Annual Methodological Archive Research Review
http://amresearchreview.com/index.php/Journal/about
Volume 3, Issue 12 (2025)

Online ISSN 3007-3197
Print ISSN 3007-3189
http://amresearchreview.com/index.php/Journal/about

Integrated Termite Management: Advances, Challenges, and Future Perspectives

Muhammad Shavaiz Baloch (Corresponding Author)
Department of Entomology, Faculty of Agriculture, Gomal University, Dera Ismail Khan, Pakistan Email: mshavaiz8@hotmail.com

Muhammad Ahmad Alizai
Department of Entomology, Faculty of Agriculture, Gomal University, Dera Ismail Khan, Pakistan Email: ahmadalizai107@gmail.com

ABSTRACT

Integrated termite management has made a lot of progress in the last ten years. This is because people are more aware of the environment, rules are stronger, and economic losses are rising, which has led to a move away from old chemical-based methods. The expenses of termite damage around the world keep going up, which shows how important it is to have control plans that work and last. To safeguard structures for a long period with less harm to the environment, modern ITM frameworks now include preventive construction design, continuous real-time monitoring, better baiting systems, and biological control agents. Recent advancements in sensor-based monitoring and molecular detection have enhanced early intervention capabilities and refined decision-making in intricate urban settings. Even while things have gotten better, there are still big problems to solve. These include the fact that biological agents don't always work well in the field, that not everyone has access to advanced monitoring systems, and those regulatory standards vary from region to region. This overview brings together changes from the last ten years, talks about the practical and economic effects of ITM, and lists the technological and policy changes that need to happen to make sustainable termite control more common in cities.

Keywords: Integrated Termites Management, Technologies, AI, Economy, Ecology

Introduction

Termites are some of the most destructive pests when it comes to structures around the globe, particularly in warm and humid urban regions where soil-dwelling types flourish and have continuous access to moisture and materials to feed on. Their ability to take advantage of cracks in foundations, plumbing connections, and expansion joints allows colonies to sneak into buildings quietly, often leading to serious internal damage before any clear signs appear. Over the last ten years, there has been a notable increase in termite infestations around the world, driven by various ecological and human-related factors. The quick growth of cities has led to tightly packed groups of buildings, creating soil profiles that support the formation of colonies and foraging

Online ISSN 3007-3197
Print ISSN 3007-3189
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networks. At the same time, changes in climate, marked by rising temperatures and shifts in seasonal rainfall, have altered soil moisture levels, which in turn has improved the survival and reproductive success of termites (Evans et al., 2013). The changes in climate have enabled some species to spread into regions that were previously considered unsuitable, leading to new infestation hotspots and the need for updated control strategies.

Modern building techniques have unintentionally increased vulnerability to termites. The widespread use of cellulose-rich building materials, such as laminated wood, engineered timber, oriented strand board, and composite flooring, has created a more plentiful food source for termites. These materials, although effective in structure and appealing for the environment, often hold moisture in their layers, creating microhabitats that subterranean termites can take advantage of. Species like Coptotermes formosanus, Reticulitermes flavipes, and Heterotermes indicola continue to be prominent in discussions about urban structural failures due to their large colony sizes, aggressive foraging habits, and ability to remain hidden for extended periods (Hassan et al., 2024). Their foraging tunnels can stretch as far as one hundred meters from the colony center, allowing termites to reach vulnerable structures even with minimal soil contact, making it harder to detect and intervene early.

Traditional termite control has typically relied on applying chemicals to the soil to create a toxic barrier around buildings. While these treatments may work well initially, they have raised lasting worries about groundwater contamination, unintended harm to helpful soil organisms, and risks to human safety during their application. Regulatory constraints and increased public awareness have intensified the scrutiny of traditional termiticides, speeding up a global shift towards more sustainable management practices. Integrated termite management (ITM) has emerged as a comprehensive approach that combines several effective components, including regular monitoring for early signs of activity, the use of targeted bait systems to reduce colonies, research into biological agents with lower ecological effects, and the integration of preventive architectural designs that limit pathways for termite entry.

Between 2014 and 2024, ITM has made significant strides, supported by improvements in sensing technologies, material science, biological research, and ecological modeling. This paper looks at recent advancements, examines current limitations that prevent widespread adoption, and explores potential technological and policy options that could enhance the sustainability and effectiveness of global termite control efforts. By bringing together ecological knowledge, engineering techniques, and economic considerations, ITM can reduce global termite-related losses while promoting safer, more sustainable, and resilient urban environments.

Advances in Integrated Termite Management

Modern Baiting Technologies

Baiting has emerged as a fundamental aspect of ITM because it effectively reduces chemical exposure while focusing on entire colonies. Recent advancements feature better cellulose matrices, tastier additives, and innovative insect growth regulators that offer enhanced environmental stability (Su, 2016). These formulations enable quicker colony removal and less frequent treatments. Field studies show that bait acceptance

Online ISSN 3007-3197
Print ISSN 3007-3189
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is better in dry and compacted soils, where previous baits occasionally had inconsistent results.

Sensor Based Monitoring Systems

The ability to monitor in real-time has transformed ITM by allowing for continuous observation of termite behavior. Modern systems use electronic sensors in monitoring stations to detect feeding vibrations or disturbances and send real-time information to management staff. (Wang et al., 2025) demonstrated that the use of sensor-based networks led to a 90 percent decrease in chemical treatments and an 80 percent decrease in long-term prevention expenses. These systems improve early detection, enabling quick actions that stop structural damage and lessen financial impacts.

Acoustic, Thermal, and Molecular Diagnostics

Improved sensor sensitivity has made it easier to detect acoustic signals, helping to identify termite feeding activity in wooden structures. Thermal imaging detects higher temperatures associated with termite activity and changes in moisture levels. Environmental DNA analysis has become a valuable method for detecting termites in soil samples before they start forming colonies in building materials (Li et al., 2025).These advances collectively enhance the precision and reliability of ITM.

Biological Control and Microbial Engineering

Studies in biological control have explored the use of entomopathogenic fungi, nematodes, and bacterial antagonists. Recent advancements in encapsulation technologies have improved the ability of fungal spores to endure harsh soil conditions and have prolonged their lifespan (Hassan et al., 2024). Advancements in termite microbiome research have revealed potential for targeted microbial disruption, although practical application in the field remains in the experimental stage. Achieving lasting success requires improved environmental stability and better delivery systems.

Preventive Construction and Architectural Design

Preventive strategies such as graded sand barriers, stainless steel mesh, termite-resistant materials, and moisture management systems show reliable long-term effectiveness (Evans et al., 2013). Incorporating these technologies into urban development regulations enhances structural durability and reduces long-term maintenance costs.

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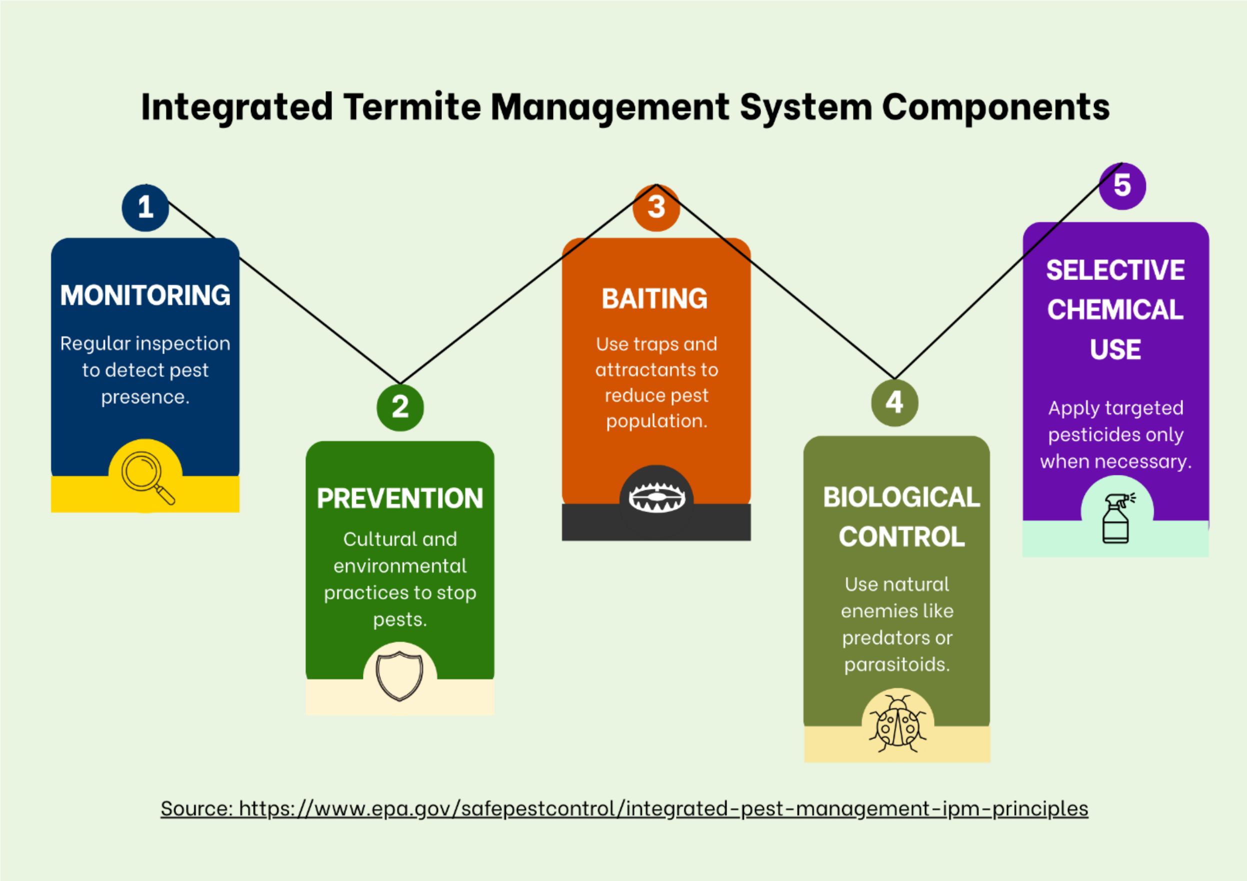

Figure 1: Integrated Termite Management System Components

Challenges in Implementation

Limitations in Early Detection

Incorporating these technologies into urban development guidelines enhances structural durability and reduces long-term maintenance costs (Hassan et al., 2024).

Field Variability of Biological Control Agents

Entomopathogenic fungi and nematodes show different levels of effectiveness depending on factors like humidity, UV radiation, and the presence of competing soil microorganisms. Widespread commercial adoption is limited until improvements in formulation technology boost environmental stability (Hassan et al., 2024).

Economic Constraints

The sophisticated monitoring and treatment systems demand a significant initial investment, creating a considerable hurdle for the broader implementation of integrated termite management in low-income areas. While numerous economic studies indicate that Integrated Pest Management (IPM) reduces overall repair expenses and minimizes the necessity for repeated chemical treatments, the initial costs associated with acquiring and installing electronic monitoring devices, bait stations, and preventive construction features may be too high for many households

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and local governments to afford. In cities where financial resources are tight, budgets for infrastructure often struggle because of competing demands such as water management, sanitation, and upkeep of public housing, which makes it hard to set aside money for proactive termite control measures. Consequently, numerous communities still depend on cost-effective yet less efficient chemical treatments. While these options might offer temporary relief, they do not ensure lasting reduction of the colony and can lead to continuous expenses for many years ahead.(Ahmad et al., 2021a; Oi, 2022).

Regulatory Inconsistencies and Training Gaps

The differences in pesticide regulations, certification requirements, and training standards make it difficult to adopt integrated approaches widely and lead to notable variations in termite management outcomes in different areas. The rules for managing termites differ widely from one country to another and even between local areas, resulting in varying approval processes for bait toxicants, biological agents, and monitoring devices. In some places, there are tight rules that limit the availability of certain safer products, while in others, outdated chemical formulas can be easily found because of a lack of proper oversight. The division in legislation makes it difficult to adopt new integrated termite management technologies and leads to a reliance on cheaper, broad-spectrum pesticides, which could go against current environmental protection goals (Shrestha et al., 2024).

Obtaining professional certification represents another important challenge. Pest management operators often experience varying levels of training, and many places do not have a uniform curriculum that incorporates up-to-date information on sensor-based monitoring, biological control, and soil ecology. The skill level of professionals in properly installing, interpreting, and maintaining integrated monitoring systems differs greatly, which can impact the reliability of treatment and the trust clients have in the process. Additionally, many countries provide inadequate institutional support for adopting sustainable practices, as building codes, insurance frameworks, and local regulations often fail to recognize or promote integrated termite management. The absence of a unified governmental approach diminishes the drive for investment in advanced technologies and creates an uneven playing field where modern and traditional practices clash without clear rules. Addressing these legal and educational gaps is essential for promoting the broad adoption of integrated solutions and ensuring consistent, environmentally friendly termite management worldwide (Deguine et al., 2021).

Key Challenges in Integrated Termite Management

Challenge	**Description**	**Why It Is a Problem**	**Supporting References**
Detecting Early Infestations	Termites remain hidden underground or inside structures, causing damage before signs appear.	Damage becomes extensive before detection.	Evans et al. 2013; Rust 2019

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Identifying Termite Species	Different termite groups require different control strategies.	Misidentification leads to ineffective treatments.	Evans et al. 2013; Rust 2019
Monitoring Termite Activity	Requires repeated inspections and specialized tools.	Seasonal foraging variability causes inconsistent detection.	Evans et al. 2013; Su 2016
Environmental Conditions	Soil moisture, temperature, and climate influence termite survival.	Favorable conditions accelerate infestation and reduce treatment efficacy.	Evans et al. 2013; Oi 2022
Limited Biological Control Options	Fungal and nematode agents perform well in labs but inconsistently in field conditions.	Environmental sensitivity reduces reliability.	Grace 2003; Oi 2022
Use of Baiting Systems	Bait acceptance varies with placement, season, and food alternatives.	Slow feeding delays colony elimination.	Su 2016; Rust 2019
Selective Chemical Restrictions	Regulations limit broad-spectrum termiticide use.	Fewer options increase labor and precision demands.	Rust 2019; Oi 2022
Structural Design Constraints	Voids, slabs, and drainage systems restrict treatment access.	Monitoring tools may not reach active areas.	Evans et al. 2013
Cost and Labor Intensity	ITM requires continuous monitoring and multiple treatment types.	High upfront cost reduces adoption.	Rust 2019; Oi 2022
Public Awareness and Compliance	Homeowners often fail to follow prevention practices.	Increases reinfestation risk.	Evans et al. 2013; Oi 2022

Table 1: Key Challenges in Integrated Termite Management

Future Perspectives

4.1 Artificial Intelligence and Predictive Algorithms

Artificial intelligence, especially machine learning, is swiftly revolutionizing the detection, interpretation, and management of termite activity. Contemporary sensor-based monitoring systems produce substantial quantities of continuous data, encompassing feeding vibrations, temperature variations, moisture profiles, and activity patterns at monitoring stations. Machine learning models possess increasing capability to examine intricate datasets and discern nuanced patterns in termite activity that may elude manual examination (Wang et al., 2025). Predictive algorithms can be developed to identify the initial indicators of colony formation, enabling management to respond prior to termites affecting structural elements. These techniques enhance the precision of distinguishing between termite activity and background noise, hence increasing reliability in difficult settings such as concrete structures or regions with electrical interference.

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As data accumulates, AI can enhance predictions concerning colony expansion rates, tunneling behavior, and seasonal variations in foraging intensity. The ability to learn adaptively renders AI-driven monitoring an effective instrument for long-term termite risk evaluation (Li et al., 2025). Furthermore, the incorporation of predictive analytics into ITM systems may enable technicians to enhance treatment schedules, pinpoint high-risk areas surrounding structures, and minimize superfluous interventions. The implementation of artificial intelligence in termite management signifies a significant progression towards proactive pest control systems, as opposed to reactive ones.

Next Generation Molecular Tools

Next-generation molecular diagnostics provide significant advancements in enhancing the speed, sensitivity, and accuracy of termite detection. Environmental DNA (eDNA) sampling has emerged as an effective method for detecting termite presence in soil prior to the manifestation of physical indicators of activity. eDNA facilitates the identification of minute amounts of termite genetic material, enabling researchers and pest management to delineate colony distribution and movement patterns over extensive spatial scales (Bourgeois & Warren, 2021). This is particularly valuable in early detection, where traditional tools often struggle to capture low level or cryptic activity.

Alongside eDNA, fast genetic probes that can identify distinct species from minute biological samples provide novel prospects for species-level diagnostics in the field. These techniques facilitate more precise control by differentiating between invasive and native species or detecting colonies with greater destructive capacity. In conjunction with genetic technology, metabolomic fingerprints provide insights into the physiological states and stress responses of termites, potentially indicating feeding intensity or colony health. Eventually, these sophisticated molecular tools may become integral elements of ITM frameworks, offering highly sensitive and noninvasive methods for assessing termite activity and forecasting infestation risk ("Myrmecia," 2021).

Advanced Biological Control

Biological control is a very promising yet hard aspect of integrated termite management. Conventional biological approaches, such as entomopathogenic fungi and nematodes, have demonstrated efficacy in laboratory environments but exhibit variable efficiency in field situations due to environmental sensitivity (Grace, 2003). Future advancements may revolutionize biological management through the use of genetically modified entomopathogens that demonstrate better resilience to temperature fluctuations, variations in soil moisture, and microbial competition. Such strains may provide more dependable colony suppression while diminishing need on synthetic chemical treatments.

Another such avenue is microbial rivals that interfere with termite symbionts. Termites depend significantly on gut microbes for cellulose digestion and nutrition cycling, rendering their microbiome a crucial target for biological intervention. Researchers may devise innovative control strategies that diminish colony strength through the introduction of microbial antagonists that can modify gut function, so avoiding direct chemical exposure. Moreover, microencapsulated delivery systems

Online ISSN 3007-3197
Print ISSN 3007-3189
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can enhance the field survival of biological agents by shielding them from UV radiation, desiccation, and predation. As these technologies advance, biological control may become a fundamental component of sustainable termite management (Ahmad et al., 2021b).

Economic and Policy Integration

The extensive implementation of ITM will rely not solely on scientific and technological advancements but also on economic and policy structures that facilitate sustainable pest management. A comprehensive transition to ITM necessitates synchronized governmental incentives that alleviate financial obstacles to improved monitoring equipment, especially in low-income areas where termite damage disproportionately impacts vulnerable populations. Subsidies for continuous monitoring systems, insurance collaborations, and low-interest financing for preventive building materials could enhance accessibility and expedite adoption (Rust & Su, 2012).

Integrating policies is crucial for harmonizing ITM with building rules, urban planning standards, and environmental restrictions. Implementing preventive designs, including moisture control systems, termite-resistant materials, and physical barriers in new constructions, may diminish long-term structural susceptibility. Moreover, defined certification criteria and national protocols for ITM deployment would improve professional training and promote uniform use across regions. Economic modeling can enhance policy decisions by illustrating the long-term cost reductions linked to integrated practices vs recurrent reactive interventions. With the backing of strong economic and legal frameworks, ITM may establish itself as the worldwide benchmark for sustainable termite management (Pretty et al., 2018).

Comparison of Traditional Termite Control and Integrated Termite Management

Aspect	Traditional Termite Control	Integrated Termite Management (ITM)	Supporting References
Detection Approach	Reactive detection based on visible signs such as mud tubes or damaged wood.	Proactive detection using monitoring stations, acoustic sensors, and advanced diagnostic tools.	Evans et al. 2013; Rust 2019
Chemical Use	Heavy reliance on broad-spectrum soil termiticides applied as continuous chemical barriers.	Reduced and targeted chemical use; emphasis on baiting systems, biological agents, and physical barriers.	Rust 2019; Su 2016
Environmental Impact	Higher contamination risk to soil, groundwater, and non-target organisms.	Lower ecological footprint due to selective, reduced-toxicity treatments and biological control.	Oi 2022

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Print ISSN 3007-3189
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Colony Elimination	Often incomplete; repellent termiticides kill workers but may not reach the colony core.	Bait systems achieve colony suppression by transferring toxicants throughout the population.	Su 2016; Evans et al. 2013
Cost Structure	Lower initial cost but higher long-term expenses due to repeated treatments and structural repairs.	Higher upfront investment but decreased long-term costs through prevention and early detection.	Rust 2019
Sustainability	Limited sustainability due to dependence on persistent chemicals.	Emphasizes ecological compatibility, durable construction methods, and long-term monitoring.	Oi 2022; Evans et al. 2013
Application Technique	Invasive treatments (drilling, trenching, broad soil application).	Non-invasive monitoring stations, strategic bait placement, and structural modifications.	Evans et al. 2013
Professional Skill Requirement	Basic pesticide application certification.	Requires advanced training in monitoring system interpretation, diagnostics, and multi-method integration.	Oi 2022; Rust 2019
Long-Term Effectiveness	Effectiveness declines as chemical residues degrade.	High long-term reliability when monitoring and interventions are maintained.	Su 2016; Rust 2019

Table 2. Comparison of Traditional Termite Control and Integrated Termite Management

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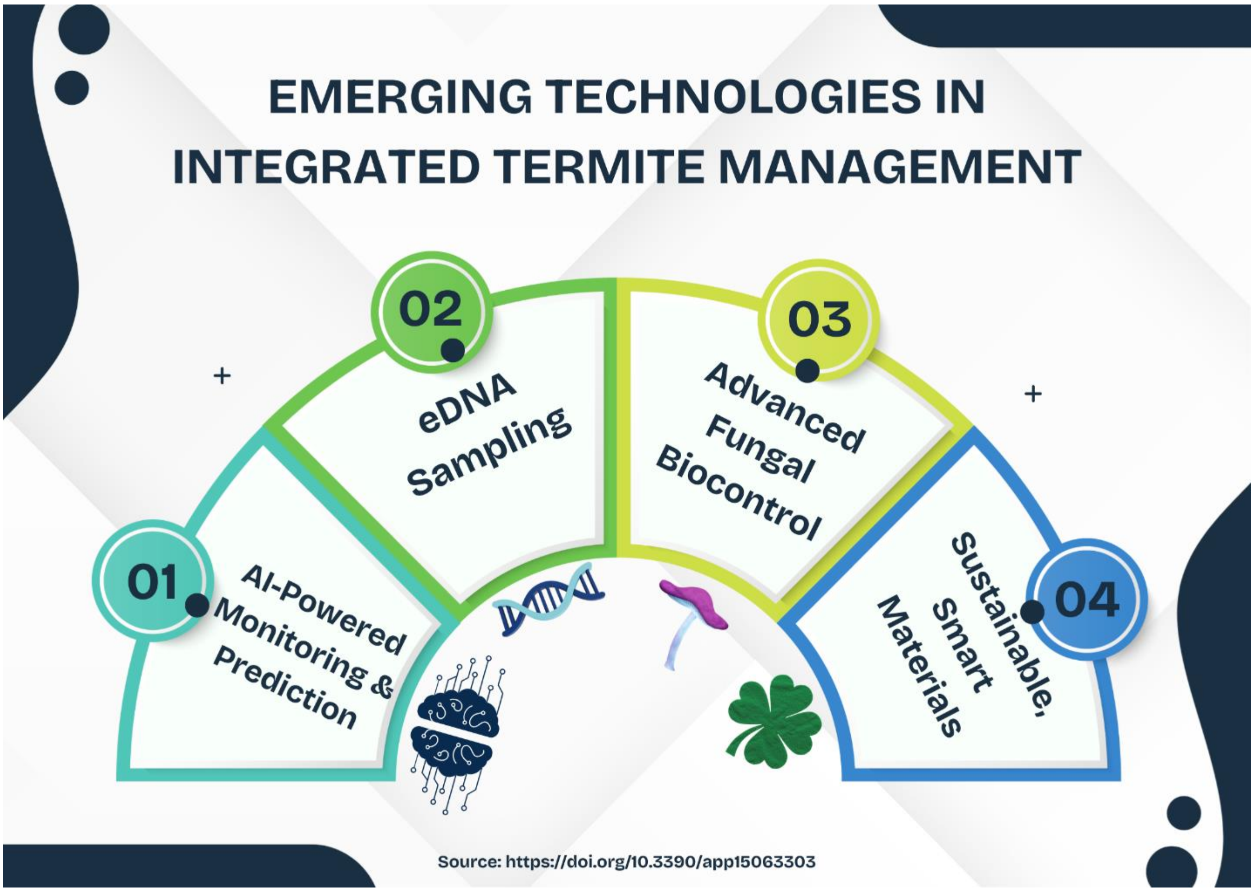

Figure 2: Emerging Technologies in Integrated Termite Management

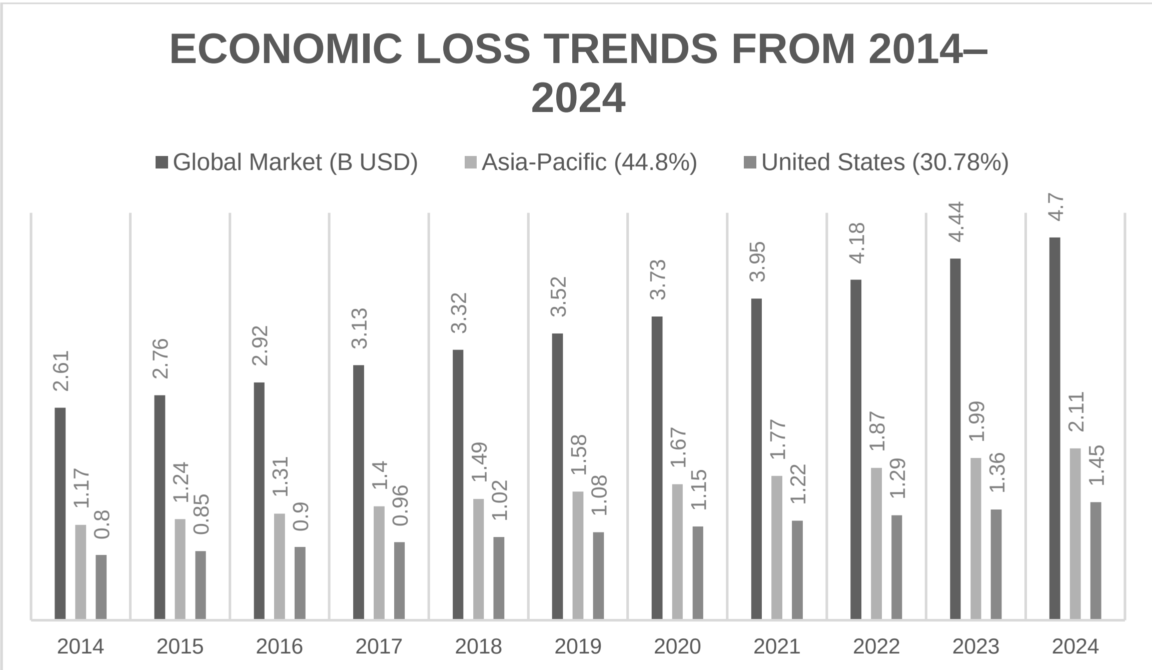

Figure:3 Economic Loss Trends from 2014–2024 (Global Termite Control Market

Online ISSN 3007-3197 Print ISSN 3007-3189
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Growth, Trends, and Forecast - 2022, n.d.; Termite Control Market Size, Share & 2030 Trends Report, 2025; Year: 2024 |, n.d.)

Conclusion

Integrated termite management has significantly advanced in the last decade, facilitated by improvements in monitoring technologies, bait systems, biological agents, and sustainable construction methodologies. These advancements have diminished dependence on chemical soil treatments and enhanced long-term economic and environmental results. Nonetheless, significant problems persist, such as deficiencies in early detection precision, substantial initial expenses for sophisticated monitoring instruments, variable efficacy of biological agents in the field, and regulatory discrepancies across different countries. Mitigating these limits necessitates enhanced policy support and better access to training and technology, particularly in economically disadvantaged regions.

Future advancements will rely on cooperation among entomology, engineering, digital technology, and regulatory domains. Innovative methods, like artificial intelligence-driven monitoring, molecular diagnostics, and more robust biological agents, present intriguing avenues for enhancing early identification and sustainable management. With suitable investment and coordinated regulatory frameworks, integrated termite management might significantly diminish global termite-related harm and bolster the resilience of urban infrastructure.

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