze waste quality for incinerator feedstock. ▪ Method: Random sampling of waste from shopping areas, office areas, industrial areas, city parks, and households, transported to Bantargebang final disposal site. ▪ Material: Waste samples analyzed for composition, proximate and ultimate analysis to assess suitability for incinerator feedstock.	▪ Wastes dominated by combustible material, suitable for incinerator fuel. ▪ Concerns include bulky, hazardous, non-combustible waste interfering incinerator performance.
7	Characterization and Sustainable Utilization of Municipal Solid Waste	▪ The study aims to review the sustainable utilization of municipal solid waste incineration ash, focusing on applications like construction materials, geotechnical uses, and agricultural	▪ Repurposing MSWI ash in construction, geotechnical, agricultural applications.

	Incineration Ash: A Review (Kumar et al. 2023)	purposes. It compares different possibilities, emphasizing environmental impact and benefits.	▪ Reduction in greenhouse gas emissions through sustainable waste utilization.
8	Identification and characterization of Municipal Solid Waste - MSW through geoprocessing and visual analysis of waste in Brazil (Pereira et al. 2022)	▪ Objectives: Identify and characterize places with irregular dumping of Municipal Solid Waste (MSW) in Belém, Brazil. ▪ Method: Mapping, photographic survey, visual classification of waste materials, data processing using Quantum GIS and Excel. ▪ Materials: MSW materials such as wood, construction waste, pruning materials, plastic materials, and residential waste.	▪ Identified places with irregular dumping of solid waste ▪ Characterized the composition of the waste materials
9	Feasibility Study on Municipal Solid Waste (MSW) as a Resource for Energy Recovery (Das et al. 2019)	▪ Objectives: Study suction characteristics of Pirana MSW for different moisture content, establish relation between suction parameters and waste strength, observe influence of volatile matters on suction. ▪ Method: Soak MSW and silty sand samples in water for 24 hours, measure suction, analyze pore size and void formation using high-magnification microscope. ▪ Material: Pirana MSW material more than 15-years old, 25 m height, compared with silty sand for construction suitability.	▪ Observing suction characteristics of Pirana MSW for different moisture content. ▪ Establishing relation between suction parameters and strength of the waste.
10	Composition and characteristics of excavated materials from a legacy waste dumpsite: Potential of landfill biomining (GHOSH and KARTHA 2023)	▪ The study aimed to assess the composition of excavated waste from legacy waste dumpsites. ▪ Method involved compositional analysis of waste from four heaps at Boragaon dumpsite in North-East India. ▪ Materials included waste samples from different heaps with varying filling heights.	▪ Proportion of combustible and non-combustible fractions decreases from HP4 to HP1. ▪ RDF preparation suitable for combustible fractions due to high surface defilements.
11	Aging stability of bio-oil produced from dewatered sewage sludge using	▪ The study examined the aging stability of bio-oil from dewatered sewage sludge under room-temperature and accelerated-aging conditions at 80 °C over 6 months.	▪ Stable at room temperature, viscosity increased with accelerated aging.

	hydrothermal liquefaction (Mujahid and Kim 2020)	▪ No significant changes were observed in fluidity, viscosity, or molecular weight of room-temperature bio-oil samples. ▪ Accelerated-aged bio-oil samples maintained fluidity for up to 1 week, with substantial increases in viscosity and molecular weight after 1 month.	▪ Low-molecular-weight species persisted during room-temperature aging, disappeared with accelerated aging.
12	Characterization of Dissolved Organic Matter Released during Municipal Solid Waste Degradation (Yue et al. 2023)	▪ Objectives: Quantify dissolved organic matter (DOM) from aged biochar, analyze its composition using FRI and PARAFAC, and assess the impact of different aging approaches. ▪ Method: Aged biochar from maize stalk and soybean straw was subjected to various aging processes using different solutions. ▪ Material: Biochar obtained from maize stalk and soybean straw, aged using farmland or vegetable-soil solution, as well as soil solution containing hydrogen peroxide (H2O2).	▪ H2O2-aged biochar had 147.26–734.13% higher WSOC than controls. ▪ Aromaticity and humification increased in aged-biochar-derived DOM.
13	Physicochemical and structural characterization of biochar derived from the pyrolysis of biosolids, cattle manure and spent coffee grounds (Stylianou et al. 2020)	▪ The study aimed to characterize biochars derived from cattle manure, biosolids, and spent coffee grounds. ▪ Biochars were produced through slow pyrolysis in a small-scale kiln at 550°C under nitrogen atmosphere. ▪ Physicochemical characterization revealed alkaline materials with varying characteristics based on the feedstock used.	▪ Biochars produced from different biowastes have alkaline materials. ▪ Surface area of raw materials is considerably low.
14	Effect of three aging processes on physicochemical and As(V) adsorption properties of Ce/Mn-modified biochar (Huang et al., 2022)	▪ The study focused on the effect of three aging processes (natural, freeze-thaw, dry-wet) on Ce/Mn-modified biochar physicochemical properties and As(V) adsorption. ▪ Ce/Mn-modified wheat straw-biochar was manufactured and aged through exposure to soil with additional natural, freeze-thaw, and dry-wet cycles.	▪ Freeze-thaw aging increased specific surface area to 214.98 m2/g. ▪ Freeze-thaw and dry-wet aging improved As(V) adsorption capacities.
15	Influence of Aged Biochar Modified by Cd 2+ on Soil Microbial Community and	▪ Objectives: Investigate the influence of aged biochar modified by Cd2+ on soil properties and microbial communities.	▪ Aged biochar increased microbial abundance and altered community structure.

	Enzyme Activity (Li et al. 2020)	▪ Method: Pre-treated wood-derived biochar to simulate aging, conducted comparative incubation studies on three age stages of biochar under cadmium adsorption or no cadmium adsorption. ▪ Material: Eucalyptus saligna Sm. wood-derived biochar, cadmium, soil samples for incubation studies.	▪ Biochar aging enhanced cadmium adsorption and altered microbial community structure.
16	Chemical and Leaching Behavior of Construction and Demolition Waste: Effects of Aging (Diotti et al. 2020)	▪ The study aimed to analyze the environmental behavior of construction and demolition wastes and recycled aggregates in terms of chemical composition and contaminant release through a leaching test. The main materials included construction and demolition wastes and recycled aggregates.	▪ The paper presents a data analysis on the environmental behavior of construction and demolition wastes and recycled aggregates. ▪ The leaching test showed that SO4, Cu, and COD are critical compounds for both CDWs and RAs.

Table 3: Utilization of Additives for Stabilization

Part 2: Utilization of Additives for Stabilization

SN	Study Details	Objective, material, and methodology	Observations and Results
1	Biopolymeric Sustainable Materials and their Emerging Applications 53	● The main observation is that biopolymers are environmentally friendly, versatile, and have diverse applications in various fields such as biomedical, food, electronics, and cosmetics.	● Biopolymers exhibit tremendous potential for various applications. ● Biopolymeric composites easily degrade in degraded environments. ● Biopolymers are extensively used in biomedical, food, electronics, cosmetics, and other emerging fields.
2	Review of current and future bio-based stabilization products (enzymatic and polymeric)	● Objective: Explore bio-based stabilisation products for road construction ● Method: Review of alternative stabilisers like enzymes and polymers ● Material: Weak subgrade soils	● The research paper does not provide specific numerical results or findings such as percentage increase or decrease, specific values, or heavy metal content related to bio-based stabilisation products for road construction materials.

	for road construction materials (Ramdas et al. 2021)	● Outcome: Need for more research on implementation and simplification of bio-based products	
3	Cross-linking of biopolymers for stabilizing earthen construction materials (Muguda et al. 2022)	● Objective: Evaluate the impact of cross-linking guar and xanthan gums on plasticity, shrinkage, strength, and durability of soil. ● Method: Cross-linking biopolymers to form hydrogels with enhanced physical integrity and mechanical properties. ● Material: Guar and xanthan gums as biopolymers for soil stabilization.	● The study found that cross-linking of biopolymers like guar and xanthan gums improved plasticity and strength of soil specimens. Increasing guar gum led to higher plasticity indices and shrinkage, while increasing xanthan gum reduced these values. Overall, cross-linking enhanced mechanical behavior and durability of the soil.
4	Sustainable biopolymer soil stabilisation: the effect of microscale chemical characteristics on macroscale mechanical properties (Armistead et al. 2023)	● Objective: Investigate the effect of microscale chemical characteristics of biopolymers on macroscale soil mechanical properties. ● Method: Used different Galactomannan biopolymers with varying G:M ratios and molecular weights on SiO_2 and SiO_2 + Fe soil systems. ● Material: Galactomannan biopolymers (Guar Gum, Locust Bean Gum, Cassia Gum), Carboxy Methyl Cellulose, SiO_2, Fe_2O_3.	● For Galactomannan G:M 1:5 stabilised soils, there was a 297% increase in Unconfined Compressive Strength (UCS) in SiO_2 + Fe systems. ● Increasing the G:M ratio from 1:2 to 1:5 resulted in an 85% reduction in UCS for SiO_2 Galactomannan-stabilised soils. ● UCS variations of up to a factor of 12 were observed across different biopolymer-soil mixes studied.
5	Characterization and Comparative Analysis of Natural Sustainable Composite Material Properties Using Bio-Binder for Eco-Friendly	● Objective: Investigate mechanical properties of okra bio-binder mixed with silica sand ● Method: Mixed okra with different weight percentages and particle sizes, compressed into samples ● Material: Okra, silica sand of various particle sizes	● 21% increase in compressive strength observed in 850 um silica sand with 10% okra by weight ● Okra addition enhances mechanical properties, especially for larger particle sizes ● Okra can increase compressive strength by filling voids between larger silica sand particles

	Construction Applications (Al-Mazrouei et al. 2023)		
6	Bio-Based Polymeric Flocculants and Adsorbents for Wastewater Treatment (Kolya and Kang 2023)	● Objective: Highlight the advantages of bio-based polymeric materials for water treatment. ● Method: Review of bio-based polymeric materials for flocculation and adsorption in water treatment. ● Material: Bio-based polymeric materials, polysaccharides, synthetic polymers. ● Outcome: Bio-based polymeric materials show effectiveness in removing contaminants, with future prospects and challenges discussed.	● Bio-based polymeric materials showed a reduction of approximately 60% in the demand for coagulants. ● Iron oxide-grafted cellulosic fibers effectively removed natural organic matter during water treatment cycles. ● These fibers successfully eliminated phosphorus from synthetic wastewater with lower coagulant doses or without any coagulant at all.
7	Use of a Biopolymer for Road Pavement Subgrade (Cabalar et al. 2023)	● Objective: Evaluate Xanthan Gum (XG) biopolymer in road pavement subgrade design ● Method: Conducted UCS and CBR tests on conventional aggregate with XG at different ratios ● Material: XG biopolymer, conventional aggregate ● Outcome: Significant improvement in UCS and CBR values with XG addition, high prediction model accuracy	● Addition of 5% Xanthan Gum (XG) in road pavement subgrade increased UCS values by 200% after 32 days. ● CBR values of clean aggregates increased by about 300% with 5% XG addition. ● Energy absorption capacity of aggregates significantly increased with XG inclusion and curing period.
8	A Brief Evaluation of Antioxidants Antistatics and Plasticizers Additives from Natural Sources for Polymers Formulation (Almeida et al. 2022)	● Objective: Develop sustainable polymers with bio-additives ● Method: Using biomass waste for antioxidants, antistatics, and plasticizers ● Material: Agro-industrial waste, grape residues, chitosan, cellulose derivatives ● Outcome: Potential for environmentally friendly polymeric materials	● Natural antioxidants like butylated hydroxyanisole (BHA), butylated hydroxytoluene (BHT), propyl gallate (PG), and tertiary butylhydroquinone (TBH) are used to prevent oxidation in biodiesel and fuels. ● These antioxidants can improve oxidation stability and increase the biodegradable, non-toxic component of the fuel. ● The use of natural antioxidants in biodiesel helps protect it from autoxidation,

			minimizing the formation of degradation compounds.
9	Biopolymeric Sustainable Materials and their Emerging Applications (Arif et al. 2022)	● The main observation is that biopolymers are environmentally friendly, versatile, and have diverse applications in various fields such as biomedical, food, electronics, and cosmetics.	● Biopolymers exhibit tremendous potential for various applications. ● Biopolymeric composites easily degrade in degraded environments. ● Biopolymers are extensively used in biomedical, food, electronics, cosmetics, and other emerging fields.
10	Lignocellulosic derivative-chitosan biocomposite adsorbents for the removal of soluble contaminants in aqueous solutions â€“ Preparation characterization and applications (Manyatshe et al. 2022)	● Objective: Evaluate methods for preparing lignocellulosic derivative-chitosan biocomposites. ● Method: Review different preparation methods and assess their efficiency in removing contaminants. ● Material: Lignocellulosic derivatives and chitosan biopolymer.	● Successful deployment in water purification and treatment applications.
11	Cross-linking of biopolymers for stabilizing earthen construction materials (Muguda et al. 2022)	● Objective: Evaluate the impact of cross-linking guar and xanthan gums on plasticity, shrinkage, strength, and durability of soil. ● Method: Cross-linking biopolymers to form hydrogels with enhanced physical integrity and mechanical properties. ● Material: Guar and xanthan gums as biopolymers for soil stabilization. ● Outcome: Cross-linking improves plasticity, shrinkage, strength, and durability of soil, addressing shortcomings of individual biopolymers.	● The study found that cross-linking of biopolymers like guar and xanthan gums improved plasticity and strength of soil specimens. Increasing guar gum led to higher plasticity indices and shrinkage, while increasing xanthan gum reduced these values. Overall, cross-linking enhanced mechanical behavior and durability of the soil.

12	Medical applications of biopolymer nanofibers. (Jeevanandam et al. 2022)	• The main observation of the research includes: • Objective: Overview of biopolymer nanofibers and synthesis approaches • Method: Utilization of nanotechnology to transform biopolymers into nanoparticles • Material: Biopolymers fabricated as nanofibers	• Enhanced biological properties for medical applications
13	Effect of green hybrid fillers loading on mechanical and thermal properties of vinyl ester composites (Nagaprasad et al. 2022)	• Objective: Utilization of Tamarind Seed and Date Seed Filler in vinyl ester composites • Method: Hybrid fillers ranging from 0 to 50 wt% added by compression molding • Material: Tamarind Seed and Date Seed Filler (TSF/DSF) with vinyl ester resin	• Hybrid fillers increased tensile, flexural, impact, and hardness properties by 1.51 times, 1.44 times, 1.87 times, and 1.46 times respectively at 10 wt% loading. • Minor impact on thermal properties observed with the addition of hybrid fillers. • Hybrid filler reinforced composites suitable for cost-effective applications with acceptable compromises in thermal qualities.
15	Bio-fibre Reinforced Composites: Mechanical Thermal and Tribological Properties and Industrial Application An Introduction (Palanikumar et al. 2022)	• The main observation includes: • Objective: Highlight recent progress and future options • Method: Review of bio fibre reinforced composites properties • Material: Bio fibres for polymeric resins	• Enhanced properties observed when introduction to bio fibres and their bio-composites
16	Review on biopolymers and composites - Evolving material as adsorbents in removal of environmental	• The main observation of the review on biopolymers and composites is: • Objective: To discuss biopolymers and composites as adsorbents for pollutant removal	• Potential substitution of conventional adsorbents, effective utilization, regeneration, and future trends.

	pollutants. (Yaashikaa et al. 2022)	● Method: Classification based on sources, preparation methods, and applications ● Material: Biopolymers and composites	
17	Enhancement of the Properties of Hybridizing Epoxy and Nanoclay for Mechanical Industrial and Biomedical Applications (Merzah et al. 2022)	● Objective: Investigate the effect of treated nanoclay loading on mechanical properties of epoxy. ● Method: Prepared NC-EP nanocomposites with different NC concentrations and acid treatment. ● Material: Nanoclay and epoxy. ● Outcome: Addition of NC and acid treatment significantly improved mechanical properties of the nanocomposites.	● Addition of 2 wt.% NC increased the impact energy from 2.6 to 18.7 Jmm2. ● Hardness of EP matrix increased from 248.2 HV at 1 wt.% NC to 275 HV at 2 wt.% NC. ● Overall findings indicate significant improvements in impact strength and hardness with the addition of nanoclay.
18	A Novel Clean Biopolymer-Based Additive To Improve Mechanical And Microstructural Properties of Clayey Soil(Ghasemzadeh et al. 2022)	● Objective: Introduce a novel biopolymer-based additive for clayey soil stabilization. ● Method: Used calcium chloride as an ionic crosslinker with Persian gum biopolymer. ● Material: Clayey soil, Persian gum, xanthan gum, calcium chloride. ● Outcome: Ionic crosslinked hydrogel showed superior performance in soil strength and durability compared to xanthan gum.	● Optimum crosslinked Persian gum showed superior performance in soil strength and ductility compared to xanthan gum. ● Crosslinking improved durability of pure Persian gum, making it comparable to xanthan gum. ● Microscale tests confirmed the impact of modified hydrogel on soil interstructure by filling pores and forming new cementitious compounds.
19	Review of current and future bio-based stabilisation products (enzymatic and polymeric) for road construction materials (Ramdas et al. 2021)	● The main observation includes: ● Objective: Explore bio-based stabilisation products for road construction ● Method: Review of alternative stabilisers like enzymes and polymers ● Material: Weak subgrade soils	● Need for more research on implementation and simplification of bio-based products

20	Characterization of CaCO3 Filled Poly(lactic) Acid and Bio Polyethylene Materials for Building Applications.(Serra-Parareda et al. 2021)	● Objective: Characterize CaCO3 filled poly(lactic) acid and bio polyethylene for building applications. ● Method: Filling biopolymers with two types of calcium carbonate, testing soundproofing using impedance tubes, and analyzing filler morphology. ● Material: Poly(lactic) acid, bio-polyethylene, two typologies of calcium carbonate.	● The incorporation of calcium carbonate into bio-based thermoplastic materials resulted in superior mechanical properties and sound barrier performance. The materials showed insulation four times higher than gypsum, making them potential lightweight building solutio

Table 4: Practical Application and Sustainability

Part 3: Practical Application and Sustainability

SN	Study Details	Objective, material, and methodology	Observations and Results
1	Engineering Properties of Recycled Materials for Use as Embankment Fill (Soleimanbeigi et al. 2014)	● Objective: Evaluate engineering properties of recycled materials for embankment fill ● Method: Characterized compaction, hydraulic conductivity, shear strength, and compressibility ● Material: Bottom ash, foundry slag, recycled asphalt pavement, recycled asphalt shingles	● Foundry slag (FS) is more compressible than bottom ash (BA) at stresses higher than 200 kPa. ● FS particles have high angularity and rough surface texture, making them more crushable than BA particles. ● Average particle size (d50) of FS reduced from 1.8 mm to 0.65 mm after compression tests. ● Fines content in FS increased from 5% to 11% after compression tests.
2	Sustainable soil stabilization: the use of waste materials to improve the engineering properties of soft soils (Chmielewska and Gosk 2022)	● Objective: Analyze the effect of waste materials on soil properties ● Method: Replacing conventional materials with waste materials ● Material: Waste materials like stone slurry, coffee grounds, rice husk ash, etc.	● Waste materials as admixtures reduce compressibility, increase maximum density, and shear strength of soft soils. ● The use of waste materials in soil stabilization is economically and ecologically beneficial. ● The study aims to analyze the impact of waste materials on improving the physical and mechanical properties of soils.

5	Application of eco-friendly and smart materials in geotechnical engineering for subgrade stabilization: a review (Dhatrak and Kolhe 2022)	• Objective: Review the application of eco-friendly and smart materials in subgrade stabilization in geotechnical engineering. • Method: Stabilization of subgrade soil using bio-enzymes and agricultural/industrial waste. • Material: Eco-friendly and smart materials for subgrade stabilization.	• Significant improvements in strength and volume change properties of subgrade soil were observed. • California Bearing Ratio (CBR), Unconfined Compressive Strength (UCS), and Swell Pressure of subgrade soil were effectively enhanced. • The use of eco-friendly and smart materials led to a more suitable subgrade soil for road pavement construction. • Conventional methods were found to have a negative impact on the environment, highlighting the importance of using cost-effective and environmentally friendly materials for subgrade stabilization.
6	Stabilization of expansive soil by using shredded tyre chips as an admixture (Haranatti et al. 2023)	• Objective: Reusing shredded tyre chips in road construction for soil stabilization. • Method: Mixing rubber tyre chips in varying proportions with existing soil. • Material: Shredded rubber tyre chips of 20mm length and 10mm width.	The study found that using 6% shredded tyre chips in soil improved the California Bearing Ratio (CBR) by 1.5 times compared to plain soil.
7	Numerical study on stability of lignosulphonate-based stabilized surficial layer of unsaturated expansive soil slope considering hydro-mechanical effect (Ijaz et al. 2022)	• Objective: Assess stability of LS-treated unsaturated expansive soil slopes • Method: Conducted uncoupled and hydro-mechanical coupled analyses • Material: LS-based stabilizers, specialized experimentations, literature review	• The LS-based stabilizer named composite cementing admixture (CCA) reasonably improved pore water pressure (PWP) profiles and wetting front depth (WFD) of the slope. • CCA effectively mitigated the heave problem of expansive soil slopes. • CCA provided the safest critical factor of safety (FS) for slope stability.
8	Analysis of the Stability of Reinforced Plastic Waste	• Objective: Analyze stability of clay soil with plastic waste as embankment fill	• Factor of safety increases as geogrid axial stiffness exceeds 500 kN/m.

	Treated Clay as Embankment Fill on Soft Soils (Amena 2022)	● Method: Finite element analysis using PLAXIS 2D software ● Material: Locally found weak clay stabilized with plastic waste	● Increasing slope height and angle lead to a decrease in factor of safety. Plastic waste treated clay can be used as embankment fill when reinforced with geogrid.
9	A Study on Stability of Pond Ash Embankments Improved by Stabilizers (Sharma et al. 2021)	● Objective: Evaluate stability of pond ash embankments with and without stabilizers ● Method: Static and seismic stability analysis of two embankment slope models ● Material: Pond ash, RBI Grade-81 stabilizer at different dosages	● Outcome: Increased stability with higher stabilizer dosage, optimal mix proportion for safe embankment design
10	Study of the hydro-mechanical behavior of a stabilized soil with water treatment plant sludge for application in sanitary landfills 76	● Objective: Use water treatment plant sludge for soil stabilization in sanitary landfills ● Method: Prepared formulations with different percentages of sludge, conducted tests ● Material: Stabilized clay soil with 0%, 15%, 30%, and 50% WTPS.	● The study identified that the mixture composed of 70% soil + 30% WTPS was the best for landfill layers. ● This mixture met the Brazilian requirements, had the highest compression resistance, and suitable permeability coefficient. The application of 50% soil + 50% WTPS in intermediate layers could contribute to sustainable development goals by 2030.
11	Stabilization of Sub-grade Soil Using Shredded Waste Plastic Bags (Salini and Jegan Bharath Kumar 2023)	● Objective: Evaluate effectiveness of shredded waste plastic in soil stabilization ● Method: Conduct UCC and CBR tests on weak soil and soil-plastic composites ● Material: Soil and shredded waste plastic of different sizes.	● Significant improvement in soil properties with the addition of finely shredded plastic waste. ● Experimental investigations on soil and soil-plastic composites with 0.1% shredded waste plastic of different sizes. ● The study evaluated the effectiveness of using shredded waste plastic covers in geotechnical applications through UCC and CBR tests on weak soil and soil-plastic composites.

12	Feasibility of Using Unbound Mixed Recycled Aggregates from CDW over Expansive Clay Subgrade in Unpaved Rural Roads. (Del Rey et al. 2016)	● Objective: Analyze behaviors of unbound mixed recycled aggregates in unpaved rural roads on expansive clay subgrade. ● Method: Constructed three road sections with different aggregate compositions, monitored compaction, deflections, and load capacity for 18 months. ● Material: Unbound mixed recycled aggregates (MRA) from construction and demolition waste (CDW), natural aggregates (NA).	● Sections made with recycled aggregates met technical specifications required by PG-3. ● Water-soluble sulphate content and Los Angeles abrasion coefficient limits can be increased for recycled aggregates without compromising road quality. ● First study using unbound MRA from CDW in construction of an unpaved rural road on expansive clay subgrade.
13	Stability Of Slopes Of Municipal Solid WasteLandfills With Co-disposal Of Biosolids (Chopra et al. 2006)	● Objective: Evaluate slope stability of MSW landfills with biosolids ● Method: Field exploration with CPT, slope stability analysis using SLOPE/W ● Material: MSW, biosolids, CPT data	● Factor of safety reduces significantly with the introduction of biosolids ● Reduction in shear strength and increase in overall moisture content ● Angle of internal friction found to be about 29°
14	Slope Stability Analysis of Artificial Embankment of Fly Ash and Plastic Recycled Polymer Using Midas GTS-NX (Chavan et al. 2023)	● Objective: Analyze slope stability of artificial embankment of fly ash and recycled plastic polymer. ● Method: Mix fly ash with different proportions of plastic recycled polymers, conduct laboratory tests, and use MIDAS GTS-NX software for analysis. ● Material: Fly ash, recycled plastic polymer.	● The maximum factor of safety is obtained at a mix percentage of 50% of recycled plastic polymer with fly ash. ● Further increase in the polymer content decreases the overall factor of safety of the artificial embankment.
15	Improvement of subgrade soil with shredded waste tyre chips (Ayothiraman and Meena 2011)	● Objective: Investigate behavior of pavement subgrade soil stabilized with shredded waste tyre chips ● Method: Mixing tyre waste material with soil, conducting CBR tests in unsoaked and soaked conditions ● Material: Shredded waste tyre chips, subgrade soil	● The CBR of stabilized soil is 22% higher than unstabilized soil even in soaked condition. ● Max. CBR values are 13.21 and 12.31 for unsoaked and soaked conditions. ● The optimum value of waste tyre content is 2 in unsoaked and soaked conditions.
16	Slope stability analysis based on elasto-plastic	● Objective: Calculate global factor of safety and study deformation state of soil slopes	● Outcome: Evaluation of FEM advantages and disadvantages in slope stability analysis

	finite element method (Chen et al. 2007)	● Method: Elasto-plastic shear strength reduction FEM ● Material: Soil slopes ●	
17	Field Performance of Embankments Stabilized with Recycled Plastic Reinforcement (Parra et al. 2003)	● Objective: Investigate performance of earth slopes reinforced with recycled plastic members ● Method: Use recycled plastic reinforcement in field test sites ● Material: Recycled plastic and steel pipe members	● Outcome: Stabilized slopes with recycled plastic performing well, showing significant remaining capacity for stability.
18	Performance assessment of mechanically stabilised earth walls with sustainable backfills: experimental and numerical approach (Mandloi et al. 2022)	● Objective: Evaluate steel slag and construction waste as sustainable backfills for MSE walls ● Method: Extensive lab experiments, triaxial and CBR strength tests, geogrid reinforcement, finite element analysis ● Material: Steel slag, construction and demolition waste (CDW)	● Outcome: Sustainable backfills showed superior performance, reduced wall displacements by 56% (slag) and 70% (CDW), lower reinforcement strains
19	Deformation response of shored MSE walls under surcharge loading in the centrifuge (Lee et al. 2010)	● Objective: Evaluate deformation mechanisms of shored mechanically stabilized earth (SMSE) walls under surcharge loading. ● Method: Testing methodology in a geotechnical centrifuge with appropriate scaling relationships for reinforcement material selection. ● Material: Dense array of instrumentation used for testing.	● Outcome: Improved understanding of SMSE wall deformation behavior under surcharge loading.
20	A case study on various developments of soil reinforced embankment slope stability with natural fibre additives (Kumar & Roy, 2023)	● Objective: Study the influence of jute fibre reinforcement on embankment stability. ● Method: Laboratory model testing, numerical analysis, soil sample testing, and numerical modeling using Geo-studio. ● Material: Jute fibre geotextile, soil samples.	● Jute fibre geotextile resulted in better performance in soil stabilization. ● Minimum value of deformation and maximum value of the factor of safety were achieved with the presence of jute fibre geotextile.

21	Mechanical Parameters of Rubber-Sand Mixtures for Numerical Analysis of a Road Embankment (Kowalska and Chmielewski 2017)	● Objective: Investigate mechanical properties of sand-rubber mixtures for road embankment ● Method: Conducted direct shear strength tests on mixtures, applied FEM model ● Material: Sand, two types of rubber granulates (0.5-2 mm, 1-5 mm)	● Unit weight of mixtures significantly smaller than sand alone, dropping by half at 50% rubber content. ● Internal angle of friction remains stable up to 10% rubber, decreases by 10° at 50%. ● Cohesion intercept generally higher in sand-rubber mixtures compared to sand alone. ● Stability factor of embankment with 30% rubber content increased from 1.60 to 2.15. ● Load carrying capacity of embankment increased from 32 kPa to 45.5 kPa with rubber inclusion.

2.4. Research Gap

Despite advancements in waste management, significant gaps remain in the geotechnical assessment and sustainable utilization of Municipal Solid Waste Fines (MSWF), particularly from riverbank dumpsites. Current research often overlooks detailed geotechnical characterization and the optimization of biopolymer dosages for stabilization, focusing instead on short-term effects without considering long-term durability and environmental impacts. The below section describes the gap identification (Ref Mind-map Figure 8)

I. **Depth-wise Characterization of MSWF:** The properties of MSWF can vary significantly with depth due to factors such as compaction and decomposition. Detailed geotechnical and chemical characterization at various depths is essential to understand its suitability for civil engineering applications. This includes examining mechanical properties and chemical stability, which influence long-term performance and environmental impact

II. **Effect of Biopolymers on MSWF:** There is a lack of comprehensive research on the short-term and long-term effects of biopolymers on MSWF stabilization. While biopolymers are known to enhance mechanical and chemical stability, studies often focus on immediate improvements without evaluating long-term durability and environmental implications. Comprehensive studies are needed to assess the performance of biopolymer-stabilized MSWF over extended periods

III. **Application in Civil Engineering:** The practical application of treated and untreated MSWF in civil engineering projects, especially in India, remains underexplored. Research should focus on real-world scenarios to evaluate the feasibility and benefits of using untreated and treated MSWF in various civil engineering applications, such as pavement subgrades and embankments, under local conditions

IV. **Sustainability Assessment:** Comprehensive assessments of the environmental, social and financial sustainability of using MSWF stabilization using biopolymers, particularly concerning the potential leaching of chemicals and alignment with circular economy principles, is required. Research should ensure that the use of MSWF in construction and using biopolymer in place of conventional binders are environmentally, socially and financially sustainable and compliant with regulations.

Structure of the thesis

To fulfil the objectives, this thesis is organized into several chapters, each focusing on a different aspect of the research on Municipal Solid Waste Fines (MSWF). The structure is given in Figure 10:

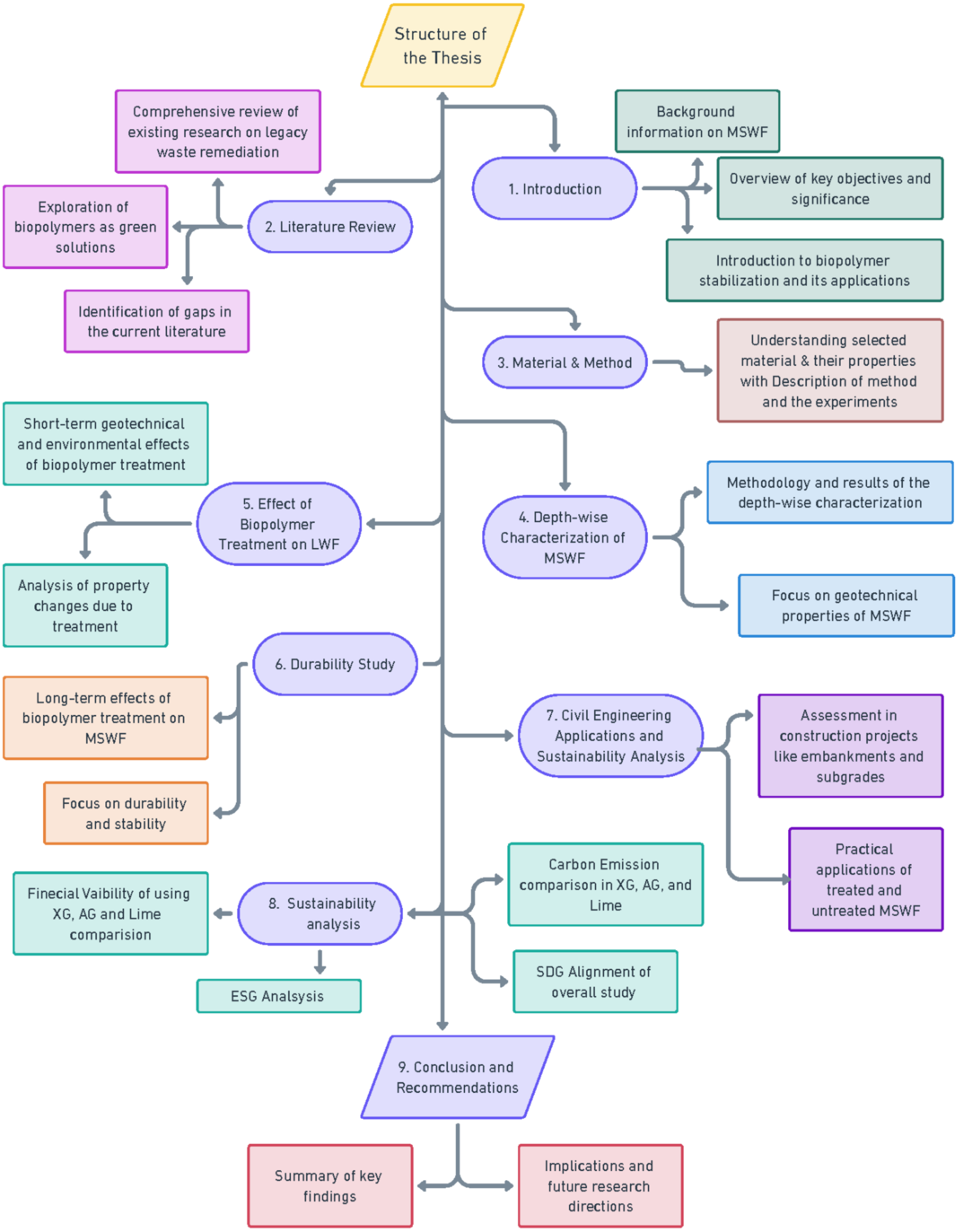

Figure 10: Thesis structure mapping

I. **Introduction**: This opening chapter sets the stage for the research, outlining the key objectives and the significance of the study. It provides background information on MSWF and the importance of sustainable utilization. The chapter also cover the background of biopolymer stabilization, its potential and aspect of biopolymer treated MSWF geotechnical application.

II. **Literature Review**: This chapter presents a comprehensive review of existing research related to legacy waste remediation, the use of biopolymers as green solutions, and their applications in civil engineering. It identifies gaps in the current literature that this study aims to address.

III. **Materials and Methods:** This chapter details the materials used in the study, including the specific biopolymers and MSWF characteristics, and describes the experimental methods employed to assess their effectiveness in soil stabilization. It covers the selection of materials, preparation procedures, and the testing methodologies for evaluating geotechnical properties.

IV. **Depth-wise Characterization of MSWF or LWF**: Focusing on the geotechnical properties of MSWF, this chapter details the methodology and results of the depth-wise characterization of legacy waste fines.

V. **Effect of Biopolymers Treatment on LWF**: This chapter discusses the short-term geotechnical and environmental effects of biopolymer treatment on LWF, including an analysis of the changes in properties due to the treatment.

VI. **Durability**: Here, the long-term effects of biopolymer treatment on LWF are examined, with a focus on the durability and stability of the treated material.

VII. **Civil Engineering Applications:** This chapter assesses the practical applications of both treated and untreated MSWF in civil engineering projects, such as in the construction of embankments and subgrades.

VIII. **Sustainability Analysis:** This chapter evaluates the environmental, economic, and social sustainability of using biopolymer-treated MSWF in civil engineering applications. The analysis includes a comparison of the carbon footprint, resource efficiency, and long-term benefits of biopolymer stabilization versus traditional methods like lime or cement stabilization.

IX. **Conclusion and Recommendations**: The final chapter summarizes the key findings of the research, discusses their implications, and suggests directions for future research in the field of sustainable waste management.

2.5. Key takeaways and Way forward

- The literature review highlighted the need for more in-depth studies on the durability and environmental impact of biopolymer-stabilized soils, particularly with legacy waste fines (LWF).
- Biopolymers offer promising sustainable alternatives to traditional stabilizers, reducing carbon emissions and preserving soil properties.
- Identified challenges include higher costs and varying performance, which require further research.
- The upcoming chapter on **Materials and Methods** will detail the materials used, including specific biopolymers, and outline the experimental procedures to assess their effectiveness in stabilizing MSWF.
- Insights from this review will guide the experimental design, ensuring that the methods address the research gaps identified in the literature.