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APPLICATIONS OF NEW TECHNOLOGIES FOR ENVIRONMENTAL CLEANING: A REVIEW

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Review Paper

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ABSTRACT

Environmental pollution has become a major global concern, requiring innovative technologies for effective remediation. This review discusses recent advancements in environmental cleaning, including bioremediation, nanotechnology, advanced oxidation processes (AOPs), artificial intelligence (AI), green chemistry, and membrane filtration techniques. These technologies offer sustainable solutions for treating soil, water, and air pollution. This paper provides a comprehensive evaluation of their mechanisms, applications, advantages, limitations, and future potential. The integration of multiple technologies for enhanced efficiency is also examined, emphasizing the need for further research and policy development for large-scale implementation.

No. of Pages: 4 **References: 30**

Keywords: Environmental remediation, bioremediation, nanotechnology, oxidation processes, artificial intelligence, pollution control, sustainable technologies, green chemistry.

1. Introduction The rapid expansion of industrial activities, urbanization, and agricultural practices has resulted in widespread environmental contamination (Kuppusamy et al., 2016). The accumulation of hazardous pollutants in soil, water, and air poses serious health risks to both humans and ecosystems (Ghosh & Mohan, 2020). Conventional pollution control methods, such as physical and chemical treatments, often require high energy inputs, generate secondary waste, and may not be effective in completely eliminating pollutants. These challenges have led to the exploration and development of advanced environmental cleaning technologies that offer cost-effective, sustainable, and efficient solutions (Singh et al., 2021).

New technologies, including bioremediation, nanotechnology, and artificial intelligence, have revolutionized the field of environmental remediation by providing targeted and adaptive solutions (Kumar et al., 2019). Moreover, the integration of multiple techniques enhances pollutant degradation and improves overall treatment efficacy. This review provides a detailed overview of cutting-edge technologies for environmental remediation, their mechanisms, applications, advantages, and limitations. It also highlights future perspectives on improving the scalability and effectiveness of these technologies for real-world environmental challenges.

2. Bioremediation Technologies Bioremediation uses microorganisms and plants to break down pollutants in soil and water (Singh et al., 2021). Strategies include:

- **Microbial Remediation:** Genetically engineered bacteria enhance pollutant degradation (Kumar et al., 2019).
- **Phytoremediation:** Plants such as *Brassica juncea* and *Helianthus annuus* accumulate contaminants (Ali et al., 2013).
- **Enzymatic Bioremediation:** Enzymes such as laccases and peroxidases degrade persistent organic pollutants (Megharaj et al., 2011).

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3. Nanotechnology-Based Solutions Nanomaterials have revolutionized environmental cleaning by providing highly efficient adsorption and catalytic degradation (Khin et al., 2012). Key applications include:

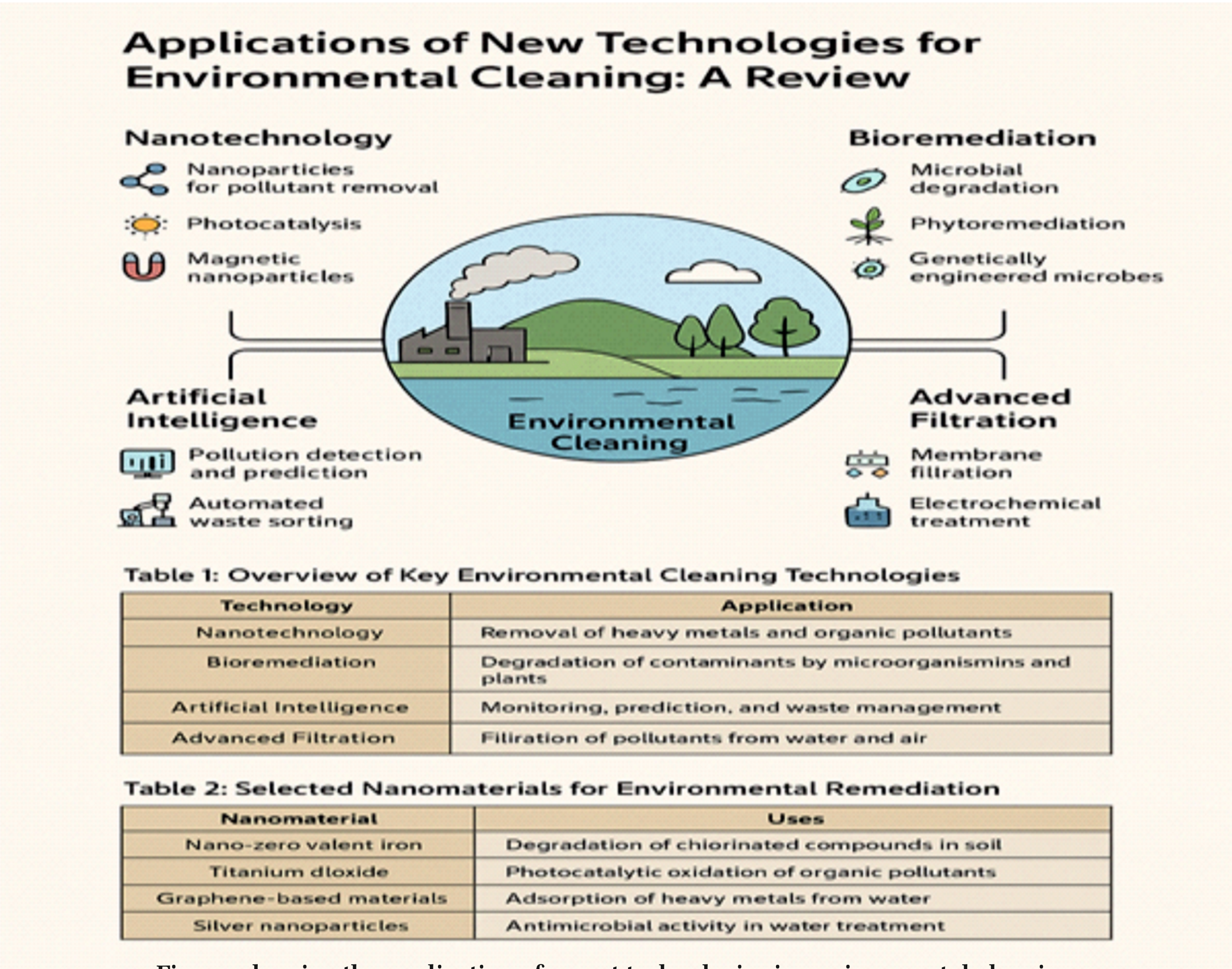
- **Water Purification:** Nano-adsorbents remove heavy metals and pharmaceuticals from wastewater (Zhang et al., 2019).
- **Air Filtration:** Carbon-based nanomaterials capture airborne pollutants (Nowack et al., 2012).
- **Soil Remediation:** Nanoscale zero-valent iron (nZVI) degrades chlorinated hydrocarbons (Sodha et al., 2020).

4. Advanced Oxidation Processes (AOPs) AOPs generate reactive radicals to break down pollutants (Oturan & Aaron, 2014). Techniques include:

- **Photocatalysis:** Titanium dioxide (TiO_2) and UV light degrade organic contaminants (Wang et al., 2016).
- **Fenton Process:** Iron-catalyzed oxidation for wastewater treatment (Kumar & Pal, 2018).
- **Electrochemical Oxidation:** Electro-Fenton processes for industrial effluent treatment (Sharma et al., 2021).

5. Artificial Intelligence in Environmental Cleaning AI enhances monitoring and decision-making in pollution control (Xu et al., 2021). Applications include:

- **Predictive Modeling:** AI-driven simulations optimize remediation strategies (Sharma et al., 2020).
- **Automated Detection:** AI-powered drones monitor air and water pollution (Tripathi et al., 2022).
- **Machine Learning for Waste Treatment:** AI-driven wastewater treatment plants improve efficiency (Singh & Joshi, 2020).



Technology	Application
Nanotechnology	Removal of heavy metals and organic pollutants
Bioremediation	Degradation of contaminants by microorganismins and plants
Artificial Intelligence	Monitoring, prediction, and waste management
Advanced Filtration	Filtration of pollutants from water and air

Nanomaterial	Uses
Nano-zero valent iron	Degradation of chlorinated compounds in soil
Titanium dioxide	Photocatalytic oxidation of organic pollutants
Graphene-based materials	Adsorption of heavy metals from water
Silver nanoparticles	Antimicrobial activity in water treatment

Figure: showing the application of recent technologies in environmental cleaning.

6. Membrane Filtration Technologies Membrane-based separation effectively removes contaminants from water (Alzahrani & Mohammad, 2014). Advanced membrane technologies include:

- **Reverse Osmosis (RO):** Desalination and heavy metal removal.
- **Nanofiltration:** Separation of microplastics and pharmaceutical residues (Gavrilescu et al., 2019).
- **Graphene Membranes:** Highly efficient pollutant removal with minimal energy consumption (Zhou et al., 2020).

7. Electrochemical Methods Electrochemical technologies are used for pollution remediation with minimal chemical input (Kumar et al., 2022). Key techniques include:

- **Electrocoagulation:** Effective removal of heavy metals from wastewater (Oturan & Aaron, 2014).
- **Electrochemical Advanced Oxidation:** Breakdown of persistent organic pollutants (Sharma et al., 2021).
- **Bioelectrochemical Systems:** Use of microbial fuel cells for pollutant degradation (Das et al., 2021).

8. Green Chemistry and Sustainable Approaches Green chemistry focuses on eco-friendly remediation strategies (Anjum et al., 2019). Examples include:

- **Bio-Based Adsorbents:** Chitosan, cellulose, and biochar for heavy metal removal (Zhou et al., 2020).
- **Enzyme-Based Detoxification:** Application of peroxidases and oxidases for wastewater treatment (Das et al., 2021).
- **Sustainable Catalysts:** Use of bio-derived catalysts for oxidation processes (Gavrilescu et al., 2019).

9. **Emerging Trends and Future Perspectives** The integration of multiple technologies can enhance environmental remediation (Tripathi et al., 2022). Research trends include:

- **AI-Assisted Bioremediation:** AI-optimized microbial consortia for enhanced pollutant degradation.
- **Nanotechnology-Enhanced Phytoremediation:** Improved heavy metal absorption using nano-fertilizers.
- **Hybrid AOP-Bioremediation Systems:** Combination of oxidation and biological degradation.
- Scalability and Policy Development: Ensuring global adoption through regulatory frameworks.

Conclusion

Emerging technologies provide promising solutions for environmental cleaning. While each technology has its strengths, integrated approaches offer superior efficiency. However, the deployment of these technologies on a larger scale still faces several challenges, including high costs, energy consumption, public acceptance, and regulatory approvals. Therefore, future research should focus on developing cost-effective, scalable, and energy-efficient remediation systems. Cross-disciplinary collaborations, industry participation, and international policy initiatives are essential to drive innovation and ensure effective implementation. As global environmental threats continue to rise, the adoption and evolution of advanced cleaning technologies are not just beneficial—they are imperative for sustainable development.

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DANCE AND ENVIRONMENT: A UNIQUE RELATIONSHIP BETWEEN CULTURE AND NATURE

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ABSTRACT

Dance is undoubtedly a great health exercise which needs a healthy body. Dancers have a unique perspective on the relationship between the body and the natural world, and their training and practice can lead to a deeper understanding of the environment. So a proper food system is required for the dancers. Staying in a polluted area, inhaling a high amount of CO^2 or such unhealthy gases will cause a risk for a dancer. So definitely we need a strong eco system and an interest in green technology. But what does the dance or dancer do for this? First of all, a dancer can spread awareness in society through their dance productions. Dance can be a powerful tool for raising environmental awareness by allowing audiences to experience the emotional and physical impact of environmental issues in a kinaesthetic way, fostering deeper understanding and connection to the problem.

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Keywords: Classical dance, folk, environment, nature, classical, folk.

Introduction

Dance can be used to highlight the unequal distribution of resources and the impact of environmental issues on marginalized communities. Choreographers are using dance to fight for climate action and raise awareness about environmental issues (Chaterjee and Dutta, 2016). The future-oriented pedagogy allows for play-based, creative, and exploratory dance practice. Within this format there is a need for identified intentional teaching moments that support students in questioning and revising their current ideas (Dasgupta, 1932). Considering how our environment sustains life, how we may be connected to that ecosystem, and observing any emerging patterns within that environment, help to guide the students as they become immersed in their explorations of place (Hiriyanna, 1995). Environmental sustainability, as defined by the United Nations Brundtland Commission, is about "meeting the needs of the present without compromising the ability of future generations to meet their own needs". Dance can play a role in sustaining the Earth by raising awareness about environmental issues, fostering cultural change, and encouraging sustainable practices through its inherent ability to connect people with nature and inspire action (Antez, 1985).

"*Biswa Tanute Anute Anute Kanpe Nrityarochhaya*"- Rabindra Nath Tagore

Dance is a very familiar word with us. If we find a definition of dance then definitely, it is the movement of the body in a rhythmic way, usually to music and within a given space, for the purpose of expressing an idea or emotion, releasing energy, or simply taking delight in the movement itself. But for individuals it can be a way by which they can express their nature, or for few people it is a way of meditation even dance is a therapy too. Cause "*Dance is the hidden language of the soul*" (Martha Graham). On the other hand, the environment is a very important thing or issue. If we want to live perfectly then we have to keep our

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environment safe from pollution, destruction etc (Antez, 1985).

But does dance plays an important role in keeping the environment safe? The answer is yes, it plays. Dance, environment, and nature are deeply interconnected because dance is often inspired by natural movements, rhythms, and elements of the environment. In fact every dance form imitates natural movements, such as the swaying of trees, the flowing of water, or the flight of birds. Traditional and indigenous dances often embody these elements. Several cultures around the planet use dance as a way to honour nature, seasons, and the environment. For example, rain dances, harvest dances, and animal-inspired performances celebrate the natural world (Chatterjea, 1996).

Some dance performances take place in outdoor spaces, blending human movement with the landscape. This creates a harmonious relationship between the dancer and the environment. Dance can be used as a medium to raise awareness about environmental issues, portraying themes of climate change, conservation, and ecological balance (Chakraborty, 2020). The rhythms of nature such as waves, wind, and heartbeats; mirror the rhythm of dance, making movement an extension of the natural world. Nature and the environment have played a significant role in shaping various Indian dance styles, influencing their *bol*, movements, themes, costumes, and expressions. Many Indian classical and folk-dance forms mimic natural elements like animals, birds, rivers, and trees. If we want to find the relation between the Nature and the Indian Classical Dances then I must say that this research will be very interesting (Kirkham, 2024).

How is dance similar to nature?

As a Language: Dance, like nature, uses movement and rhythm to communicate ideas and emotions without words. Nature also communicates through movement (wind, water, animals), rhythm (seasons, tides), and patterns (sunlight, constellations) (Kumar, 2022).

Connection and Rhythm: Dance is a physical art form that connects us to our bodies and the rhythms within them. Experiencing nature can also connect us to our bodies and the rhythms of the natural world (sun, moon, various seasons). Both dance and nature often exhibit rhythmic patterns, whether it's the beat of music in a dance or the ebb and flow of the tides (Kumar, 2022).

What characteristics do dance and nature have in common?

Dance and nature share the characteristics of movement, rhythm, and the ability to express emotions and stories, often through the use of natural elements and forms.

Expression of Emotions and Stories: Dance, like nature, can be used to express emotions and tell stories. Dance can evoke a wide range of feelings through its movements and music, while nature can inspire awe, wonder, and a sense of connection through its beauty and power (Allen, 1987).

Natural Elements and Forms: Dance can incorporate natural elements and forms, such as water, fire, earth, and air, to create a more immersive and expressive experience. For example, a dance piece could mimic the movement of waves or the flow of a river, or use costumes and props that evoke natural imagery (Kishore et al., 2018).

Improvisation and Creativity: Both dance and nature allow for improvisation and creativity. Dancers can create new movements and choreographies based on their own interpretations and emotions, while nature's processes are constantly evolving and changing, offering endless possibilities for observation and inspiration (Balslev, 2009).

The relation between the Indian Classical Dances and Nature: According to Dasgupta (1932) the Indian classical dances collectively are sometimes also believed to be a representation of the five elements of nature when regarded together. *Kuchipudi* and *Odissi* are believed to be Earth and Water respectively, with *Mohiniyattam* being Air, *Bharatnatyam* being Fire, and *Kathakali* the Sky. The movements themselves give a nod to these representations-with *Odissi*'s sensual and graceful nature like the rippling of rivers, *Bharatnatyam*'s sharp and swift extended movements like those of flames, and *Mohiniyattam*'s feminine and agile nature reminding the viewer of gusts of wind. *Kathak* is a dance form with very smooth moves, where steps segue from one to another, and the eyes express every emotion. At the same time, it includes extensive and fast footwork. This in itself symbolizes nature as nature has two sides: the caring side and the destructive one (Antez, 1985).

Bharatanatyam (Tamil Nadu): Bharatnatyam's *abhinaya* is also quite renowned for narrating themes of nature, with extensive use of *hasta mudras* to depict the same. From the *Simhamukha mudra* depicting a lion, or sometimes a deer, to *Kapittha*, *Kapota*, and *Ardhachnadra* used to show the moon-these *mudras* require expressive storytelling skills for a solo dancer to portray an entire story of nature singlehandedly on the stage. *Bharatanatyam* (Tamil Nadu) includes movements resembling the graceful swaying of trees, fluttering of birds, and flowing of rivers (Lal, 1998).

Odissi (Odisha): *Odissi* is known for its *tribhangi* (three-bend posture), which is believed to be inspired by the gentle curves of nature. The dance form also constitutes a heavy connection to the ground and the Earth itself, with grounded movements such as *chowka*. Numerous '*pallavis*', or pure *nritta* compositions set to *raagas*, depict themes such as rain, peacocks dancing, the composition of trees and forests, the gait of animals, and likewise, which are enmeshed with ancient legends in classical dance.

Kathak (North India, UP): The footwork is often inspired by the sounds of nature. "*Bols*" include words like "*jhan-jhan*", which conveys the sound of a river or water. Kathak dancers wear "*ghungroo*" around both their legs, which generate pleasant sounds synonymous with the harmony and synchrony of Mother Nature. One can also see many "*tukdas*" or pieces being about different aspects of nature as well for instance, the '*parmelu*', which synthesises various sounds of nature like the cuckoo bird and the sound of thunder.

Kathakali (Kerala) includes dynamic movements influenced by the strength of elephants and the agility of tigers.

Manipuri dance (Manipur) often portrays scenes from Lord Krishna's life, including playing near the Yamuna River and in lush forests.

Mohiniyattam (Kerala) incorporates slow, swaying movements that resemble the calm waves of Kerala's backwaters. Dancers wear materials sourced from nature, such as silk, cotton, and natural dyes.

Yakshagana (Karnataka) uses elaborate headgear and vibrant costumes inspired by the colors of forests, rivers, and the sky.

Folk dances are closely linked to harvests, monsoons, and other environmental cycles. *Bihu* (Assam) celebrates spring and agriculture, incorporating fast-paced movements resembling farmers' joyous celebrations. *Garba* (Gujarat) and *Ghoomar* (Rajasthan) are performed during seasonal festivals (Krishna, 1992). Several tribal and folk dances serve as rituals honor the land, rain, and deities associated with nature. *Chhau* (Jharkhand, Odisha, West Bengal) incorporates martial movements and animal-inspired postures. *Kummi* and *Kolattam* (Tamil Nadu) are performed in rural areas to express gratitude to nature. Major Indian dance styles evolved based on regional landscapes (Kishore et al., 2018). In coastal regions, movements are fluid and graceful (*Odissi*, *Mohiniyattam*). In mountainous regions, dances involve energetic footwork (*Ladakhi, Himachali Nati*). Thus, Indian dance forms are deeply connected to the environment, embodying the rhythm of nature in their art, movements, and traditions (Kirkham, 2024).

How can artists use nature for choreographic inspiration?

Inspiration for dance making comes from many sources. The natural world provides numerous cues that nudge us into intuitive improvisations and creative dance compositions. Observing Nature's Movements and Rhythms, Animal Behaviour, Natural Phenomena, Plant Growth help to translate Nature into Choreography like- Dance Sequences, Costumes, Stage Design, Music etc. (Rayapureddy and Rayapureddy, 2017).

Davalois Fearon: Considering Water Scarcity-"*As part of her work* Consider Water*, two dancers randomly distribute cups to audience members and a third pours water into some of the cups. The symbolism allows other audience members to glimpse what it feels like to be denied a resource, overlooked and ignored*." (Mohanty et al., 2016).

Jill Sigman: Disrupting Disposability- "*Jill Sigman, whose* The Hut Project *involves building huts out of scavenged materials, creates spaces that disrupt people's expectations of disposability, reuse and value*." (Mohanty and Saha, 2018).

Jennifer Monson: Exploring Ecological Phenomena- Jennifer Monson said "*I pay attention to those subtle movements by dancing, not just by observing*," she says. Cultivating this kind of embodied knowledge helped Monson think about climate change in terms of creativity and improvisation rather than fear (Radhakrishnan, 1929). In *Gitanjali* Tagore observed, "*The same stream of life that runs through my veins night and day runs through the world and dances in rhythmic measures*." Tagore believed that man is supposed to live in harmony with Nature and recognise that divinity prevails in all elements including plants and animals; otherwise, if he wished to walk upon the single way of human development, he would lose his balance (Yang and Zang, 2023). From his extensive writings about the relation of man to Nature, we discover that the experience of the world is not isolated from the experience of Nature. Along with her beauty and appeal, Nature's meaning and purpose were equally important to him where both were indispensable elements. Nature was not merely a showcase of objects but a habitation wherein man's place was splendid and significant. Nature without man would be a 'broken arch' and man without Nature a 'deserted land'. At Santiniketan, classes were held outdoors because he believed that "*nature [is] the greatest of all teachers*" and that *"children should be surrounded with the things of nature which have their own educational value*." (Norton-Smith, 2010).

The integral relationship between environment and dance from the perspective of Earth Day

The relationship between environment and dance is deeply intertwined, as dance has historically been a way for humans to connect with nature, express ecological awareness, and celebrate the rhythms of the Earth (Ross, 2025). From the perspective of Earth Day, this connection becomes even more significant, as dance can serve as both a form of environmental advocacy and a reflection of our relationship with the planet (Mallik et al., 2011).

Dance as a Reflection of Nature: Many traditional and indigenous dances are inspired by the natural world, imitating the movements of animals, elements, and celestial bodies. For example: Native American hoop dances reflect the cycles of nature and life. The Balinese dance incorporates movements inspired by water, wind, and animals. *Butoh*, a Japanese dance form, often embodies themes of decay and renewal, mirroring ecological processes. On Earth Day, such dances can serve as a reminder of the deep wisdom embedded in these traditions and the need to protect the ecosystems they celebrate (Page, 1933).

Dance as an environmental advocacy tool: In contemporary contexts, dance has been used as a powerful medium for raising awareness about environmental issues. Through eco-performance art, dancers communicate messages about climate change, deforestation, pollution, and sustainability. Choreographers create works that depict the effects of industrialization on nature. Using dance as a call to action can urge and inspire ordinary people to adopt more sustainable lifestyles. Incorporating natural settings (forests, oceans, deserts) as a performance space, promotes merging art with activism (Norton-Smith, 2010; Ross, 2025). On Earth Day, performances of eco-dance can serve as a direct appeal for environmental justice and conservation.

Dance and sustainable spaces: The places where we dance matter. Many Earth Day initiatives encourage sustainable practices in the performing arts, such as: using outdoor performances to highlight the beauty of natural spaces; and designing eco-friendly stages with recycled materials. Furthermore, promoting zero-waste costumes and sustainable production techniques help in spreading environmental awareness. By emphasizing environmental consciousness in dance events, we align artistic expression with ecological responsibility (Radhakrishnan, 1958).

Dance as a ritual for healing the Earth: Many cultures use dance in ceremonies to honour the Earth and seek harmony with natural forces. On Earth Day, community dances can: serve as collective rituals to express gratitude for the planet. Dance can inspire movements that symbolize renewal and environmental restoration. Bringing people together to physically embody the urgency of protecting our world can also be successfully achieved (Thobani, 2017).

Dance is an essential, expressive, and transformative tool for reconnecting with nature and advocating for a healthier planet. On Earth Day, it can serve as a vibrant call to action, reminding us that just as dance is shaped by its environment, our well-being is deeply linked to the health of the Earth. Through movement, we can honour, protect, and celebrate the rhythms of nature, ensuring a more sustainable future for generations to come. So, Dance can be used to educate the public on environmental concerns, allowing people to connect with issues on an emotional level, which can encourage action. Choreographers can use dance to explore themes of climate change, environmental justice, and the relationship between humans and the natural world. Dance can help people reconnect with nature and understand the interconnectedness of ecosystems. Dance can be used to raise awareness about the impact of human activities on the environment (Saha et al., 2013).

How can dance advocate for environmental change?

Dance can powerfully advocate for environmental change by translating complex issues into emotionally resonant, accessible performances, fostering empathy and engagement with the natural world through movement and storytelling (Kirkham, 2024).

Here's how dance can be used to advocate for environmental change:

- **Emotional Connection and Empathy:** Dance, with its ability to express emotions and tell stories through movement, can create a powerful emotional connection between audiences and environmental issues, making them more relatable and tangible (Thobani, 2017).
- **Raising Awareness:** Choreographers can create works that directly address environmental themes, such as climate change, pollution, or deforestation, raising awareness about these issues and inspiring action (Saha etal., 2013).
- **Cultural and Historical Context:** Integrating cultural symbolism and historical narratives within dance performances can connect environmental issues with cultural heritage and foster a deeper understanding of the relationship between humans and the environment (Mohanty and Sahay, 2018).
- **Promoting Sustainability:** Dance performances can showcase sustainable practices and inspire audiences to adopt more eco-friendly lifestyles, both in their personal lives and within the dance community itself (Ross, 2025).
- **Community Engagement:** Dance can be a tool for community engagement, bringing people together to discuss and address environmental challenges, fostering a sense of collective responsibility and action (Page, 1933).
- **Reconnecting with Nature:** Dance can help audiences reconnect with the natural world, promoting a sense of awe and appreciation for the environment, which can lead to a greater desire to protect it (Norton-Smith, 2010).
- **Using Dance as a Vehicle for Change:** Dance can be used as a platform for activism, with choreographers and dancers using their art to advocate for environmental policies and inspire social change (Mallik et al, 2011).
- **Embodied Awareness:** Dance can foster an embodied awareness of the environment, helping people understand their impact on the planet and the importance of sustainable practices (Vatsyayan, 1992).

Examples:

- Vertigo Dance Company uses sustainable practices in its operations and artistic approaches, including an Eco-Arts Village built with recycled materials and renewable energy.
- Lena Guslina raises awareness on environmental destruction through dance, inspired by her experiences with flooding in her city.
- KT Nelson's production "Dead Reckoning" demonstrates how humans are navigating blindly through environmental damage.

Environmental Dance:

Environmental dance is a dance form that explores the relationship between the body and the environment, often seeking to promote ecological balance and raise awareness about environmental issues through movement and performance (Yang and Zang, 2023). The interactive website environmental-dance.com combines knowledge of the earth's climatic changes with traditional and contemporary dances from around the world that reflect human beings and their integration into nature (Samanta et al., 2012). The aim of Environmental Dance is to make climate change tangible and visible on different levels, using dance, scientific data and personal testimonies from many countries around the world (Ross, 2025).

Conclusion

Ecology and natural harmony have played a crucial role in the evolution and stylization of dance across cultures (Kirkham, 2024). The relationship between humans and their natural environment has influenced movement patterns, aesthetics, and even the purpose of dance. Ecology and natural harmony has shaped dance by providing inspiration, themes, and movement vocabulary (Sharma, 2000). They foster a deep connection between humans and the natural world, ensuring that dance remains a reflection of life's organic rhythms and the environment that sustains it (Yang & Zang, 2023).

1. **Imitating Nature in Movements:** Many traditional dances mimic the movements of animals, birds, trees, or natural elements like water and wind. Example: Classical Indian dance forms like *Bharatanatyam* and *Odissi* incorporate movements inspired by animals (e.g., peacock, deer, snake).
2. **Cultural Reflections of Environment:** Indigenous and folk dances often arise from ecological settings. Example: Hawaiian *Hula* dance tells stories of nature, volcanoes, and ocean waves, preserving ecological wisdom.

3. **Seasonal and Agricultural Influence:** Many dance forms are connected to agricultural cycles, celebrating planting and harvest seasons. Example: *Bihu* dance of Assam (India) marks the arrival of spring and harvest.

4. **Rhythms and Patterns from Nature:** The rhythm of natural sounds, like rain, animal calls, or rustling leaves, inspires dance beats and movement flow. Example: African and Latin American tribal dances incorporate drumming that mimics the heartbeat of the earth.

5. **Spiritual and Ritualistic Harmony:** Many traditional dances are performed to honour natural elements-sun, moon, rain, and earth. Example: Native American rain dances invoke rainfall to sustain crops and ecosystems.

6. **Eco-conscious Modern Dance:** Contemporary choreographers create performances reflecting environmental concerns, Climate Change, and conservation. Example: Earth-cantered dance projects use movement to advocate for sustainability and ecological balance.

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LIFE CYCLE ASSESSMENT OF CASTOR-BASED CONSTRUCTED WETLAND SYSTEMS: A COMPARATIVE STUDY ON BIO-DIESEL AND ERI-SILK COCOON PRODUCTION FOR SUSTAINABLE RICE-MILL WASTEWATER MANAGEMENT

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ABSTRACT

Constructed wetlands (CWs) offer a sustainable method for treating nutrient-rich rice mill wastewater while enabling biomass valorization. This study uses Life Cycle Assessment (LCA) to compare two castor-based CW models—for biodiesel and eri-silk cocoon production—across key impact categories such as human health, ecosystem quality, resource use, energy, water footprint, and compost sustainability. Fine particulate matter formation and global warming dominate environmental impacts, contributing 97% of total damage. Biodiesel production shows higher burdens in global warming (4.94E-07 DALY), fossil resource use (8.49E-03 USD), and eutrophication (8.47E-09 species.yr), mainly due to its energy-intensive processing. Eri-silk production has higher particulate matter formation (2.72E-07 DALY) and fossil resource scarcity (3.63E-03 USD), linked to silkworm rearing. Biodiesel demands more energy (1.28 MJ/kg) and water (0.078 m^3/kg) than eri-silk (0.554 MJ/kg and 0.034 m^3/kg). Compost from the eri-silk system has lower environmental impacts, particularly in eutrophication. The study highlights the need for integrated optimization to balance the eco-sustainability of eri-silk with the economic viability of biodiesel.

No. of Pages: 7 **References: 29**

Keywords: Castor-based Wetland, Eri-silk, Biodiesel, Compost, Life Cycle Assessment, Damage Assessment.

INTRODUCTION

Rice mill wastewater is associated with significant environmental concern due to the large volumes of effluent generated during the rice milling process, particularly in regions where rice is a staple food (Pandhan & S K Sahu; 2011).If not properly treated, it can lead to severe pollution of surface and groundwater resources, affecting both human health and ecosystems (Chen et al., 2023). The effluent typically contains high levels of organic matter, suspended solids, and nutrients, which can degrade water quality and disrupt aquatic life (Kiran & Prasad; 2020)..

The environmental impact of rice mill wastewater requires effective management and treatment strategies to mitigate its adverse effects, caused by virtue of stressed water quality parameters, viz. pH, turbidity, and biochemical oxygen demand (BOD) in affected water bodies(Rahman et al., 2020).In fact, high levels of total dissolved solids (TDS) and other pollutants in the effluent can harm aquatic ecosystems, leading to reduced biodiversity and altered ecosystem functions as well as soil degradation (Adeleye et al 2021; Bharti et al.,2020).

Constructed wetlands (CWs) are increasingly recognized as a sustainable approach to wastewater treatment, offering an eco-friendly alternative to conventional methods.CWs are a cost-effective solution for treating wastewater, requiring lower operational costs compared to traditional systems,

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because of usage of natural processes involving plants, soil, and microorganisms to remove pollutants from sustainability. Besides, they can be decentralized, allowing for localized treatment and minimizing energy consumption (Paul et al., 2015). Their ability to support diverse microbial communities contributes to effective contaminant degradation and nutrient cycling (S Kumar & R Singh 2018; Wang et al., 2023).In fact, specific configurations and plant-microbe interactions enhance the removal of organic micro pollutants for various types ofwastewater, including municipal, agricultural, and industrial effluents.

The castor plant (*Ricinus communis L.*) has been a promising candidate for both wetland remediation and as a cash crop, particularly in areas contaminated with heavy metals, by virtue of its ability to thrive in polluted environments while accumulating and stabilizing toxic substances makes it a valuable asset in phytoremediation efforts (Kataki et al.,2021). Various researchers have demonstrated that the ability of castor to grow in highly contaminated soils, due to its high tolerance and biomass accumulation, which is crucial for effective remediation, it possess significant capacity for phyto-extraction of heavy metals such as copper, lead, and zinc (Flota et al., 2022) Beyond its environmental benefits, castor is also a rich source of ricin oleic acid, making it suitable for biodiesel, offering a renewable alternative to fossil fuels as well as glycerine, which is valuable in pharmaceuticals and cosmetics ,thus providing economic incentives for its cultivation. Hence, the integration of castor cultivation in contaminated sites can lead to sustainable agricultural practices, enhancing soil health while generating income (Deshmukh et al., 2021; Kataki et al., 2021). Even after oil extraction, over 50% of the castor seed remains as de-oiled cake, which can be used as biomass for energy production (Chowdhury & Rahman, 2017).

Yet another domain of economic and sustainable utility of castor leaves is its use as feed for eri silkworms (*Samiacynthiaricini*), which forms a critical aspect of sericulture, influencing both the growth of the silkworms and the quality of silk produced. Research indicates that the nutritional value and health of castor leaves directly affect the productivity of eri silkworms, with various treatments and genotypes showing significant differences in feed efficiency and silkworm performance (Chakraborty & Ray, 2015).

Life Cycle Assessment (LCA) has been globally recognized as an effective tool for sustainability assessment, particularly in evaluating the environmental impacts of products and processes throughout their entire life cycle (K B Aviso, 2024; Novemyanto & Nazri, 2024).There have been extensive studies on LCA-based sustainability assessment of Constructed wetlands and wetland ecosystems, as well as the associated processes (Chen et al., 2023; Kataki et al., 2021; Zhou et al., 2023).

In the present work two pathways of castor-based wetland models are investigated for their sustainability using Life Cycle assessment (LCA), targeting towards two distinct end-products, such as bio-diesel and eri-silk cocoons, with their attendant by-products, namely compost.

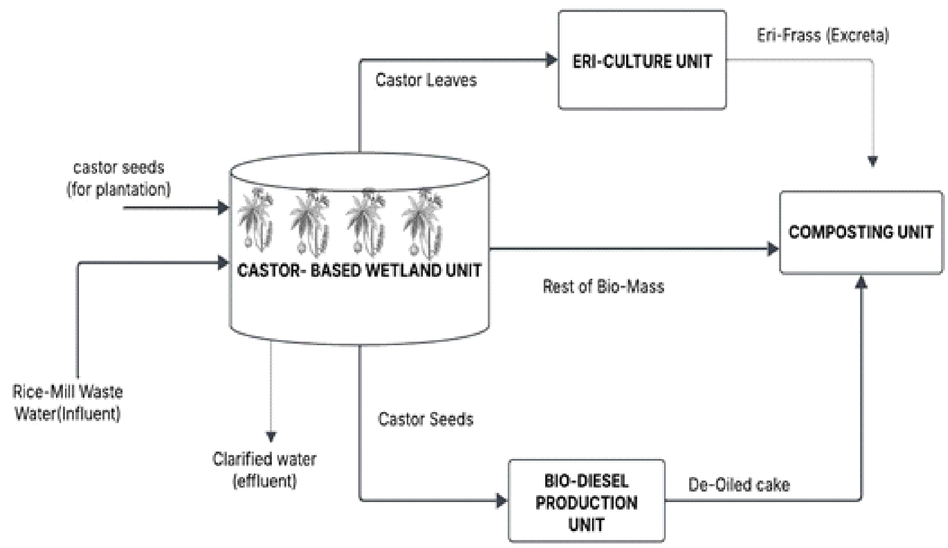


Fig. 1: Integrated the Closed-Loop Castor-Rice Mill wastewater Wetland System.

Since, the castor plants produce various outputs that feed into different units, one of which is its leaves harvested for Eri-Culture Unit, where they serve as food for eri silkworms. These silkworms generate excreta (eri-frass), which is further processed in the Composting Unit to produce nutrient-rich compost. Additionally, the castor seeds also harvested from the wetland unit are sent to the Bio-Diesel Production Unit, where they are processed to extract bio-diesel, a renewable energy source. This extraction process also generates a by-product known as de-oiled cake, which, instead of being discarded, is also sent to the Composting Unit.

Additionally, any residual biomass from the wetland system that is not directly utilized in other processes is also funnelled into the Composting Unit. This ensures that all organic matter is effectively recycled into compost, which can then be used for soil enrichment or reintroduced into the plantation cycle. The entire system is designed to be a circular economy model, where waste from one process becomes an input for another, minimizing environmental impact and maximizing resource efficiency. The integration of wastewater treatment, eri-culture, biofuel production, and composting highlights the framework's sustainability by closing the loop on waste, water, and energy.

Design of Castor-Rice Mill Wastewater (WW) Wetland System

The constructed wetland, being a vital component behind sustainable rice mill waste water management, was designed and construction to handle an inflow rate of 1 kilolitre per day (KLD) of effluent from rice milling operations. The constructed wetland is configured in a rectangular shape, measuring 10 meters in length, 5 meters in width, and 0.5 meters in depth. This design is favoured for its simplicity in construction and maintenance, as well as its effectiveness in facilitating pollutant adsorption through vertical flow mechanisms. The vertical flow design allows for optimal interaction between the wastewater and the plant roots, enhancing the removal of contaminants from the water. The various design specifications are provided in Table-1.

Table 1: Design parameters of wetland system.

S. No	Design Parameter	Values
1.	Wetland Dimensions	50 m^2
2.	Wetland Size	10m (Length) x 5m (Width) x 0.5m (Depth)
3.	Hydraulic Load	1.0 m^3/day
4.	BOD Removal Efficiency	60-90%
5.	TSS Removal Efficiency	70-90%
6.	NH3/NH4 Removal Efficiency	60-80%
7.	TN Removal Efficiency	50-70%
8.	TP Removal Efficiency	50-80%
9.	Retention Time (HRT)	5-10 days
10.	Aspect Ratio (L:W)	2:1
11.	Substrate Composition: Gravel	Coarse (20-40 cm), Fine (10-20 cm)

To prevent groundwater contamination, an impermeable liner made of PVC has been installed at both the base and sides of the wetland. This barrier is essential for containing the wastewater within the system and preventing leachate from impacting surrounding soil and water resources. Additionally, a distribution pipe is strategically placed at the top of the wetland to ensure an even distribution of influent across the surface area. At the bottom, a perforated pipe collects treated effluent, helping to maintain a consistent water level within the wetland. This design feature is vital for sustaining the biological processes necessary for effective wastewater treatment.

Plant Selection and Substrate Composition

For this wetland, castor plants (*Ricinuscommunis*) have been selected due to their adaptability to well-drained soils. The substrate used consists of a combination of natural materials aimed at ensuring effective drainage and filtration. Specifically, coarse gravel (20-40 mm) and fine gravel (10-20 mm) are utilized to create a suitable environment for the castor plants while promoting optimal water flow through the system. The density of castor plants is maintained at approximately 4 to 6 plants per square meter for ensuring adequate coverage and maximizing pollutant uptake, thereby enhancing the overall efficiency of the wetland. The plant growth and yield studies are given in Table 2.

Table 2: Plant growth and yield studies.

S. No.	Parameter	Specifications
1.	Plant Height	00 - 300 cm
2.	Number of Leaves per Plant	20 - 96 leaves
3.	Number of Capsules per Plant	18 - 137 capsules
4.	Seed Yield (kg/m2)	0.05 -0.15kg/m^2
5.	Oil Content (%)	40 - 50%
6.	Spike Length (cm)	24.4 - 27.21 cm
7.	Capsule Dry Weight (g/seed)	0.95-1.41 gm
8.	Plant Density	4-6 plants/m^2
9.	Leaf size	15 - 45 cm
10.	Biomass yield per m^2	3.5-9 Kg

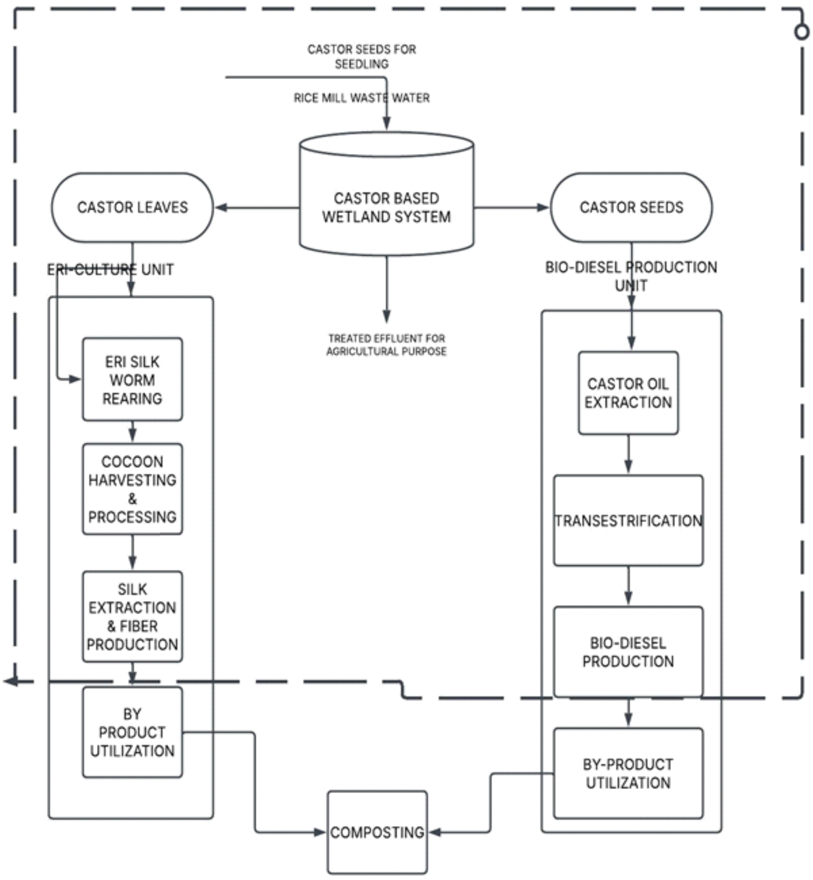
LCA Framework for Wetland System Components

This study employs a comparative Life Cycle Assessment (LCA) approach to evaluate the environmental performance of two distinct castor-based wetland systems, each producing different end products-eri-silk cocoons (Figure 3) and bio-diesel (Figure 4). The LCA focuses on assessing their impacts on human health, ecosystem quality, and resource depletion, considering both short-term and long-term emissions. The study extends to the evaluation of normalized sustainability parameters, a comparative impact assessment of composts derived from both systems, and an analysis of the water footprints associated with these processes. The methodology follows the ISO 14040/14044 guidelines, covering goal and scope definition, life cycle inventory (LCI) using Eco-invent database (Version 3.10), life cycle impact assessment (LCIA), and interpretation using SimaPro 9.6, so as to ensure a rigorous and standardized analysis.

System Boundaries and Functional Units

A cradle-to-grave boundary is established for both systems (batch type, each cycle extending up to 90 days) (Figure 2), incorporating processes from castor cultivation and wastewater treatment to final product generation and waste management. The functional unit is defined as the production of 1 kg of the final product (either bio-diesel or eri-silk cocoons) for a single cycle, in order to enable meaningful comparisons. The study considers multiple impact categories, including human health, ecosystem and resource depletion, along with their sub-categories. The infrastructural set up (for the wetland, process & product handling) as well as usage of products and by-products (viz. treated wastewater, biodiesel, glycerine, eri-silk cocoon and the respective composts) are not included in the present LCA study.

Since, the route for eri-silk production and that for biodiesel generation are dependent on two distinct yields from wetland, namely leaves and seeds, whose productivity of the former affects the latter, because more leaves harvested reduces less yield of seed and thus lesser generation of biodiesel, the two wetland system was studies separately for each of the routes, so as to provide the framework of their integration, based on characteristics of rice mill wastewater as well as available infrastructure. The quality of rice-mill wastewater, which is influent to the wetland system has been pre-treated to a level acceptable for growth of the castor plants, based on the experimental studies carried out in the laboratory of the authors.



Figu. 2: LCA boundary of Castor based Rice-mill waste water wetland system.

System 1: Eri-Silk Production Method Materials and Process Flow

In order to produce eri-silk cocoons as the primary end product, system-1 was deployed (Figure 3), the main inputs and processes being rice-mill wastewater and Castor seeds leading to castor cultivation in wetland basin, while the primary outputs being wetland-treated wastewater, castor biomass (classified as : castor leaves, and rest of the castor biomass). In fact, the eri-worm eggs, which are placed in a rearing unit, where the larvae primarily eat castor leaves yielding progressively unto matured eri-worms, pupae and cocoons, whereas the residues from all

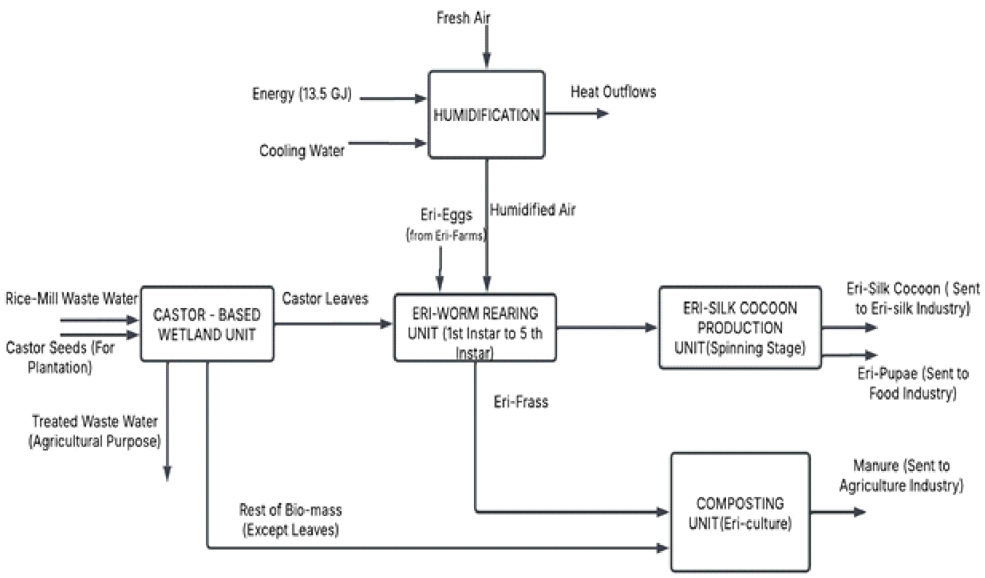


Fig. 3: Flow Diagram of Eri-Culture (Castor based) Unit.

Subsystems being undergone composting to yield organic manure. Hence, this system is primarily comprised of threes subsystems, namely,(1) rearing of eri-worm (up to 5th Instars stage) with a supporting humidification sub-system to maintain an ideal environment for eri-worm development (24–25°C temperature, 75% relative humidity), (2) production of cocoons with development of the pupae, and (3) preparation of compost with a castor-based wetland residues (predominantly consisting of castor non-leafy biomass and eri-frass).Eri-frass refers to an excreta produced by eri-worms after their voracious consumption of castor leaves, as they undergo through five instar stages and are high in nutrients. The next metamorphosed stage of eri-worm is their transformation untoEri-pupae (with the outer layers of spinned-cocoons). Eri-pupae are mostly used as protein supplement, baby-food and even in preparation of biscuits, whereas the eri-silk cocoons are utilized for the eri-silk manufacturing. Now, the circular waste management strategy gets completed by composting the left over biomass (leaves excluded) into organic manure.

System 2: Bio-Diesel Production Route Materials and Process Flow

The bio-diesel system, also referred to as System-2, (Figure 4) starts with the same basic unit as the system-1 :(1) castor-based constructed wetland set up to treat rice mill wastewater. The influent to this sub-system is the castor seeds as well as the rice mill wastewater and the output includes treated wastewater grown-up castor plants, as in the case of System-1. However, the biomass yields form this subsystem is segregated as oil-seed and the rest of the biomass, because here the focus is the oilseed for their usage for biodiesel production (in contrast to castor leaves for their usage in eri-culture as in case of the System-1). The next subsystem involves (2) processing of harvested castor seeds in an oil-extraction unit so as to obtain castor oil, the primary raw material for bio-diesel production, with a portion (roughly 3%) retained for future of castor plantation cycles. This sub-system requires external power for milling the seeds and generates de-oiled cakes along with the castor-oil. The castor-oil so generated needs to undergo (3) trans-esterification process, which in contact with Methanol and catalyst, turns castor oil into bio-diesel as well as glycerin.

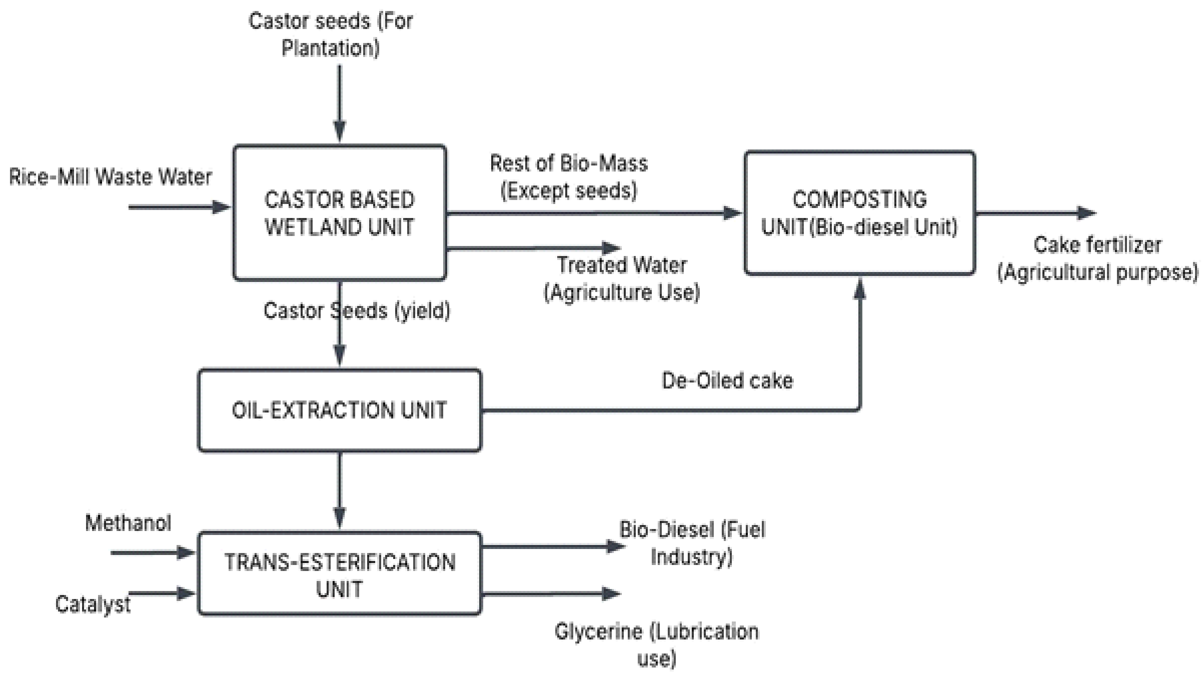


Fig. 4: Flow Diagram of Bio-Diesel (Castor based) Unit.

Byproduct. Finally, the de-oiled cake, a substantial by-product of oil extraction, is (4) composted into organic fertilizer combined with leftover biomass. Hence, the various products generated through the process include treated wastewater, oil-seed (for cultivation for next cycle in the wetland), castor oil (and associated rang of usages), glycerin (utilized for lubricating purposes), bio-diesel (as a substitute to diesel) as well as composted cake fertilizers.

Life Cycle Inventory (LCI) and Information Gathering

LCI phase includes quantification of material flows, energy use, emissions, and waste outputs for both systems, i.e. system-1 & system-2. Site-specific measurements and studies on pilot-plantof experimental castor-wetland units are used for estimating castor biomass yields, wastewater treatment efficiency, energy inputs, and product outputs, composting, bio-diesel production and eri-worm rearing. The emission data associated with all these processes are obtained from Eco-invent database (V 3.10) with special emphasis to India.

Methodology for Life Cycle Impact Assessment (LCIA)

Various impact categories are selected based on their relevance to agriculture-based wetland systems and industrial processing, which are categorized in terms their effects on three primary environmental domains: human health, ecosystem and resources as well as the related subdomains.TheSimapro (9.6) is used to assess comparative environmental impacts, encompassing important areas like water footprint, freshwater eutrophication, human toxicity, global warming potential, and fossil depletion, based on ReCiPe 2016 Midpoint (H) technique.

Comparison of Compost Quality and Environmental Impacts

Both systems generate compost as a by-product, but with varying quality and environmental impact. The compost derived from the eri-worm production system is rich in eri-frass, expected to enhance soil microbial activity and nutrient availability and in contrast, the bio-diesel system is likely to produces de-oiled cake that serves as a fertilizer with higher nitrogen content. The environmental footprint of these composts is compared in terms of greenhouse gas emissions, soil enrichment potential, and overall nutrient retention, using ReCiPe 2016 Midpoint (H) approach.

Water Footprint & Energy Network Analysis

Since, water usage plays a critical role in both systems, assessment of the direct and indirect water footprints across all stages (starting from rice-mill wastewater treatment to product processing) were evaluated using AWARE (V1.06) method. Besides, network analyses for the two components are also carried out to estimate the energy consumption across both the routes of Castor-wetland system.

Sustainability-Magnitude Assessment

The sustainability of each system is assessed using normalized impact scores, which provide insights into the dominant environmental parameters affecting each route. The results are interpreted to determine the relative benefits and drawbacks of eri-silk and bio-diesel production in terms of resource efficiency, emissions reduction, and circular waste management, irrespective of the associated units, so as to ascertain the major environmental hotspots and provide scope for informed sustainable decision-making for castor-based wetland applications by offering a holistic comparison of environmental impacts.

RESULTS AND DISCUSSIONS

Comparative Evaluation of Possible Damages for Different Impact Types

Table.3 provides a comprehensive assessment of comparative evaluation of significant variations across different impact categories as revealed by the short-term and long-term damage assessments components for the eri-silk cocoon and castor-based bio-diesel systems. The long-term impairments typicallyappears to be by and large insignificant or nonexistent, whereas short-term effects predominate in both systems. This distinction is crucial in understanding the immediate versus prolonged environmental and health consequences of each production route.

Table 3: Damage Assessment of Bio-Diesel & Eri-Silk Cocoon (Long-term *vs* Short-term).

IMPACT	Various Category	DAMAGE ASSESSMENT					
		Bio-diesel (Castor -based)			Eri-Silk Cocoon (Castor based)		
		Total	Short-term	Long-term	Total	Short-term	Long-term
Human Health \(DALY)	Global warming, Human health	4.94E-07	4.94E-07	0.00E+00	1.63E-07	1.63E-07	0.00E+00
	Stratospheric ozone depletion	5.60E-11	5.60E-11	7.00E-18	2.40E-11	2.40E-11	3.00E-18
	Ionizing radiation	1.80E-10	1.89E-11	1.62E-10	7.74E-11	8.10E-12	6.93E-11
	Ozone formation, Human health	6.62E-09	6.62E-09	3.10E-15	3.49E-10	3.49E-10	1.32E-15
	Fine particulate matter formation	9.56E-07	9.55E-07	1.94E-10	2.72E-07	2.72E-07	8.32E-11
	Human carcinogenic toxicity	1.63E-07	5.13E-09	1.58E-07	7.00E-08	2.20E-09	6.78E-08
	Human non-carcinogenic toxicity	1.33E-07	1.77E-08	1.16E-07	5.72E-08	7.60E-09	4.96E-08
	Water consumption, Human health	3.93E-10	3.93E-10	0.00E+00	1.69E-10	1.69E-10	0.00E+00
Eco-Systems (species.yr)	Global warming, Freshwater ecosystems	4.07E-14	4.07E-14	0.00E+00	1.34E-14	1.34E-14	0.00E+00
	Ozone formation, Terrestrial ecosystems	2.11E-10	2.11E-10	4.40E-16	5.00E-11	5.00E-11	1.86E-16
	Terrestrial acidification	3.46E-10	3.46E-10	2.60E-16	1.15E-10	1.15E-10	1.10E-16
	Freshwater eutrophication	8.47E-09	8.20E-09	2.73E-10	1.30E-10	1.28E-11	1.17E-10
	Marine eutrophication	6.25E-10	6.25E-10	4.13E-14	1.83E-14	6.07E-16	1.77E-14
	Terrestrial ecotoxicity	8.24E-12	8.18E-12	5.83E-14	3.53E-12	3.51E-12	2.50E-14
	Freshwater ecotoxicity	9.30E-12	7.58E-13	8.55E-12	3.70E-12	3.83E-14	3.67E-12
	Marine ecotoxicity	1.93E-12	1.50E-13	1.78E-12	8.00E-13	3.66E-14	7.63E-13
	Land use	3.41E-09	3.41E-09	0.00E+00	3.13E-11	3.13E-11	0.00E+00
	Water consumption, Terrestrial ecosystem	1.45E-11	1.45E-11	0.00E+00	6.20E-12	6.20E-12	0.00E+00
	Water consumption, Aquatic ecosystems	4.02E-15	4.02E-15	0.00E+00	1.73E-15	1.73E-15	0.00E+00
Resources (USD2013)	Mineral resource scarcity	3.37E-03	3.37E-03	0.00E+00	1.44E-04	1.44E-04	0.00E+00
	Fossil resource scarcity	8.49E-03	8.49E-03	0.00E+00	3.64E-03	3.64E-03	0.00E+00

The category-specific assessment are provided in the subsequent paragraphs.

Assessment of Damage Potential related to Human Health for the Castor-based wetland Systems

For human health-related impacts (Figure 5 & 6), both bio-diesel and eri-silk cocoon systems exhibit only short-term damage for global warming, ozone formation, particulate matter formation, and water consumption, with long-term values being negligible. For instance, the biodiesel production shows almost four-fold higher short-term effects of global warming on human health (i.e., 4.94E-07 DALY), compared to its counterparts for eri-silk production system (i.e., 1.63E-07 DALY); whereas the long-term component is nil in both the cases, indicating the greenhouse gas emissions and the resulting health costs are mostly immediate in nature (rather than appreciably protracted over time). In the similar line, the short-term implications of fine particulate matter generation by biodiesel (9.56E-07 DALY) is about four-fold of the short-term fine particulate.

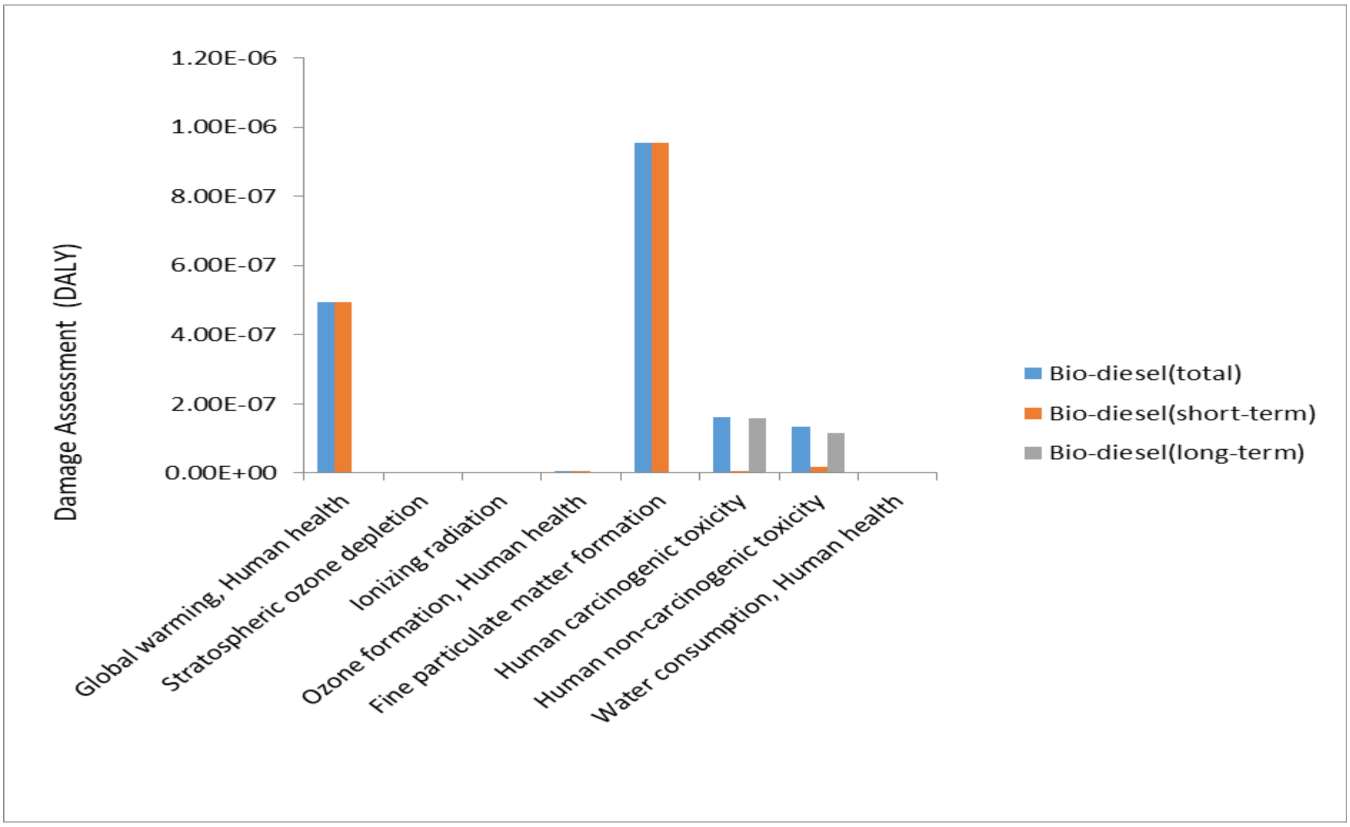


Fig. 5: Damage Assessment with Regard to Human Health for Biodiesel Castor Wetland Systems.

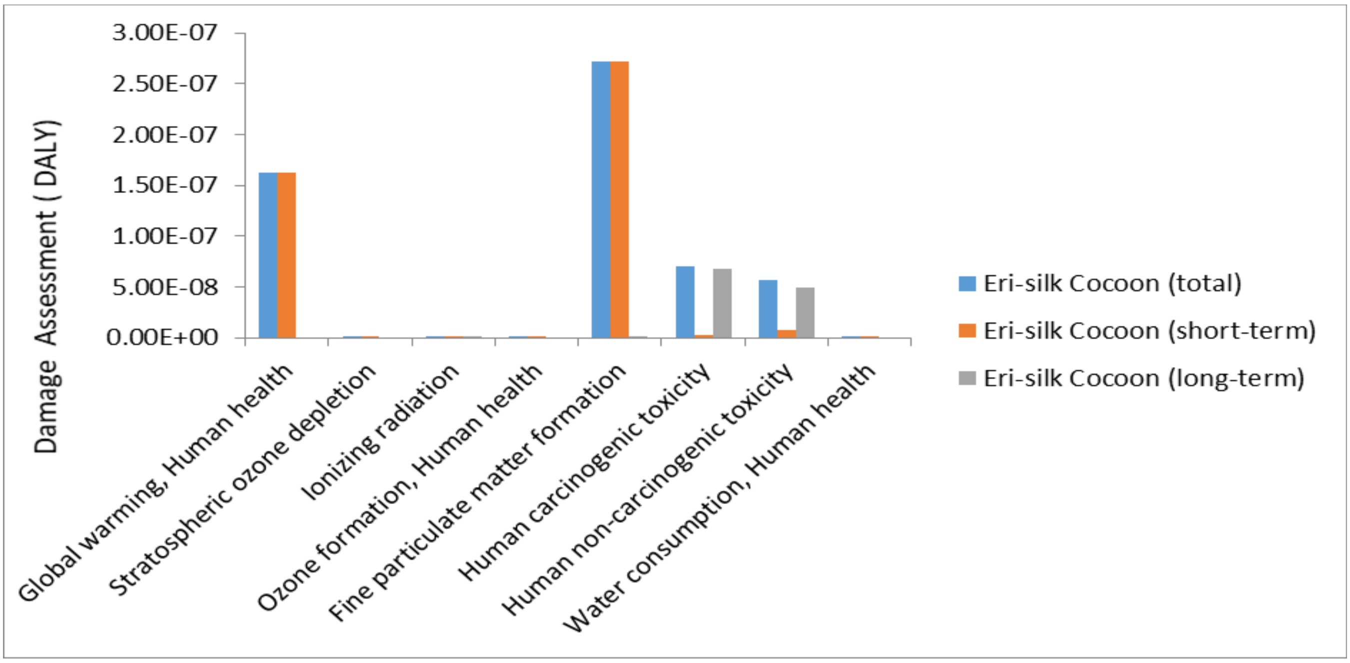


Fig. 6: Damage Assessment with Regard to Human Health for Eri Silk Castor Wetland Systems.

Matter generation for eri-silk production (2.72E-07 DALY), which constitutes a significant cause of respiratory disorders, whereas the long-term effects are negligible. This pattern seems to suggest that emissions produced during the production of gasoline or the rearing of silk contribute to air pollution mostly in the short term rather than over time.

It may also be noted that, with regard totoxicity effects, a slight long-term component is observed for both systems, but with varying magnitudes indicating that the magnitude of chemical exposure from bio-diesel processing has longer-lasting consequences. We can see that the human carcinogenic toxicity for bio-diesel (1.36E-07 DALY total) includes a small long-term impact (1.58E-07 DALY), whereas eri-silk cocoon production (7.00E-08 DALY total) has a lower long-term toxicity impact (6.78E-08 DALY).non-With regard to carcinogenic toxicity,bio-diesel (1.16E-07 DALY) is an order to high with regard to that associated with production of eri-silk Cocoon (4.96E-08 DALY). It is also evident that the pollutants from both processes have some degree of long-term health effects, although the bio-diesel pathway is more noticeable.

Assessment of Damage Potential related to Ecosystem for the Castor-based wetland Systems

For ecosystem-related impacts, most categories are dominated by short-term effects, with minimal long-term contributions (Figure 7 & 8). For instance, terrestrial acidification shows significant short-term impacts of 3.46E-10 species.yr for bio-diesel and 1.15E-10 species.yr for eri-silk, while their long-term contributions are almost negligible (2.06E-16 species.yr and 1.10E-16 species.yr, respectively). It is also observable that both the systems' (i.e., biodiesel-system&eri-system) acidifying emissions and fertilizer runoff have a short-term impact on ecosystems with limited long-term durability. Similarly, the long-term component of freshwater eutrophication in bio-diesel is higher by an order (8.47E-09 species.yr) compared to that caused by production of eri-silk cocoons' (1.30E-10 species.yr), although both of the cases it is negligible. However, there are several categories, such as terrestrial ecotoxicity and marine eutrophication, wherein there is aslight long-term effects, probably associated with lingering chemical and waste product residues from these systems.

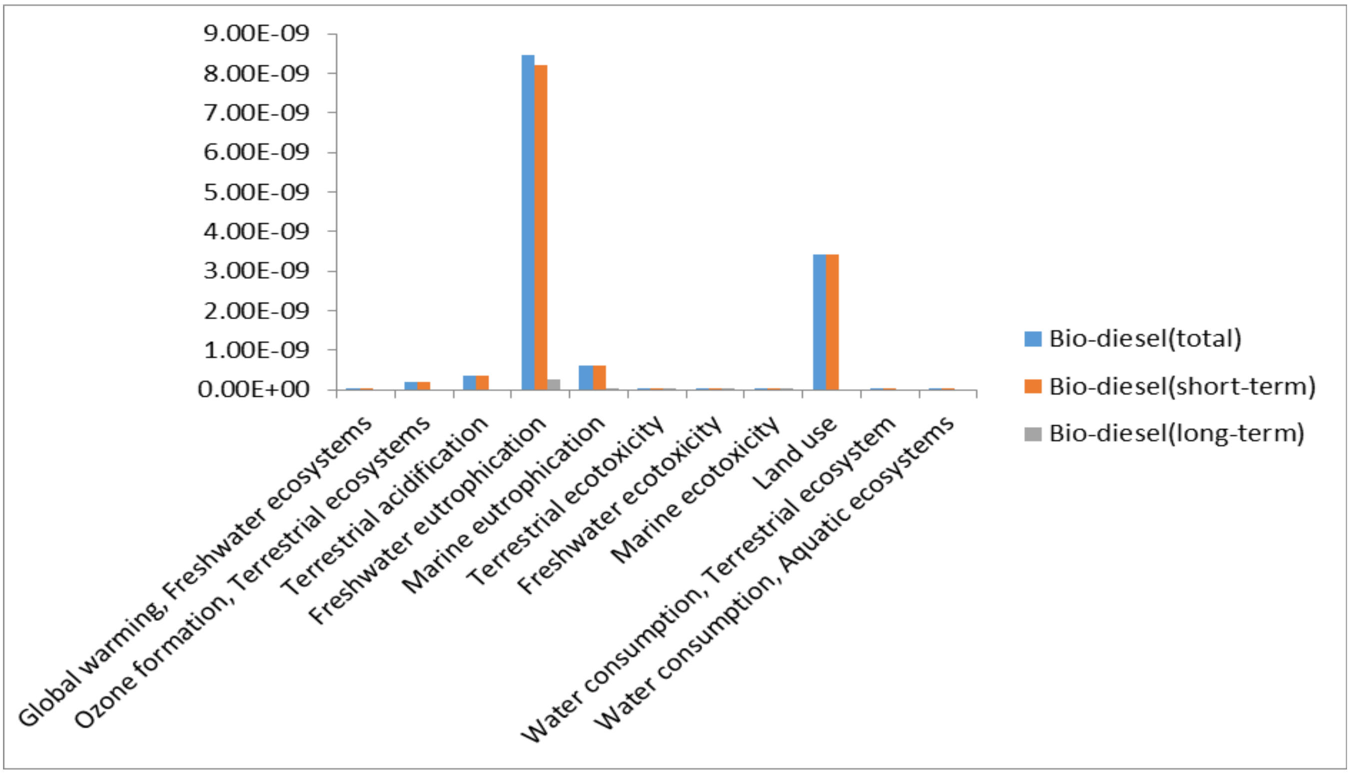


Fig. 7: Damage Assessments with Regard to Ecosystem for Biodiesel Castor Wetland Systems.

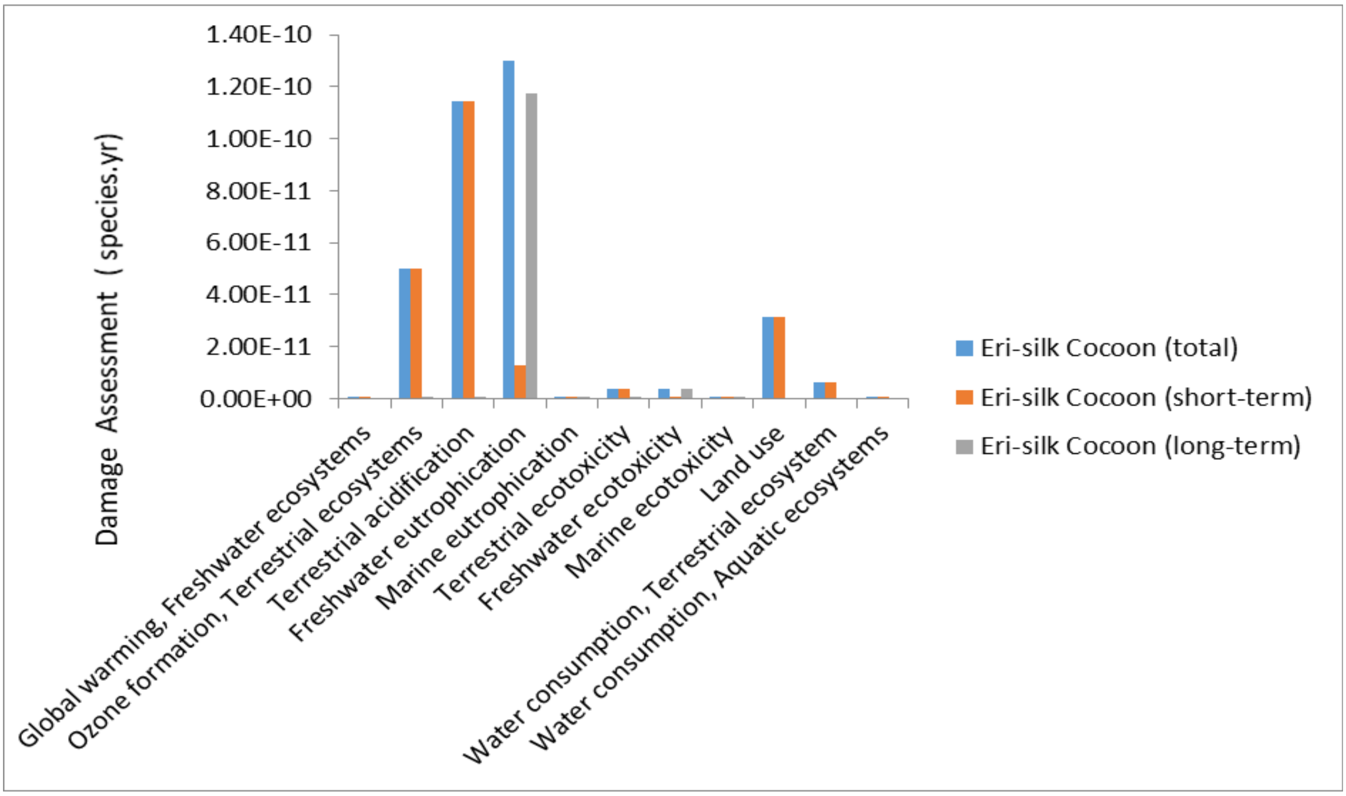


Fig. 8: Damage Assessment with Regard to Ecosystem for Eri Silk Castor Wetland Systems.

Assessment of Damage Potential related to Resource Depletion for the Castor-based wetland Systems

Resource depletion impacts also exhibit short-term dominance. Mineral resource scarcity for bio-diesel (3.37E-03 USD) and eri-silk (1.44E-04 USD) remains short-term, with no significant long-term impact (Figure 9 & 10). So also the case of fossil resources scarcity, which is predominantly short term depletion, with almost two and half times damage potentials in case of biodiesel system (8.49E-03 USD) than the eri-silk system (3.64E-03 USD). Hence, in all these cases, steps to mitigate short-term resource depletion necessitates scope for improvisation, especially with regard to bio-diesel system.

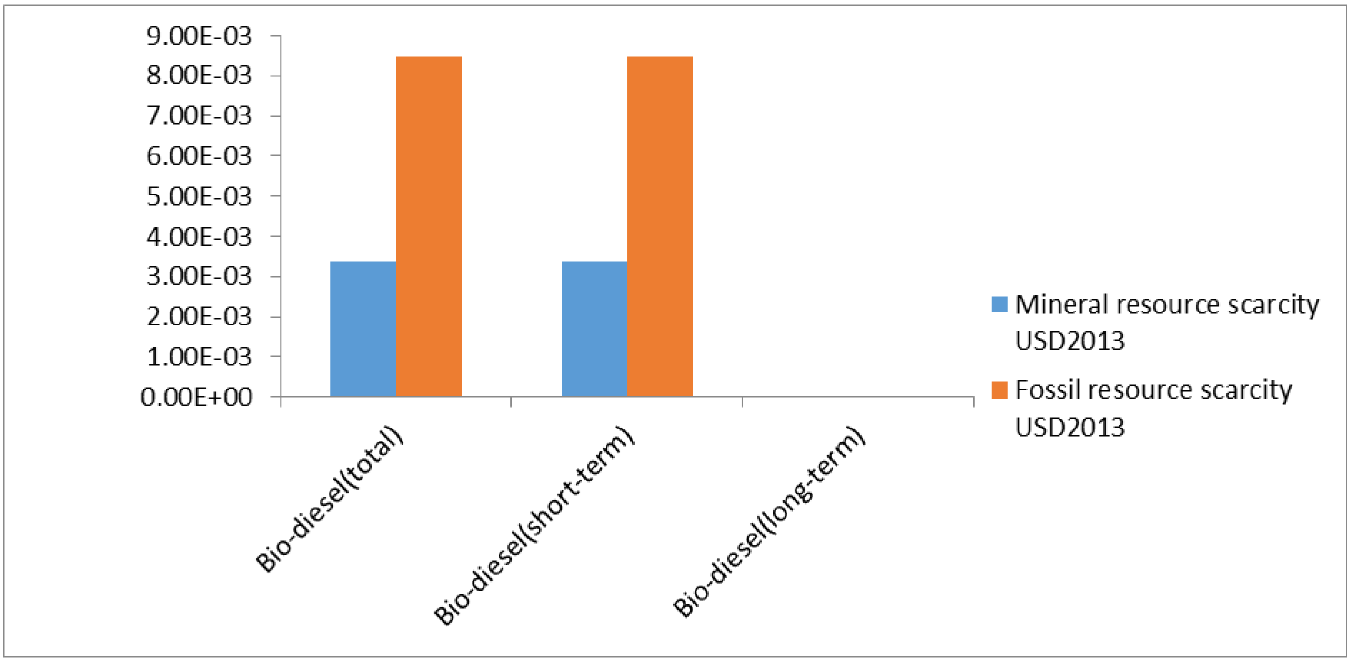


Fig. 10: Damage Assessment with Regard to Ecosystem for Eri Silk Castor Wetland Systems.

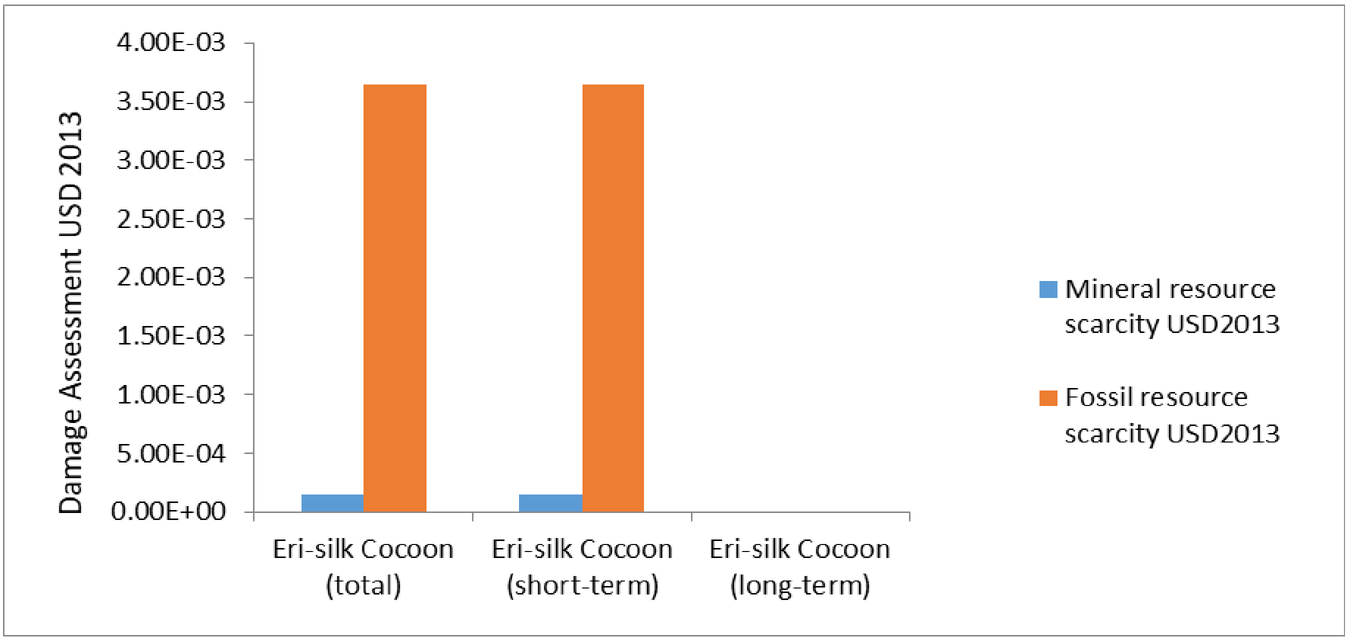


Fig. 10: Damage Assessment with Regard to Ecosystem for Eri Silk Castor Wetland Systems.

As we can see with the present study, the effects of bio-diesel and eri-silk cocoon systems on resource categories, ecosystems, and human health are primarily short-term. It may be noted that, when they do occur, the long-term effects are mostly linked to toxicity-related consequences, like toxicity that can cause cancer in humans and non-carcinogenic effects, as well as small contributions to ecosystem deterioration. In fact, in comparison to eri-silk, bio-diesel production typically seems to have more short- and long-term effects, especially in the areas of resource depletion and health. Given the preponderance of short-term consequences, mitigation methods ought to concentrate on waste management and immediate emissions in order to reduce their environmental impact.

Comparative Evaluation of Damage Potential for Various Impact Types

In order to identify the main effect categories in each system, normalization procedure was deployed with regard to the respective contributions of eri-silk cocoon and bio-diesel systems on the human health, ecosystem and resource depletion (Figure 11).Supporting the findings of the previous impact assessment, demonstrating enhanced production of biodiesel (for both short-term and long-term global warming) and associated greenhouse gas emissions, the normalized study also reveals the excessively large contribution of global warming (human health), especially for bio-diesel. The eri-silk cocoon system also contributes to this category, although to a much less or degree. With regard to the generation of fine particulate matter, both systems do have fairly comparable normalized scores, indicating need of careful consideration production pathways leading to the hazards to respiratory health and the deterioration of air quality.

Both the systems show a considerable standardized score with regard to human carcinogenic, with eri-silk cocoon pathway showing relatively higher toxicity. The health effects of exposure to harmful compounds during the growing or processing of silk may be might besevere than those of bio-diesel generation.
Similarly, human non-carcinogenic toxicity is also slightly higher for eri-silk, implying that non-cancerous health effects—potentially from chemical residues in silk processing—are of concern. On the other hand, categories related to marine and freshwater ecotoxicity, terrestrial acidification, and eutrophication show relatively higher contributions in bio-diesel, indicating that the fuel production pathway has a greater influence on ecosystem degradation.

Since the eri-silk production necessitates a large amount of land for the breeding of silkworms and the growth of castor plants, in case of the eri-silk cocoon system, land use stands out as a category that makes a substantial contribution. On the other hand, when adjusted, the impact of bio-diesel production is less noticeable. On being compared, water use efficiency

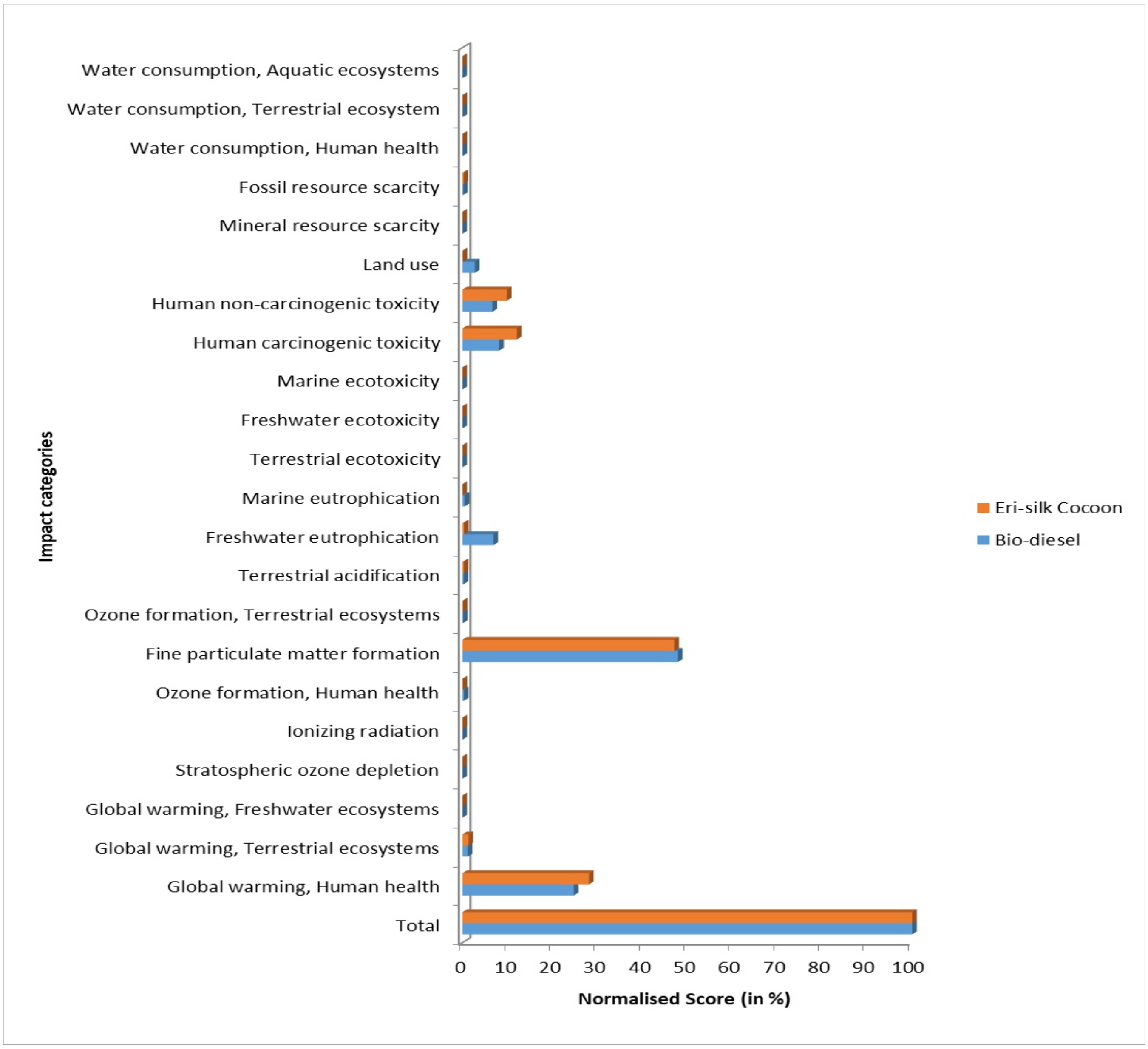


Fig. 11: Normalized Damage Assessment of Castor Wetland Systems.

in these processes does not appear to be a significant environmental burden because water consumption in terrestrial, aquatic, and human health ecosystems are small in both systems.

Although, both systems, resource scarcity—including mineral and fossil resources—displays comparatively lower normalized scores. Nonetheless, bio-diesel has a marginally greater scarcity of fossil resources, which emphasizes the need for energy inputs and resource extraction to produce fuel. This is to be expected as the synthesis of bio-diesel requires methanol and other processing chemicals. Overall, the normalized ratings show that the impact profile of both systems is dominated by categories relating to human toxicity, fine particulate matter production, and global warming. The eri-silk cocoon system has greater effects on land usage and human toxicity, whereas bio-diesel has a greater impact on ecosystem-related categories like acidification and eutrophication. These findings do highlight the necessity for tailored mitigation techniques addresses certain effect categories pertinent to each system.

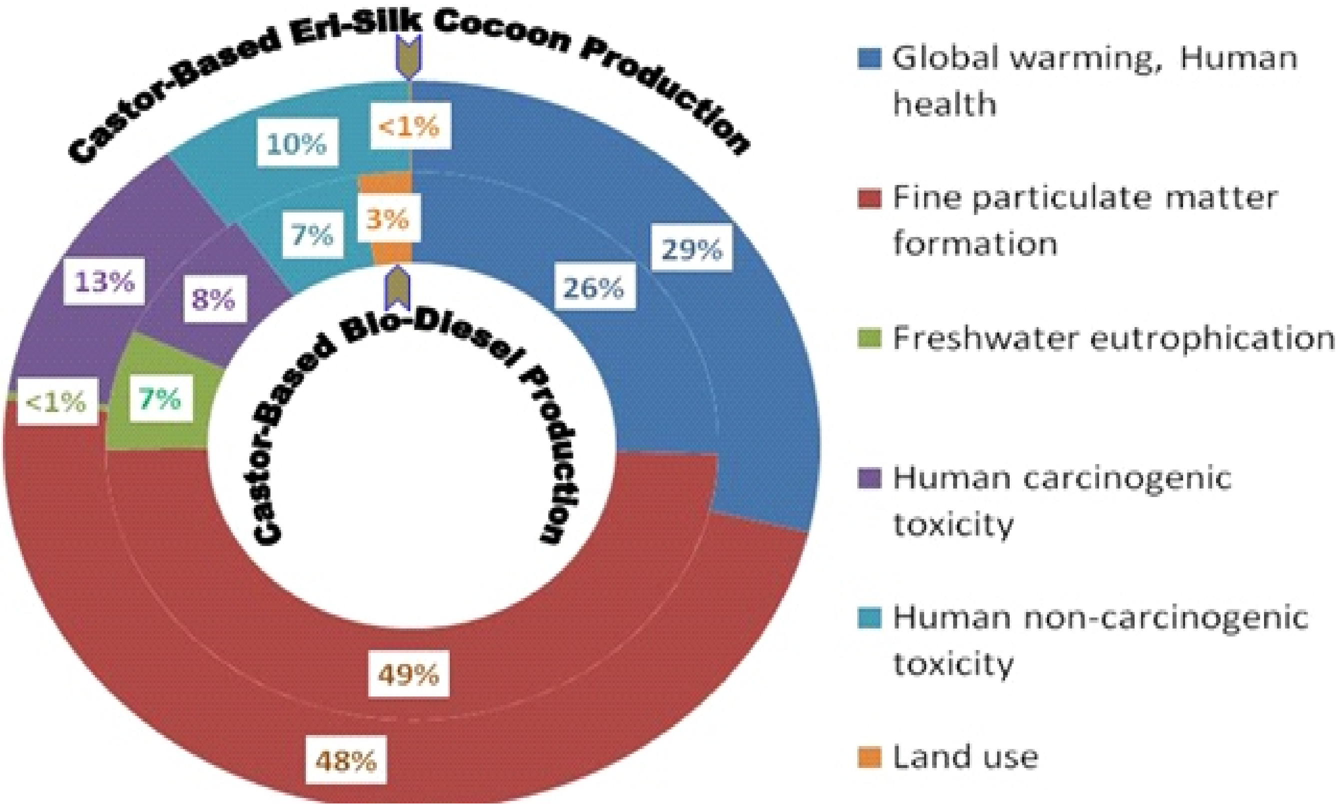


Fig.12: Environmental Hotspot Assessment of Castor Wetland Systems

A Hierarchical Evaluation of key impact categories are highlighted (figure 12) by the hierarchical assessment of environmental hotspots for the production of eri-silk cocoons and castor-based bio-diesel, which covers 97% of all normalized damage. Both these systems are dominated by fine particulate matter generation, which accounts for over half of the overall damage (49% for bio-diesel and 48% for eri-silk). This suggests that combustion and farming practices are major sources of air pollution.

The production of biodiesel (29%) is more affected by global warming (human health) than eri-silk (10%), most likely as a result of greenhouse gas emissions from fuel processing and agricultural inputs.. For bio-diesel, fertilizer runoff causes significant freshwater eutrophication (7%) but eri-silk has little effect (<1%). On the other hand, because of the space needed for silk rearing, the land use impact of eri-silk (3%) is greater than that of bio-diesel (<1%). On aggregation, human carcinogenic and non-carcinogenic toxicity account for 20% of biodiesel and 18% of eri-silk, indicating potential dangers of chemical exposure in both processes. In general, eri-silk also exhibits larger land use and toxicity implications, whereas bio-diesel displays higher greenhouse gas emissions and nutrient runoff.

Castor Wetland Systems' Water Footprints

The figure 13 water footprint evaluation measures the overall amount of freshwater used in castor-based wetland systems for the production of biodiesel and eri-silk cocoons. According to the findings, the water footprint of producing bio-diesel is substantially larger (0.078 m^3, 70%) than that of producing eri-silk cocoons (0.034 m^3, 30%). This implies that the production of eri-silk, which mostly consists of the cultivation of castor leaves and the raising of silkworms, requires less water than bio-diesel processing, which comprises the irrigation of castor crops, oil extraction, and transesterification. The reason behind such disparity, in case of the bio-diesel pathway, could be usage of more water during industrial processing steps like oil refining and bio-diesel conversion. The process of producing eri-silk, on the other hand, is fairly water-efficient, requiring less water for post-harvest processing even if it also depends on castor leaves.

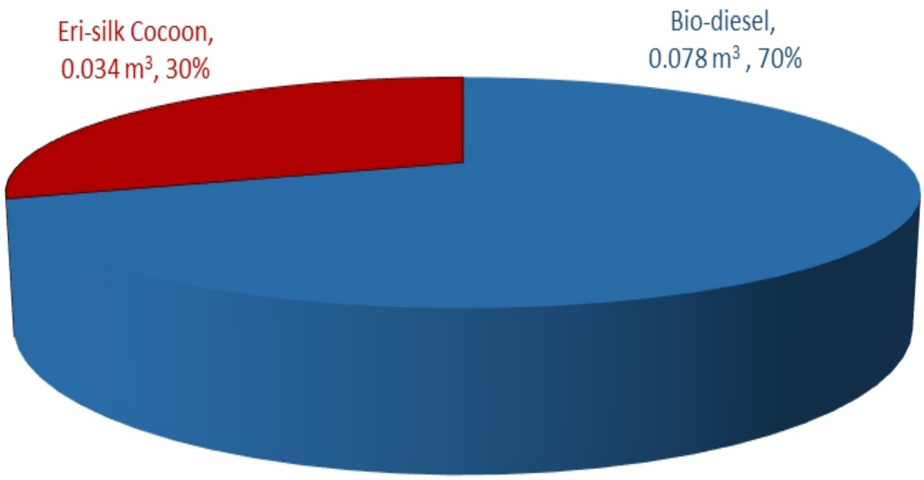


Fig. 13: Water Footprint Assessment of Castor Wetland Systems.

The striking difference in water useas observed herein does also fit with the larger sustainability evaluation, demonstrating that resource-intensive operations like chemical processing and oil extraction leading to incremental the environmental burden as well. In order to improve water-use efficiency and lessen the depletion of freshwater resources, this analysis emphasizes the necessity of better water management techniques, especially during the manufacture of biodiesel.

Energy Flow Assessment in Eri-Silk Cocoon and Bio-Diesel Production Systems

Figure 14illustrate the energy demands associated with the production of eri-silk cocoons and bio-diesel from castor seeds, highlighting differences in their energy intensities and production complexities.

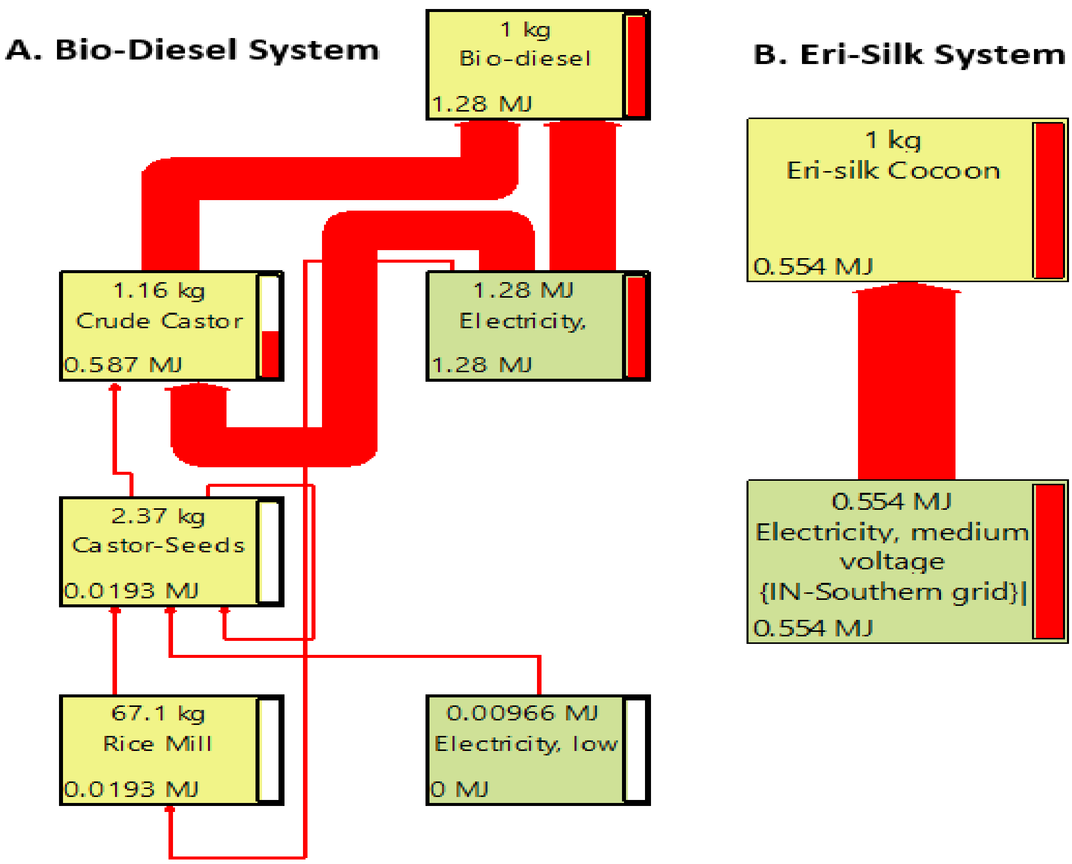


Fig. 13: Water Footprint Assessment of Castor Wetland Systems.

The study (Figure 14-A) demonstrates a fairly complex energy flow for bio-diesel production, amounting to a total energy demand of 1.28 MJ per kg of output.

In fact, at each step of this process (viz. processing seeds, extracting crude castor oil, and refining the finished bio-diesel) there is incrementalloading of energy input to the system, with crude castor oil extraction accounts for the biggest portion of energy usage (0.587 MJ), followed byancillary energy demands from seed processing and auxiliary electrical inputs.

On the other hand, the energy inputs needed to produce 1 kg of eri-silk cocoons (Figure 14-B), i.e., 0.554 MJ of electricity, is mostly related to the power needed to maintain ideal conditions in silk manufacturing, with no additional energy requirement (for fuel or raw material processing, unlike biodiesel-system) as shown in the diagram as a straight red bar indicating a relatively simple and direct energy flow. The simplicity of this process implies a reduced reliance on fossil fuels or additional processing steps, which could help to reduce environmental impacts in terms of carbon emissions and resource depletion.

Impact Assessment of Composts generated from the Castor wetland systems

Since compost is one of the common by-product of both the systems, a comparative impact assessment is likely to shed more light on the effect of the common-sink. The impact assessment study of compost derived from the biodiesel production system and the eri-silk production system highlights significant differences in their environmental burdens (Figure 15), where in the bar graph displays the normalized percentage contributions of both compost kinds across a number of impact categories. When compared to compost from the biodiesel system, compost from the eri-silk system continuously and persistently performs better environmentally and contributes less to major environmental problems.

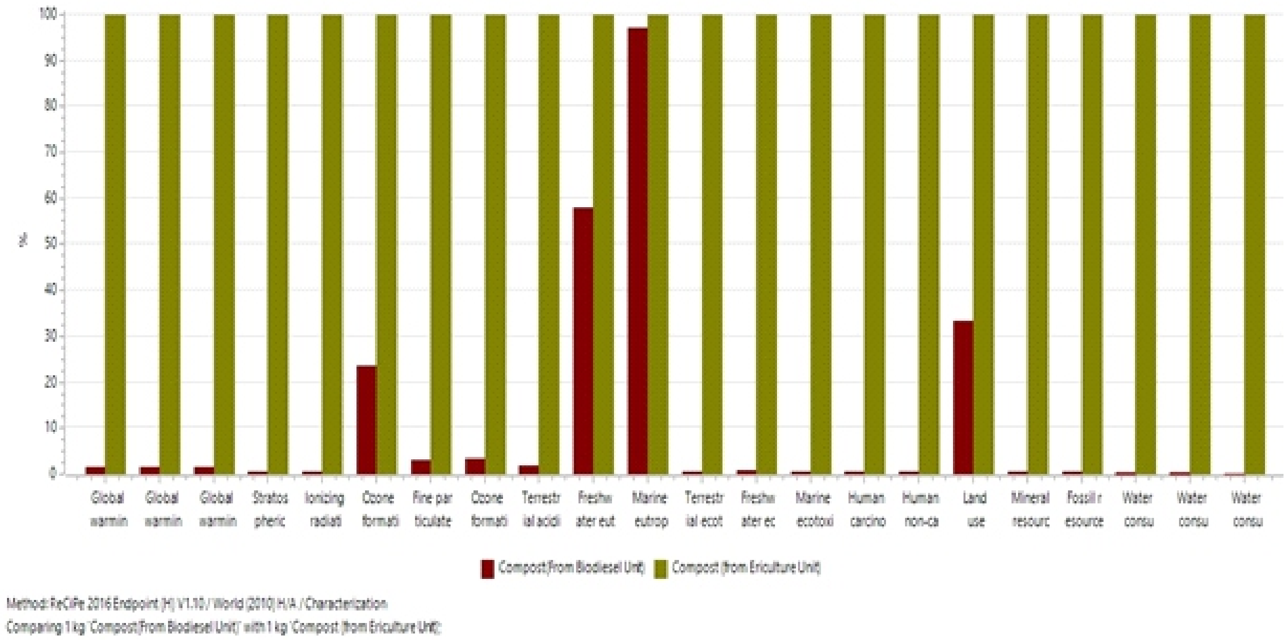


Fig. 15: Impact Assessment of Composts generated by the Castor Wetland Systems.

Compost from the eri-silk system shows dominance across nearly all impact categories, suggesting that it has lower environmental damage compared to its counterpart from the biodiesel system. This is likely due to the relatively low energy intensity of eri-silk production, as previously noted, which translates into fewer emissions and resource depletion impacts in the compost phase. Since the inputs needed for eri-silk production are much less dependent on fossil fuels and resource extraction, the compost's negligible contributions to global warming, stratospheric ozone depletion, ionizing radiation, and water consumption reflect its more sustainable lifecycle.

On the contrast, in case of the biodiesel production system, the compost generated shows significant environmental consequences (esp. freshwater eutrophication, marine eutrophication, and land use effect). Higher ecosystem degradation through enhanced marine and freshwater eutrophication ratings (esp. through nitrogen and phosphorus runoff) are probably contributed by nutrient-loaded waste streams associated with biodiesel system. Hence, even in the compost-front, castor-based biodiesel has a greater impact due to the higher energy and material inputs needed for manufacture, such as seed processing and oil extraction. These findings imply that compost from the manufacture of eri silk might be a more environmentally benign byproduct, especially in applications of the circular economy where waste valorization is a top concern.

These revelations offer more support for the idea that eri-silk production is a more environmentally friendly and sustainable option. However, from techno-economic robustness, biodiesel system is more reliable and cash-generating because of higher demand of biodiesel & glycerin as well as less sensitive than eri-culture (wherein improper handling of the worms can keep the system a standstill) thereby necessitating a proper blend of the two system, wherein adequate leaves to be reserved after harvesting the leaves for growth of eri-worm, so as to maintain the growth of the castor plant to yield seeds, adequate for oil-production as well as plantation for the forthcoming cycles. Together, the results highlight how crucial it is to consider the full life cycle of bio-based systems because, depending on where they come from, even waste-derived products can have serious effects on the economic and environmental sustainability.

CONCLUSION

The present work offers a thorough comparative life cycle assessment (LCA) of two castor-based wetland models, namely, the production of bio-diesel (with higher potential for global warming, fossil depletion, and eutrophication) and the production of eri-silk cocoons (with a stronger impact on land usage and human toxicity), both the systems being dominated by short-term impacts (with toxicity categories alone largely responsible for long-term environmental hazards). On overall assessment, the manufacturing of eri-silk is relatively more environmentally friendly in terms of emissions, energy as well as water-footprint compared to biodiesel-system. However, sensitivity of the former system and techno-economic robustness of the later system necessitates the scope of an integrated hybrid approach that combines the lower ecological impact of eri-silk production with the biofuel potential of castor and this forms a significant finding from this study. Through the optimization of energy efficiency, resource allocation, and wastewater treatment, such a unified system could improve environmental performance while lowering individual trade-offs. To further increase the sustainability of bio-based wetland systems, future research should concentrate on possible nutrient recovery, hybrid process design, proportioning of leaf and seed harvest, and the integration of composts from the two systems, and so forth.

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PESTICIDES, HERBICIDES AND THEIR EFFECTS ON POLLINATORS

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ABSTRACT

Pesticides used in agriculture, urban areas, and gardens are raising concerns about their impact on pollinators. Exposure to pesticides through direct contact, ingestion, and accumulation can harm pollinators. High pesticide concentrations cause immediate harm, while chronic exposure weakens their immune systems, impairs reproduction, and leads to population declines. Neonicotinoids, a type of insecticide, are especially problematic. They are absorbed by plants and spread to nectar and pollen, affecting foraging abilities, navigation, immunity, and reproductive success in pollinators. Integrated pest and pollinator management (IPPM), sustainable agriculture practices, and pesticide-free zones aim to maintain ecological balance and reduce chemical use. We observe lethal, sub lethal impacts on pollinator species including Honeybees (*Apis mellifera*), Bumblebees (*Bombus* spp.), butterflies, and other beneficial insects, and assess ecological consequences. Empirical data from field and laboratory studies are synthesized, and a comparative table summarizes pesticide usage and recorded pollinator mortality rates. Raising awareness about pollinator importance and pesticide impacts is crucial for conservation, and by balancing pest control with pollinator protection, long-term sustainability of agriculture and natural ecosystems dependent on pollination services can be ensured.

No. of Pages: 4 **References: 8**

Keywords: Pollinators, Pesticides, Herbicides, Honeybees, Sub-lethal Effects, Agriculture, IPPM.

INTRODUCTION

Pollinators, including bees, pollen wasps (Masarinae); ants; butterflies, moths, flies, beetles, and birds, (Figure.1) are indispensable agents in the reproduction of over 75% of leading global crops and nearly 90% of wild flowering plants (Klein et al., 2007; Baskar et al., 2017). Unfortunately, multiple pollinator species are currently experiencing contracting ranges and reductions in species richness and abundance (Evans *et al.*, 2018). For instance, domestic honeybee stocks declined by 59% in the USA between 1947 and 2005, and by 25% in Europe between 1985 and 2005. Even though beehives have increased by 45% since 1961, however, the proportion of agricultural crops depending on pollinators is increasing much more rapidly (>300%) so that the demand for pollination services could outstrip the increase in hive numbers (Aizen and Harder, 2019).

Pesticides are any substance or mixture of substances intended for preventing, destroying, repelling, or mitigating any pest including weeds. The term pesticide applies to insecticides, herbicides, fungicides, and various other substances used to control pests. Pesticides also include plant regulators, defoliants, and desiccants (Aoun, 2020; Arya *et al.*, 2021; Prakash and Verma, 2021). The introduction to the market in the early 1990s of Imidacloprid and thiacloprid opened the neonicotinoid era of insect pest control. This class of systemic water-soluble insecticides chemically related to nicotine affects the central nervous system of insects. Acting systemically,

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this class of neurotoxic insecticides taken by plants, primarily through the roots, and translocate to all parts of the plant through stem transport. This systemic property combined with very high toxicity to insects enabled formulating neonicotinoids for soil treatment and seed coating with typical doses high enough to provide long-lasting protection of the whole plant from pest insects (Van der Sluijs *et al.,* 2013). The declines of pollinator populations, excessive anthropogenic activities and pollution have raised alarms over potential cascading effects on biodiversity, ecosystem stability, and agricultural yield (Prakash and Verma, 2022; Verma and Prakash, 2022; Singh *et al*., 2023). Concurrently, the intensification of agricultural practices has driven the extensive use of synthetic pesticides and herbicides to control pests and weeds. While these chemicals enhance crop output, they often exert unintended adverse effects on non-target organisms, particularly pollinators and field observations. Pollinators play an essential role in the sexual reproduction of most flowering plants while obtaining pollen and nectar rewards from their flowers. Most plant species on earth depends on pollination services from animal pollinators (Kearns *et al.,* 1998; Arya *et al.,* 2024).

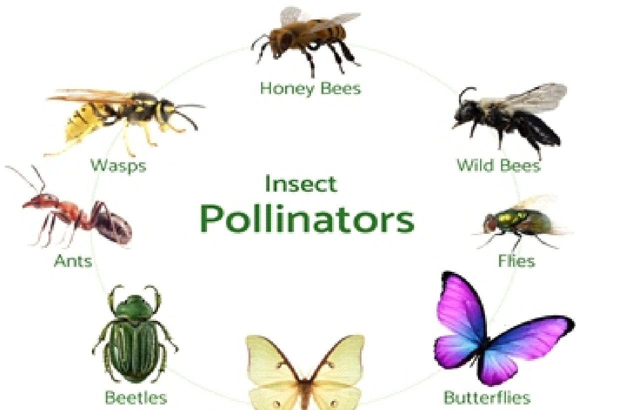


Fig. 1: (16-22 June, 2025- Pollinator Week).

This mutualism is not only crucial for the maintenance of biodiversity but also provides important services, with an estimated 35% of global food production relying on insect pollination (Klein *et al.,* 2007). Other pesticides that can be harmful to pollinators include organophosphates such as diazinon, chlorpyrifos, disulfoton, azinphosmethyl, and fonofos. This class of organophosphorus compounds has been used widely in agriculture and in household applications as pesticides (Verma and Prakash, 2018; Prakash and Verma, 2020). Pyrethroids, a class of synthetic insecticides similar to natural pyrethrins, have neurotoxic effects on insects as well. These were introduces into widespread use for the control of insect pests and disease vectors more than three decades ago (Aoun, 2020). Pollinators can be bare to pesticides not only in agricultural areas but in urban areas as well. Surface water residue data suggest that the intensity of pesticide use in urban areas may sometimes exceed that of agricultural areas, and for some pesticides, labeled application rate can be much higher for non-agricultural than for agricultural use. This is the case of pesticides used for mosquito abatement and in aerial application in response to fears of insect-borne virus. These were found to be a major contaminant of pollen collected by honeybees (Long and Krupke, 2016; Guarino, 2016).

1. Pesticides, Herbicides vs Pollinators:

Types of Pesticides and Herbicides:

1. **Neonicotinoids:** Systemic insecticides (e.g., Imidacloprid, Clothianidin) that bind to nicotinic acetylcholine receptors in insects.
2. **Organophosphates:** Acetylcholinesterase inhibitors (e.g., Chlorpyrifos) reducing neural function.
3. **Pyrethroids:** Synthetic analogues of pyrethrins (e.g., cypermethrin) affecting sodium channel gating.
4. **Glyphosate:** Broad-spectrum herbicide inhibiting the shikimate pathway enzyme EPSP synthase.
5. **Atrazine:** Triazine herbicide that disrupts photosynthesis by inhibiting photosystem II.

Key Pollinator Species: (Figure. 2)

1. Honeybees (*Apis mellifera*): Economically dominant, managed colonies.
2. Bumblebees (*Bombus* spp.): Wild and managed, critical in cooler climates.
3. Butterflies and Moths (Order Lepidoptera): Indicators of environmental health.
4. Hoverflies (Family Syrphidae): Dual-role pollinators and aphid predators.

Fig 2: Honeybee, Humming bird, butterfly and beetle.

Insect pollinators in particular bees (Hymenoptera: Anthophila) are uniquely specialized for pollen transport and account for the bulk of pollination services. European honeybees (*Apis mellifera*) often considered as the most valuable agricultural pollinator. However, wild pollinators, such as wild bumblebees (*Bombus* spp.), solitary bees, flies, wasps, and Lepidoptera pollinate certain and prevalent crops such as oilseed rape and orchard fruit species and contribute approximately the same value toward crop production as managed bees do (Kleijn *et al.,* 2015). Pollinator loss impact two broad groups of pollinator-dependent flowering plants: wild flowers and cultivated crops. In wild plant species, almost 80% are directly dependent on insect pollination for fruit and seed set, although this may vary markedly between sites and seasons (Potts *et al.,* 2010).

One of the most frequent proximate causes of reproductive impairment of wild plant populations in fragmented habitats is careful pollination limitation. In cultivated crops, until now, most growers have either matched their pollinator needs by renting honeybees or utilized the "free" services of wild bee species foraging in farm fields, a component of pollination services that has mostly overlooked in economic calculations. It has been likely that without bees, some 60 species of crop plants would fail to produce fruit (Heard, 1999); the economic consequences of this impact are obvious. The global annual economic value of insect pollination was estimated to be approximately153 billion during 2005 (i.e., 9.5% of the total economic value of world agricultural output considering only crops that are used directly for human food. Complete pollinator loss would translate into a production deficit over current consumption levels of 12% for fruits and 6% for vegetables (Halm *et al.,* 2006).

In addition, declining pollinator supply has the potential of increasing costs of food production. Increased yields are usually the result of increasing farm inputs such as fertilizers, labor, and water. For some crops, this increasingly intensive management may have overcome any losses in pollination services, but it also increases production costs. There is also evidence that one response to lower yield growth for highly pollinator-dependent crops is a growing demand for land in a time when farmland is contracting as development replaces agriculture (Aizen and Harder, 2009). Of particular importance is the collapse of honeybee (*Apis mellifera*) colonies in America and other developed countries, because they provide honey and wax commodities to our society. One of the main fronts advanced for their decline along with other pollinators is the use of pesticides, including not only insecticides and acaricides but also fungicides and herbicides (Sanchez-Bayo and Goka, 2014; Siviter *et al.,* 2018).

Instances of "bee kills" associated with use of pesticides have documented since the late 19thcentury. But the discovery in the mid-2000s of parallel declines in wild pollinators and plants depending on pollinators. Along with widespread losses of managed honey bees raisedthe possibility that the effects of pesticides on pollinators might be more than merely episodic (Sponsler *et al.,* 2019).Pesticides and herbicides target specific physiological pathways in pests and weeds but can cross-react with similar pathways in pollinators. Systemic uptake leads to residues in pollen and nectar, exposing foraging insects. Global pesticide usage exceeded 3.5 million tons in 2020, with neonicotinoids accounting for 25% of insecticide market share (Wanner *et al.,* 2022). Herbicide application rates have risen by 30% over the past two decades, primarily driven by glyphosate-resistant crop cultivation. Pollination services are valued at an estimated USD 235–577 billion annually (Gallai et al., 2009). Loss of pollinators jeopardizes fruit set, seed quality, and nutritional diversity. The diversity and abundance of pollinators is crucial in maintaining biodiversity on land and food production demands by the agricultural industry. Unfortunately, multiple pollinator species are currently experiencing contracting ranges and reductions in species richness and abundance (Evans *et al.,* 2018).

3. Effects of Pesticides and Herbicides on Pollinators:

In agricultural areas, an adverse relationship was found between pesticide use on agriculture sites and pollinator abundance, group richness, and diversity. Pollinators in agriculture areas can be visible to plant protection products in two ways (Arya and Dubey, 2013; Sanchez-Bayo and Goka, 2014):

1. By direct exposure to either drift droplets, which are scattered during the foliar spraying of crops, dust from seed drilling at planting, or inhalation of volatile pesticides during or after application to the crops.
2. By exposure to residues present in pollen, wax, nectar, honey, and guttation drops, which may result either from direct spray contamination of flowers, translocation through the treated plants or soil, or direct contamination during treatment

of the combs (for honey bees only). In fact, the most frequently detected pesticides for honey bees and the two that occur in the highest quantity are those used by beekeepers to control Varroa mites (coumaphos and fluvalinate) (Mullin *et al.*, 2010).

Bees also drink water and were observed drinking from paddy field waters contaminated with pesticides. Although herbicides target plants, surfactants and adjuvants can be toxic to insects. Glyphosate formulations cause mortality in bee larvae at high application rates (Balbuena et al., 2015). Herbicide-driven reduction of flowering weeds diminishes forage diversity and floral resources. Atrazine use in field margins reduced wildflower richness by 60%, affecting bumblebee foraging ranges (Rundlof *et al.*, 2015). Pesticides encompass a diverse range of chemicals used in agriculture, forestry, and public health to manage pests. In the agricultural sector alone, pesticides play a pivotal role in ensuring food security by protecting crops from insects, weeds, and diseases. They can have short-term toxic effects on directly exposed organisms, and long-term effects can result from changes to habitats and the food chain. Excess use of pesticides may lead to the destruction of biodiversity (Prakash and Verma, 2014; Masih, 2021; Arya *et al.*, 2023).

1.1 Acute Toxicity and Mortality

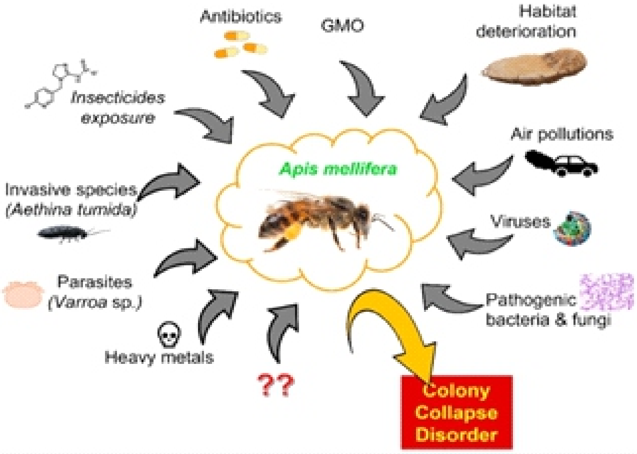
The toxicity of hydrophobic pesticides is mostly by contact exposure, whereas the toxicity of hydrophilic pesticides is mainly by oral ingestion of residues in pollen and honey. It should be noted that pyrethroids, which are highly hydrophobic compounds, are on average three times more toxic to bees by contact than by oral exposure. By contrast, 60% of the systemic (hydrophilic) pesticides have oral toxicities higher than their contact toxicities, up to13 times higher for some products (Sanchez-Bayo and Goka, 2014). Trials report median lethal dose (LD_{50}) values for imidacloprid at 3.7 ng/bee (Decourtye et al., 2003). Field exposures often exceed sublethal thresholds, causing acute colony losses during peak application periods. Neonicotinoids pose the highest direct threat to bees due to their acute toxicity, while herbicides like glyphosate and atrazine cause significant indirect effect by altering bee habitats and food sources. Understanding both direct and indirect pathways is crucial in evaluating the overall impact of agrochemicals on pollinator populations.

3.2 Sublethal Effects on Behavior and Physiology of Pollinators:

Exposure to pesticides can be lethal or sub lethal with chronic detrimental effect on the individual pollinator and the colony. Sub lethal neonicotinoid concentrations impair navigation, foraging efficiency, brood development, and immune function (Henry et al., 2012).Chronic exposure leads to reduced colony growth, reproductive success and increased disease susceptibility. Chronic toxicity by constant dietary exposure to residues found in pollen and honey affects the mortality of individual bees and the growth and reproduction of their colonies. Such effects include not only sub lethal impairments but also delayed mortality (Tennekes and Sanchez-Bayo, 2011). Pesticide use, fate dynamics, and environmental conditions determine the spatiotemporal patterns of pesticide contamination in the environment (Prakash and Verma, 2020). Connecting patterns of contamination to patterns of pollinator exposure, however, requires an understanding of the behavioral and life history traits that govern the interactions between pollinators and their environment, and hence the spatiotemporal intersection between pollinators and environmental contaminants (Sponsler and Johnson, 2017; Kopit and Pitts-Singer, 2018).

3.3 Colony Collapse Disorder (CCD):

Foraging bees are exposed to multiple pesticides sprayed directly on to crops found on plant tissues including flowers. Thus, foraging bees can suffer combinatorial effect of multiple pesticides. High exposures to pesticides can cause acute mortality of foraging bees, while, at low levels, pesticide exposure has been associated with changes in individual bee behavior such as reduced foraging efficiency and decreases in colony queen production (Kuan *et al.*, 2018).



(Figure 3 - Factors of CCD (Colony Collapse Disorder) Source: Leska et al.2021)

There are many putative factors of CCD, (Figure.3) such as air pollution, GMO, viruses, or predators (such as wasps and hornets). However, it believed that pesticides and microorganisms play a huge role in the mass extinction of bee colonies. Insecticides are chemicals that are dangerous to both humans and the environment. They can cause enormous damage to bees' nervous system and permanently weaken their immune system, making them vulnerable to other factors. Some of the insecticides that negatively affect bees are, for example, neonicotinoids, coumaphos, and chlorpyrifos. Microorganisms can cause various diseases in bees, weakening the health of the colony and often resulting in its extinction. Infection with microorganisms may result in the need to dispose of the entire hive to prevent the spread of pathogens to other hives. Many aspects of the impact of pesticides and microorganisms on bees are still unclear. The need to deepen knowledge in this matter is crucial, bearing in mind how important these animals are for human life. (Leska *et al.,* 2021) Managing plant pests at the time of flowering period is very crucial to achieve maximum yield in agriculture. However, often this step displays undesirable effects on the foraging bees, which are very active at flowering, thus making their foraging trip into a hazardous trip. Due to common behavior of licking and grooming of bees, the pesticides can contaminate to other bees and thereby affecting the entire colony. The affected colony shows decline in its pollen and nectar collection and honey production ultimately resulting in the colony collapse. Honeybees already stressed by a poor diet have been found to be more sensitive to several pesticides (Challa *et al.,* 2019).

4. Experiential Data and Comparative Analysis

Data were compiled from peer-reviewed studies (2010–2023) and national pesticide usage databases in table 1. Pollinator impact metrics include LD_{50}, colony loss percentages, and visitation rate changes.

Table 1: Comparative Table of Pesticide Usage and Pollinator Impact.

S. No	Pesticides	Active Ingredient	Annual Use (tons)	LD_{50} (ng/bee)	Observed Colony Loss (%)
1.	Neonicotinoids	Imidacloprid	110,000	3.7	20–35
2.	Organophosphates	Chlorpyrifos	80,000	30	10–15
3.	Pyrethroids	Cypermethrin	70,000	35	8–12
3.	Glyphosate	Glyphosate	820,000	N/A	Indirect (15–25)
5.	Triazines	Atrazine	60,000	N/A	Indirect (10–20)

5. Mitigation Strategies and Best Practices

1. Integrated Pest and Pollinator Management (IPPM):

Integrated Pest Management (IPM) is a program of prevention, monitoring, and control which offers the opportunity to eliminate or drastically reduce the use of pesticides, and to minimize the toxicity of and exposure to any products, which are used. IPM does this by utilizing a variety of methods and techniques, including cultural, biological and structural strategies to control a multitude of pest problems. IPM is a term that is used loosely with many different definitions and methods of implementation. IPM can mean virtually anything the practitioner wants it to mean. Beware of chemical dependent programs masquerading as IPM. Those who argue that IPM requires the ability to spray pesticides immediately after identifying a pest problem are not describing IPM. Conventional pest control tends to ignore the causes of pest infestations and instead rely on routine, scheduled pesticide applications. Pesticides are often temporary fixes, ineffective over the long term (Arya and Dubey, 2013). Integrated Pest and Pollinator Management IPPM emphasizes for the integration of various pest management strategies, such as cultural practices, monitoring, biological controls, and judicious chemical use to minimize pollinator exposure (Chreil and Maggi, 2023).

2. Alternative Agrochemicals and Bio pesticides:

Bio pesticides (e.g., *Bacillus thuringiensis*, neem oil) offer lower non-target toxicity (Verma, 2017). Crop varieties with pest-resistant traits reduce chemical reliance. Neem oil form a coating on the insect body, which block the breathing process and suffocating the insect. Neem oil also work as a repellent on certain insect pests and mites also. The various parts of this tree live neem oil, neem seed cake, neem leaves, neem extracts, neem bark and roots are used in insect-pests management. Azadirectin can act as a feeding differentiates against a number of insect pests including beetles. It reduces the level of the insect hormone 'Ecdysone' by disrupting the insect's molting process so that the immature larvae cannot develop in to adult (Arya and Dubey, 2017). Nanobiopesticides have higher pesticide activity, targeted or controlled release with top-notch biocompatibility and biodegradability. Due to the drawbacks of synthetic pesticides, an alternative means of pest control is being encouraged, which is the use of bio pesticides. The effectiveness of bio pesticides in pest management comes from various modes of action, which include actions that regulate gut disruption, pest growth, and pest metabolism. Bio pesticides work by denaturing protein, causing metabolic disorder and paralysis, activating target-poisoning mechanisms, exhibiting multisite inhibitory actions, and releasing neuromuscular toxins and bioactive compounds. (Ayilara *et al.,* 2023).

3. Pollinator-friendly farming practices and Habitat restoration:

Understanding pesticide-induced changes to plants, microbes, and pollinator attraction is a particularly relevant question. Question given widespread initiatives to plant pollinator-friendly wildflowers in urban, suburban, and agricultural settings, which may inadvertently expose pollinators to pesticides (Williams *et al.,* 2015).Conserving and restoring pollinator habitat, such as native wildflower meadows and hedgerows, plays a crucial role in mitigating the impacts of pesticides. By providing alternative forage sources and nesting sites, pollinators can access pesticide-free areas, reducing their exposure and promoting their overall well-being. (Fountain, 2022). Pollinator-friendly farming enhances biodiversity and crop productivity by supporting bees, butterflies, and other pollinators. Key practices include planting diverse native flowering plants, maintaining wildflower strips and hedgerows, reducing pesticide use, and adopting integrated pest management. Providing nesting habitats, using organic or low-till methods, and preserving natural areas also help sustain pollinator populations. These approaches not only improve pollination and crop yields but also contribute to long-term ecological balance and farm sustainability (Rundlof *et al.*, 2022).

4. Public Awareness and citizen science:

Increasing awareness and providing education and training to farmers, beekeepers, pesticide applicators, and the public are essential for promoting responsible pesticide use and minimizing harm to pollinators. By understanding the importance of pollinators and the potential impacts of pesticides, individuals can make informed decisions and adopt practices that prioritize pollinator health. The Global Action on Pollination Services for Sustainable Agriculture provides guidance to member countries and relevant tools to use and conserve pollination services that sustain agroecosystem functions and to formulate policies that will ensure sustainability of these ecosystem services. At a legal level, some environmental organizations and several beekeeping organizations and concerned citizens filed lawsuits in federal courts in the USA against registration or use of neonicotinoid insecticides linked with destruction of bee colonies and other beneficial insects. At societal level, accumulative role of Non-Governmental organizations (NGOs) that advise native managers around pollinator health (Sponsler *et al.,* 2019).

5. Policy and Regulatory Frameworks

The first major restriction of pesticide use prompted by concern for pollinator safety occurred in 1999, when France Suspended the insecticide fipronil and the neonicotinoid insecticide imidacloprid applied as seed treatment to pollinator-attractive sunflower crops (Suryanarayanan and Kleinman, 2014). This was followed by a more extensive European Union-wide moratorium in 2013 on three neonicotinoid insecticides (imidacloprid, clothianidin, and thiamethoxam)applied as seed treatments to pollinator-attractive crops (European Commission 2013). Recently, the European Union has issued a ban on all outdoor use of neonicotinoid insecticides (The European Commission, 2018), citing a European Food Safety Authority report concluding that the compounds pose an unacceptable risk to bees (European Food Safety Authority, 2018). In North America, United States Environmental Protection Agency (USEPA), working in collaboration with Health Canada Pest Management Regulatory Agency (PMRA) developed beginning in 2012 a conceptual framework for quantifying risks to bees, is resulting in the 2014 harmonized Guidance for Assessing the Risk of Pesticides to Bees (US Environmental Protection Agency, 2014). Therefore, in 2013, USEPA ordered the revision of thousands of pesticide labels to reduce acute exposure of bees to neonicotinoid insecticides at bloom on crops requiring contracted pollination services. Regulatory measures, such as the EU's neonicotinoid restrictions (2013), demonstrate efficacy in reducing pollinator mortality. National guidelines should incorporate buffer zones and application timing restrictions.

In January 2017, USEPA released its policy to mitigate the acute risk to bees from pesticide products, which affects a broader range of pesticide classes (Fishel *et* *al.,* 2017), focusing on pesticide use by agricultural applicators when beekeepers are under contract to provide pollination services. When evaluating the safety of pesticides. There is a need to consider several parameters including the risk of exposure to multiple pesticides, or of the same pesticide being applied to different (adjacent) crops, and the need for longer-term toxicity testing on both adult bees and larvae. New protocols to detect cumulative toxicity effects and separate risk assessment schemes for different pollinator species are needed (Gill *et al.,* 2012). These will have clear implications for the conservation of insect pollinators in areas of agricultural intensification, particularly social bees with their complex social organization and dependence on a critical threshold of workers performing efficiently to ensure colony success. It is worthy to note here that the science of exposure to pesticides is still crude for honeybees, nascent at best for wild bees, and practically nonexistent for non-bee pollinators (Sponsler *et al.,* 2019).

Not only synthetic pesticides need to be assessed for safety on pollinators but also botanical pesticides. Few studies showed that field applications of botanical pesticides might represent a risk as the applications of synthetic compounds, indicating that these alternative products should also be submitted to risk assessments comparable to those required for synthetic products (Challa *et al.,* 2019; Tschoeke *et al.,* 2019). It is critical to recognize that the legitimate need to manage harmful pests underlies the phenomenon of pesticide use. Particularly in agriculture accordingly; efforts to protect pollinators from pesticide impacts should reconcile pest control needs with the conservation of pollinators, incorporating pollinator conservation into integrated pest management (IPM) frameworks rather than seeing pesticide use per se as an antagonist of conservation (Biddinger and Rajotte, 2015).

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COMPARATIVE ASSESSMENT OF CASTOR CULTIVATION IN WASTEWATER-FED WETLANDS VERSUS AGRICULTURAL FIELDS FOR OPTIMIZED ERI-SILKWORM REARING

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ABSTRACT

This study explores the integration of rice mill wastewater-fed constructed wetlands with Eri (*Samia ricini*) sericulture, using castor (*Ricinus communis*) as a dual-purpose crop for phytoremediation and silkworm feed. Castor leaves grown in constructed wetlands showed significantly higher moisture (75.2% vs. 72.5%), nitrogen (2.7% vs. 2.1%), sulphur (0.22% vs. 0.16%), protein (17.4 mg/g vs. 15.6 mg/g), and phenol content (2.1 mg/g vs. 1.6 mg/g), compared to those from agricultural fields—indicating enhanced metabolic and adaptive responses. However, Eri silkworms fed with agricultural leaves achieved greater larval weights at the 5th instar (4.54 g vs. 4.27 g), cocoon weights (2.1 g vs. 1.95 g), shell weights (0.5 g vs. 0.43 g), and shell ratios (23.8% vs. 22.3%), with all differences statistically significant ($p < 0.00001$). Seasonal effects were notable in mature leaf yield, with agricultural sites performing better in winter. While wetland castor presents a sustainable option for wastewater reuse and offers high nutritional value, its benefits did not translate into improved silk yield. Agricultural castor remains more effective for commercial eri-silk production. These findings offer actionable insights for optimizing sericulture systems that balance environmental sustainability with economic viability.

No. of Pages: 19 **References: 35**

Keywords: Eri-Silkworm, Castor Cultivation, Wastewater Irrigation, Constructed Wetlands, Eri-Silk Production, Phytoremediation.

INTRODUCTION

India is the world's second-largest silk producer, with the sector crucial to the economy and rural livelihoods. Raw silk production rose from 31,906 metric tonnes in 2017–18 to 38,913 in 2023–24, driven by expanded mulberry cultivation and better sericulture (Central Silk Board, 2024). However, FY 2024–25 saw a 21% decline due to adverse weather and market instability (Business Standard, 2024). Mulberry silk forms 75% of total output, while Eri, Tasar, and Muga silks make up the rest (Chakraborty & Ray, 2015).

India remains a net exporter of silk goods, with exports growing from 1,649 crore in 2017–18 to 2,027 crore in 2023–24, despite a drop to $215 million in the first three quarters of FY25 (Ministry of Textiles, 2024). Simultaneously, raw silk imports fell from 3,874 metric tonnes in 2022–23 to 1,561 in April–December 2024, reflecting improved domestic capacity (Central Silk Board, 2024).

The sector supports 9.76 million people, including 4.7 million farmers in over 52,000 villages (Central Silk Board, 2024). There's a strong correlation ($r = 0.976$) between silk production and employment, which has grown at 2.37% CAGR (Kumar et al., 2018). Sericulture offers incomes 1.5–2 times higher than traditional farming (Chakraborty & Ray 2015). Government schemes like Silk Samagra-2 (4,679 crore) have

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enhanced training and market access, benefiting over 78,000 individuals (Ministry of Textiles, 2024).

Silk exports contribute 0.2% to GDP and support 5.6 million people, with women making up 60% of the workforce (Central Silk Board, 2024). Karnataka and Assam have seen notable rural gains from silk-related activities (Chakraborty & Ray, 2015). Yet, climate change and market shifts pose challenges. Diversifying into eco-friendly Vanya silks like Eri and Tasar offers promise (Kiran & Prasad 2020). Value addition through innovation can further global competitiveness (Kataki et al., 2021).

Eri silk, from silkworms fed on castor leaves, is gaining traction in home textiles for its soft, durable, and hypoallergenic qualities, thermal insulation, and moisture absorbency .Its woolly texture makes it ideal for items like curtains and cushion covers, meeting demand for sustainable furnishings. Wetland-castor-based Eri silk production offers rural income potential, especially in castor-rich regions like Gujarat, which has over 650,000 hectares of castor farms. Initiatives such as Gujarat's Eri sericulture project promote sustainable integration without needing more land or water, thanks to castor's drought resilience.

This system supports small farmers and women's cooperatives, spreading economic gains and aligning with eco-conscious consumer trends .Its low carbon footprint and compatibility with natural dyes boost its sustainability credentials .The gradual adoption of machine-spinning is expected to scale production and open up wider market access.

In objective of the present research work is to study the scope of qualitative and quantitative assessment of rice mill-fed wetland-grown castor leaves and their functional role in eri-culture, from rearing generating the cocoons, the raw materials for production of eri-silk. The model developed herewith is likely to support existing agriculture, empowers women, and contributes to a more resilient and inclusive silk industry.

MATERIALS AND METHODS

Procurement of Castor Leaves from Agricultural Land *vs* Constructed wetland

Castor leaves were harvested from two distinct environments: an agricultural field and a constructed wetland. Collections were performed during two seasonal periods-summer (March to May) and winter (October to December)-to assess seasonal variation in leaf production. For each season and site, leaves were further categorized into two developmental stages: fresh (young) leaves and matured leaves.

Sampling was conducted by selecting representative plots within each environment. In each plot, all visible castor plants were surveyed. The leaves were hand-harvested in the morning hours to minimize water loss and physiological changes, as recommended for foliar studies (Sannappa & Jayaramaiah 2002). Fresh leaves were identified based on their bright green colour, tenderness, and lack of visible signs of senescence, while matured leaves were recognized by their darker colour, increased toughness, and full expansion.

After harvesting, leaves from each category (fresh and matured) and environment (agricultural field and constructed wetland) were counted and recorded separately for each season. The total number of leaves in each category was tabulated for both summer and winter seasons, as shown in the Table. This approach allows for the assessment of environmental and seasonal effects on castor leaf production.
All samples were handled with care to avoid mechanical damage and were counted immediately after collection to ensure accuracy. The methodology aligns with standard protocols for leaf sampling and enumeration in agronomic and ecological studies (Sannappa & Jayaramaiah, 2002).

Procurement of Eri-Silkworm Eggs.

Fig 1: Eri-silk worm eggs.

The species used for this study was *Samia ricini* commonly known as the Eri silkworm. Disease-Free Laying's (DFLs) were procured from the Central Silk Board, Germplasm Centre, located at Hosur. Each DFL (wt0.5 g), is likely to contain around 300 eggs (Fig 1), was kept for incubation under shaded and well-ventilated environment (temperature range: 24–27°C; relative humidity = 80-85%) for hatching (incubation period: 7 - 10 days) and specification of procured eggs as shown in table 1.

Table 1: Specification of Eri-silk worm-eggs procured.

Parameter	Specification
Size	1 to 2 millimeters in diameter (About the size of a mustard seed)
Color	Creamy white to pale yellow
Shape	Oval, laid in clusters
Eggs per Female	300-350 (up to 400-450 in optimal conditions)
Laying Period	2 to 3 days
Hatching Time	5to 10 days
Optimal Temperature	24 - 27 °C for laying
Optimal Humidity	80 - 85%
Health Indicator	Clustered, gummy-covered eggs

Collection and Characterization of Castor Leaves

Fresh leaves of ***Ricinus Communis*** (castor plant) were collected from two distinct cultivation environments: (i) conventional agricultural fields irrigated with bore well water, and (ii) constructed wetlands designed for the treatment of rice mill wastewater. To account for seasonal variability, the study was conducted during two major climatic periods-summer (March to May) and winter (October to December). Accordingly, leaf samples were harvested during each season from both cultivation sources. The collected leaves were subjected to both qualitative and quantitative characterization.

Qualitative Characterization of the Leaves:

Morphological Observations

Observation of color, shape, and size was performed in natural daylight. Leaves were visually examined for symmetry, pigmentation, and lobbing. Leaf yield was determined by manually counting the number of tender and mature leaves per plant. Measurements were performed in triplicates for statistical validity (Rajan et al., 2015).

Leaf Weight Measurement

Tender and matured leaves were harvested, separated manually, and weighed using an analytical balance with ±0.001 g precision. Leaves were collected early morning to avoid moisture loss and placed in pre-weighed containers (AOAC, 2016)

Quantitative Characterization of the Leaves:

Proximate Analysis

Moisture Content

To determine the moisture content of castor leaves, fresh, thoroughly cleaned leaves are first chopped into small pieces. Approximately 2 to 5 grams of the sample are weighed using an analytical balance and placed in a pre-weighed moisture dish. This sample is then dried in a hot air oven at 105°C for 24 hours or until a constant weight is achieved, ensuring complete removal of water. After drying, the sample is cooled in a desiccator to prevent reabsorption of atmospheric moisture and then reweighed. The moisture content is calculated using the formula:

$$\text{Moisture Content}(\%) = \frac{\text{Initial weight} - \text{Final weight}}{\text{Initial weight}} X100$$

This method is standardized and widely accepted for plant materials (AOAC, 2000; Kataki et al., 2021).

Volatile Matter

For volatile matter estimation, the oven-dried leaf sample is used. About 1 gram of this dried sample is placed in a covered crucible and heated in a muffle furnace at 600 ± 10°C for seven minutes. The high temperature volatilizes all organic compounds except fixed carbon and ash. After ignition, the crucible is cooled in a desiccator and weighed again. The loss in weight during this process represents the volatile matter, which is calculated as:

$$\text{Volatile Matter}(\%) = \frac{\text{Weight loss on ignition}}{\text{Oven-dried sample weight}} X100$$

This procedure follows the ASTM E872-82 protocol and is suitable for biomass analysis (ASTM E872-82; Kataki et al., 2021).

Ash Content

To determine ash content, the residue from the volatile matter test is further heated in the muffle furnace at 700 ± 10°C for three to four hours or until a constant white or grey ash is obtained, indicating complete combustion of the organic matter. The crucible is then cooled in a desiccator and weighed. The ash content is calculated as:

$$\text{Ash Content}(\%) = \frac{\text{Weight of ash}}{\text{Oven−dried sample weight}} X100$$

This method is in accordance with AOAC Official Method 942.05 (AOAC, 2000; Kataki et al., 2021).

Fixed Carbon

Fixed carbon is not measured directly but is calculated by difference. After determining the percentages of moisture, volatile matter, and ash, fixed carbon is obtained by subtracting their sum from 100. The formula is:

$$\text{Fixed carbon}(\%) = 100 - (\text{moisture}(\%) + \text{volatile Matter } (\%) + \text{Ash } (\%))$$

This approach is recommended by ASTM D3172 and is commonly used in biomass and coal analysis (ASTM D3172; Kataki et al., 2021).

Ultimate Analysis

Carbon (%)

To determine the carbon content, a known weight of the air-dried sample is combusted in a high-temperature furnace in the presence of pure oxygen. The carbon in the sample is oxidized to carbon dioxide (CO_2). This CO_2 is then absorbed in a pre-weighed absorber containing soda lime or similar material. The increase in mass of the absorber corresponds to the amount of CO_2 produced, which is then used to calculate the percentage of carbon in the sample (ASTM, 2015).

$$\text{Carbon } \% = \frac{12(\text{Mass of } CO_2)}{44(\text{Sample mass})} X100$$

Hydrogen (%)

Hydrogen is measured simultaneously with carbon during the combustion process. The hydrogen in the sample is converted to water vapour (H_2O), which is then absorbed in a pre-weighed absorber containing a desiccant such as magnesium perchlorate. The increase in mass of the absorber is used to calculate the hydrogen content (ASTM, 2015).

$$\text{Hydrogen } \% = \frac{2 \text{ (Mass of } H_2O \text{ absorbed)}}{18 \text{ (Sample mass)}} X\ 100$$

Nitrogen (%)

Nitrogen content is commonly determined using the Kjeldahl method. The sample is digested with concentrated sulphuric acid and a catalyst, converting organic nitrogen to ammonium sulphate. After neutralization with sodium hydroxide, the released ammonia is distilled and collected in a known volume of standard acid, then titrated to determine the amount of nitrogen present (AOAC,2019).

$$\text{Nitrogen } (\%) = \frac{1.4X(V_1 - V_2)XN}{\text{Sample mass}} X100$$

Where V_1 = volume of acid used for sample (mL), V_2= volume for blank (mL),

N = normality of acid.

Oxygen (%)

Oxygen is typically not measured directly but is calculated by subtracting the sum of the percentages of carbon, hydrogen, nitrogen, sulphur, and ash from 100. This method assumes that all other major elements have been accounted for (ASTM, 2015).

$$\text{Oxygen } (\%) = 100 - [C\% + H\% + N\% + S\% + \text{Ash } \%]$$

Sulphur (%)

Sulphur is determined by combusting the sample in oxygen, converting all sulphur to sulphur dioxide (SO_2). The SO_2 is absorbed in a solution such as hydrogen peroxide and then titrated with a standard solution of iodine or measured gravimetrically (ASTM, 2015).

$$\text{Sulphur}(\%) = \frac{32(\text{Mass of } SO_2 \text{ absorbed})}{64(\text{sample mass})} X100$$

Biological Assessment

Total Protein

Total protein in castor leaves is commonly estimated using the Lowry method, where leaf tissue is homogenized in phosphate buffer, centrifuged, and the supernatant is reacted with alkaline copper reagent and Folin-Ciocalteu reagent. After incubation, absorbance is measured at 660 nm, and protein content is calculated from a standard curve using bovine serum albumin (BSA) (Lowry et al., 1951).

$$\text{Total Protein}\left(\frac{mg}{g}\right) = \frac{\text{Concentration from standard curve } \left(\frac{mg}{ml}\right) X \text{ extraction volume}}{\text{Sample weight (gm)}}$$

Amino Acids

Amino acids are determined by the ninhydrin method, where an ethanol or buffer extract of the leaf is mixed with ninhydrin reagent, heated, and the absorbance is measured at 570 nm. The concentration is calculated using a standard curve with glycine (Moore & Stein, 1948).

$$\text{Amino acids}\left(\frac{\text{mg}}{\text{g}}\right) = \frac{\text{Concentration from standard curve}\left(\frac{\text{mg}}{\text{ml}}\right)\text{X extraction volume}}{\text{Sample weight (gm)}}$$

Starch Content

Starch content is measured by extracting leaf tissue with hot ethanol to remove sugars, then hydrolysing the residue with per chloric acid. The resulting glucose is quantified by the anthrone method, measuring absorbance at 620 nm and using a glucose standard curve. (Hedge & Hofreiter, 1962).

$$\text{Starch Content}\left(\frac{\text{mg}}{\text{g}}\right) = \frac{\text{Glucose equivalent from satndard curve X extraction volume}}{\text{sample weight (gm)}}$$

Soluble Sugars

Soluble sugars are extracted with hot 80% ethanol, reacted with anthrone reagent, and the green color formed is measured at 620 nm. Concentration is determined from a glucose standard curve (Yemm & Willis, 1954).

$$\text{Soluble sugars}\left(\frac{\text{mg}}{\text{g}}\right) = \frac{\text{Concentration from standard curve}\left(\frac{\text{mg}}{\text{ml}}\right)\text{X extraction volume}}{\text{Sample weight (gm)}}$$

Reducing Sugars

Reducing sugars are estimated using the DNS method, where the extract is mixed with DNS reagent, heated, and absorbance is measured at 540 nm. The amount is calculated from a glucose standard curve (Miller, 1959).

$$\text{Reducing sugars}\left(\frac{\text{mg}}{\text{g}}\right) = \frac{\text{Concentration from standard curve}\left(\frac{\text{mg}}{\text{ml}}\right)\text{X extraction volume}}{\text{Sample weight (gm)}}$$

Total Phenols

Total phenols are quantified by the Folin–Ciocalteu method (Singleton & Rossi, 1965), mixing the extract with Folin–Ciocalteu reagent and sodium carbonate, and then measuring absorbance at 765 nm. Gallic acid is used for the standard curve.

$$\text{Total Phenols}\left(\frac{\text{mg}}{\text{g}}\right) = \frac{\text{Gallic Acid equivalent from standard curve}\left(\frac{\text{mg}}{\text{ml}}\right)\text{X extraction volume}}{\text{Sample weight (gm)}}$$

Chlorophyll A and B

Chlorophyll a and b are extracted using 80% acetone, and absorbance is measured at 663 nm and 645 nm, respectively. Concentrations are calculated using Arnon's equations (Arnon, 1949).

$$\text{Chlorophyll A}\left(\frac{\text{mg}}{\text{g}}\right) = \frac{12.7(A_{663} - 2.69)A_{645}}{1000}\text{X}\frac{\text{extraction volume(ml)}}{\text{sample weight (g)}}$$

$$\text{Chlorophyll B}\left(\frac{\text{mg}}{\text{g}}\right) = \frac{22.9(A_{645} - 4.68)A_{663}}{1000}\text{X}\frac{\text{extraction volume(ml)}}{\text{sample weight (g)}}$$

Configuration of Rearing System for Eri Silkworm Production

Eri-silkworms (Samia ricini) were reared under controlled laboratory conditions to observe and document their complete life cycle, from egg to cocoon and pupal stage. The methodology followed standard sericulture protocols as outlined by the Central Silk Board and published research.

Collection and Incubation of Eggs:

Eri-silkworm eggs were procured from a certified sericulture center. Eggs were spread evenly in a single layer on sterile filter paper in plastic trays and incubated at 25–28°C with 80–85% relative humidity. The trays were kept in a dark environment to simulate natural conditions and ensure uniform hatching (Singh et al., 2011).

Eri-eggs growth requirements and key practices as followed by central silk borad practices, tabulated in Table 2.

Table 2: Stage-wise Duration, Rearing Requirements, and Key Management Practices for *Samia ricini*.

Stage	Duration	Key Activities & Requirements
Egg	6-8 days	Incubate at 24-26°C, 75-85% RH. Eggs darken before hatching.
1st Instar	3 days	Feed tender castor leaves, 29-31°C, 80-85% RH. Tray rearing.
2nd Instar	3 days	Feed slightly mature leaves, maintain hygiene, and continue in trays.
3rd Instar	3 days	Feed whole soft leaves, increase feeding frequency.
4th Instar	3 days	Feed mature leaves, transfer to larger trays or bamboo platforms.
5th Instar	3 days	Feed mature leaves, space adequately, prepare for cocooning.
Cocooning	4 days	Place in cocooning trays or wrap in newspaper, maintain moderate humidity.
Pupa	15-19 days	No feeding, maintain suitable environment until moth emergence.

Hatching:
After an incubation period of 6-8 days, hatching was observed. Newly hatched larvae (neonates) were counted and transferred gently to fresh, tender castor leaves (*Ricinus communis*), which served as their primary food source.

Black Boxing:
To synchronize larval development, the hatched larvae were subjected to "black boxing," a process where larvae are kept in darkness for 24 hours. This encourages uniform molting and instar progression (Chutia et al., 2009).

Larval Rearing and Instar Stages:
Larvae were reared in plastic trays lined with moist filter paper. Fresh castor leaves were provided ad libitum and replaced twice daily. The rearing environment was maintained at 25–28°C and 80–85% humidity. The growth of larvae was monitored daily, and molting events were recorded to identify the transition between instars. The Eri-silkworm passes through five larval instars, each marked by a molt:

- **1st Instar:** Neonate larvae, fed with tender castor leaves.
- **2nd Instar:** After first molt, larvae were transferred to new trays and fed with slightly mature leaves.
- **3rd Instar:** After the second molt, larvae increased in size and feeding rate.
- **4th Instar:** After third molt, larvae became more voracious and required more frequent leaf changes.
- **5th Instar (Mature Stage):** After the fourth molt, larvae reached their largest size and consumed the maximum quantity of leaves.

Cocoon Formation:
Upon completion of the 5th instar, mature larvae ceased feeding and began spinning cocoons using their silk glands. Cocoons were collected and counted daily.

Pupal Stage:
Cocoons were kept in a well-ventilated tray under laboratory conditions. After 7–10 days, the pupal stage was confirmed by gently opening a subset of cocoons.

Data Recording and Analysis
At each stage, the number of individuals, duration, and morphological changes were recorded. Photographic documentation was performed for each growth stage using a digital camera.

The above figure 2 illustrates the complete biological progression of the eri silkworm (Samia ricini), a non-

Fig 2: Visual Representation of the Growth Stages of Eri Silkworm (*Samia ricini*) from Egg to Cocoon.

mulberry silk-producing insect, through its key developmental stages under controlled rearing conditions. The cycle begins with eri-silkworm eggs, followed by hatching and the black boxing stage—a method used to synchronize hatching. The larval stage progresses through five instars (1st to 5th), during which larvae feed predominantly on castor leaves, with their nutritional content directly influencing larval growth, weight gain, and cocoon quality. From the mature 5th instar stage, larvae spin open-ended cocoons, inside which they transform into pupae. After pupation, adult moths emerge to restart the cycle. This visual sequence emphasizes the practical stages followed in eri-culture units and can help standardize management protocols, especially when comparing outcomes between agricultural and constructed wetland-based castor feeding systems.

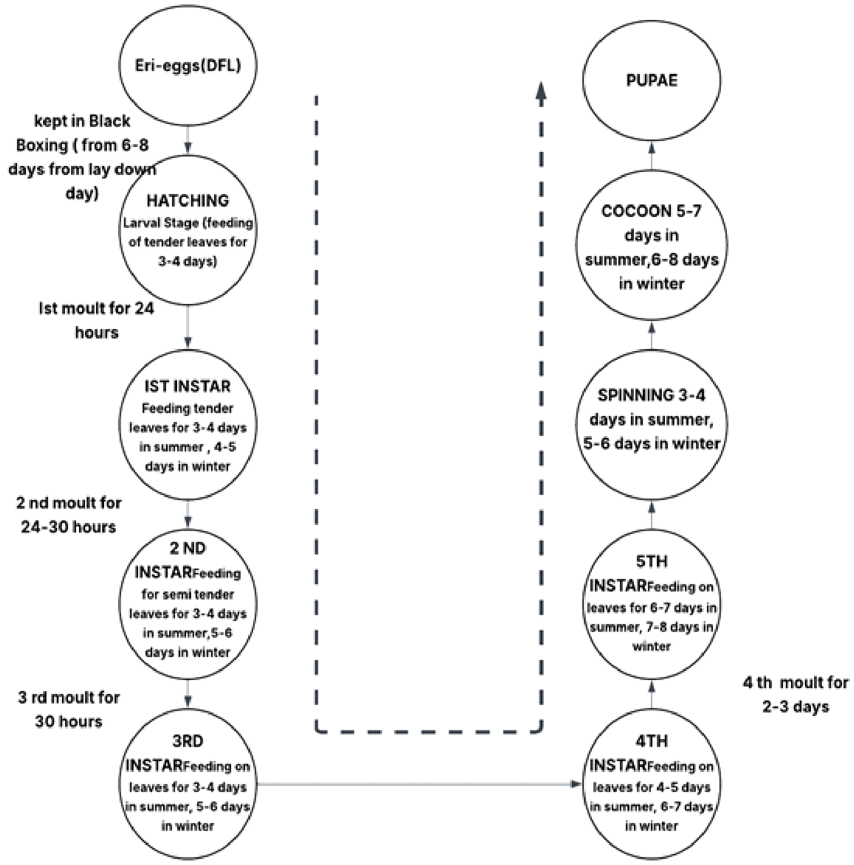

Fig. 3: Detailed Lifecycle Flowchart of Eri Silkworm (*Samia ricini*) under Seasonal Feeding and Moulting Regimes.

The above figure 3 flowchart outlines the complete developmental timeline of the eri silkworm (*Samia ricini*), beginning from the egg stage (Disease-Free Laying's, DFL) to the pupal stage, highlighting the feeding durations, moulting periods, and seasonal variations at each phase.

After laying, eri eggs are kept under black boxing conditions for 6–8 days to synchronize hatching. Once hatched, the larvae enter the 1st instar, feeding on tender castor leaves, and proceed through five distinct instars, each separated by a moulting period. These moults last from 24 to 30 hours (for earlier instars) and up to 2–3 days before the 5th instar.

Each instar's feeding duration differs with season:

- In summer, instar durations range from 3–7 days,
- While in winter, cooler conditions prolong feeding by 1–2 days per stage.

The fifth instar represents the peak of leaf consumption, crucial for cocoon formation. After feeding, larvae begin spinning cocoons over 3–6 days, followed by pupation lasting 5–8 days, depending on ambient temperature and humidity.

This lifecycle chart provides a practical protocol for rearing management, reflecting how seasonal factors influence feeding time, instar transition, and silk yield potential. It is especially useful for comparing silkworm development when fed on agricultural vs. constructed wetland-cultivated castor leaves, as part of integrated bio resource and wastewater reuse systems.

Larval Progression Parameters

Larval Duration (days)
The number of days required by the silkworm to complete each instar stage and reach the spinning stage. Record the start and end dates of each instar stage. Calculate the duration for each stage. Sum all five instars to get total larval duration (Hazarika & Phukan (2012); Gogoi et al. (2024).

Larval Weight (g)
Average weight of larvae during the final instar stage (usually 5th instar).Weigh 10–15 larvae individually or in groups during the 5th instar. Calculate the average and standard error (Bora et al., 2024; Praveen Kumar & Suresh 2019).

Effective Rate of Rearing (ERR %)
Percentage of larvae that successfully form cocoons out of the total number reared.

Count total number of hatched larvae (or DFL equivalent).Count number of successfully formed cocoons (Sarkar et al. (2016); Anitha & Rajasekar (2015)).

Cocoon Progression Parameters

Cocoon Weight (g)
Weight of the full cocoon (including pupae and shell).Weigh each cocoon using a digital balance. Take the average of 10–15 samples (Anujaa & Arivudainambi (2024)).

Pupal Weight (g)
Weight of the pupa after removing the silk shell. Carefully cut open the cocoon and extract the pupa. Weigh and average across multiple samples (Lakshmi et al., 2019).

Shell Weight (g)
Weight of the silk shell after pupae removal and cleaning. Weigh cocoon first. Remove pupae, dry the shell, and weigh again.

Shell weight = Cocoon weight – Pupal weight.

Shell Ratio (%)
The percentage of the cocoon's weight that is made up of shell material (Swathiga et al., 2019).the formulae used as follows,

Rate of Pupation (%)
Percentage of larvae that successfully pupate (Blanca et al. 2023; Ramakrishna et al., 2006).

RESULTS AND DISCUSSIONS

Seasonal Variation of Castor Leave Characteristics
The total number of castor leaves had been harvested during two distinct seasons—summer (March to May) and winter (October to December)—to assess seasonal variation in leaf production (Table 5.7). Leaves had been collected from two different cultivation environments: traditional agricultural fields and constructed wetlands designed for wastewater treatment and plant growth.

Table 3: Characteristics of Castor Leaves from Agricultural Land vs Constructed wetland.

Stages of the Leaf	Total number of Castor leaves harvested during Summer season (March-May)				Total number of Castor leaves harvested during Winter season (October-December)			
	Leaves from Agricultural Field		Leaves from Constructed Wetland		Leaves from Agricultural Field		Leaves from Constructed Wetland	
Tender-leaves	32	42	45	48	21	42	18	48
Matured Leaves	99	26	90	30	11	26	30	30

During both seasons, leaves had been categorized based on their developmental stage into tender leaves and matured leaves. For each category, the quantity of leaves had been counted separately from the agricultural fields and the constructed wetland systems. This (Table 3) data had been systematically recorded to enable a comprehensive comparison of castor leaf yield across environments and seasons.

The harvested tender and matured leaves had been carefully quantified to analyse the growth performance and productivity of castor plants grown under varying conditions. This analysis had provided insights into how constructed wetlands, as an alternative cultivation system, had supported castor leaf production relative to conventional agriculture during different climatic periods

Assessment of Association of Season on Yield of Castor Leaves

To evaluate the association of the Castor leaves produced from agri-land and wet-land site during varying seasons, Chi-square test was performed based on the leaf counts (incl. both tender- and mature-types), the result of which is presented in Table 4.

Table 4: Effect of Season and Cultivation Site on the Distribution of Tender and Matured Castor Leaves: A Chi-Square Test.

Leaf Type	Cultivation Sites	Season Categories	X^2 Value	Df (Degrees of Freedom)	Critical Value (0.05)	Significance	Conclusion
Tender Leaves	Agri-land, Wetland	Summer, Winter	0.271	1	3.841	Not Significant ($p > 0.05$)	**X** No significant association between season and cultivation site
Matured Leaves	Agri-land, Wetland	Summer, Winter	8.815	1	3.841	Significant ($p < 0.05$)	✓ Significant association between season and cultivation site

The chi-square test results for castor plant leaf harvests reveal distinct patterns across different cultivation environments and seasons. For tender leaves, the analysis yielded a chi-square value of 0.271, which falls well below the critical value of 3.841 at a significance level of 0.05 with 1 degree of freedom, resulting in $p > 0.05$. This indicates no significant association between season and cultivation site for tender leaves, suggesting that early leaf development in castor plants remains relatively consistent regardless of whether they grow in rice mill wastewater-fed wetlands or agricultural land with normal ground water. These findings align with the known adaptability of Ricinus communis L., which demonstrates considerable resilience during initial growth stages even under challenging conditions. In contrast, matured leaves exhibited a markedly different pattern, with a chi-square value of 8.815 exceeding the critical threshold, producing $p < 0.05$. This statistically significant association between season and cultivation site for matured leaves indicates that as castor leaves develop, they become increasingly susceptible to environmental influences from both water quality and seasonal variations. This sensitivity likely reflects the cumulative effects of prolonged exposure to varying nutrient compositions and potential contaminants in rice mill wastewater, with effects that may intensify or change across different seasons. Research consistently shows that while castor plants demonstrate tolerance to challenging conditions, including wastewater irrigation, the long-term development of mature tissues responds more dramatically to these variables than initial growth. The plant's differential response between growth stages carries important implications for cultivation practices and environmental applications. The resilience observed in tender leaves suggests castor plants can be successfully established in diverse water quality conditions, making them potentially valuable for phytoremediation in contaminated sites, particularly for metal extraction. However, the significant season-site interaction observed in matured leaves indicates that seasonal monitoring and possibly supplementary nutrients may be necessary to optimize overall biomass production, especially in wastewater-irrigated conditions. These findings contribute valuable knowledge for both agricultural applications and potential environmental remediation projects involving castor plants, highlighting how environmental factors uniquely influence different developmental stages of the same plant species.

Quantitative Characterization of Castor Leaves from Agricultural Land and Constructed Wetland of the Leaves:

Proximate Analysis

Table 5 depicts proximate analysis of winter-harvested castor leaves reveals statistically significant differences between those grown in agricultural land with normal groundwater versus rice mill wastewater-fed wetlands. All measured parameters exhibited extremely significant variations (p-values ranging from 4.36E-08 to 2.68E-04), indicating that the cultivation environment substantially alters the leaf composition. Wetland-grown castor leaves contained notably higher moisture content (75.2 ± 2.0% versus 72.5 ± 1.8%), which suggests greater water retention capability possibly due to adaptation to consistent water availability in wetland environments or differences in cellular structure developed in response to wastewater constituents. Similarly, volatile matter was significantly elevated in wetland samples (17.1 ± 1.0% versus 15.3 ± 0.9%), indicating higher levels of organic compounds that readily vaporize upon heating, potentially reflecting differences in secondary metabolite production as a response to the wastewater environment. Interestingly, fixed carbon content was higher in agricultural land samples (8.4 ± 0.6% versus 7.8 ± 0.5%), suggesting potential differences in carbon allocation and storage strategies between plants grown in different environments, which may relate to varying photosynthetic efficiencies or carbon utilization patterns. Ash content, representing inorganic mineral residue, was elevated in wetland samples (4.3 ± 0.5% versus 3.8 ± 0.4%), likely reflecting the higher mineral load typically present in rice mill wastewater. These findings complement the previous chi-square analysis results, where mature leaves showed significant differences based on growing environment while tender leaves did not. The proximate analysis further confirms that the rice mill wastewater-fed wetland environment induces measurable physiological adaptations in castor plants, altering fundamental leaf composition parameters. These adaptations may represent the plant's strategy to cope with different nutrient profiles, potential contaminants, or other

Table 5: Proximate Analysis and Characterization of Castor Leaves from Agricultural Land and Constructed Wetland.

Parameters	Avg ± SE		p-value (as per 2-tailed independent t-test)
	Agri-Land	Wetland	
Moisture Content	72.5 ± 1.8	75.2 ± 2.0	4.36E-08
Volatile Matter	15.3 ± 0.9	17.1 ± 1.0	5.77E-07
Fixed Carbon	8.4 ± 0.6	7.8 ± 0.5	2.68E-04
Ash Content	3.8 ± 0.4	4.3 ± 0.5	4.25E-05

Biotic and abiotic factors present in the wastewater-fed environment, and could have important implications for the potential use of castor plants in phytoremediation systems or for optimizing cultivation practices in different environments.

The Figure 4 provides a clear visual comparison of the proximate analysis parameters for castor leaves from agricultural and wetland environments. Moisture content is high in both cases, but the wetland-fed leaves show a slight increase, visually confirming their greater water retention, likely due to continuous exposure to the water-rich wetland environment. Volatile matter is also higher in the wetland samples, as depicted by the taller bar, suggesting an increased presence of easily vaporized organic compounds, which may be a response to the nutrient and organic load in rice mill wastewater.

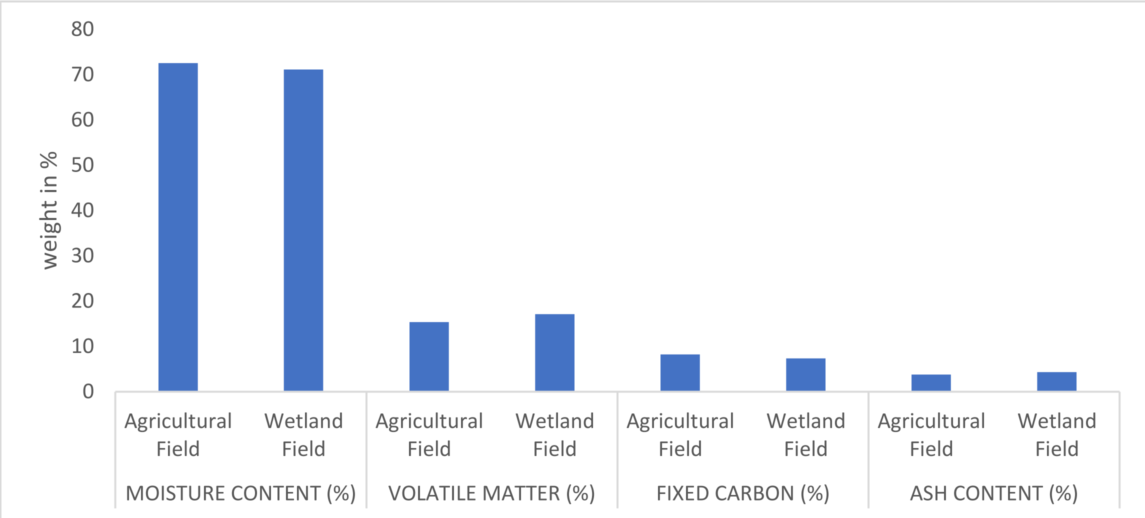

Fig. 4: Comparative Proximate Analysis of Castor Leaves from Agricultural Field and Constructed Wetland.

In contrast, fixed carbon content is marginally higher in the agricultural field samples, as shown by the slightly taller bar for this parameter, indicating a greater proportion of stable carbonaceous material-possibly reflecting differences in plant metabolism or environmental stress adaptation. Ash content, which represents the inorganic residue after combustion, is visibly higher in the wetland-fed leaves, highlighting the greater mineral uptake from the effluent-rich wetland.

Overall, the graph visually reinforces the statistical and analytical findings, emphasizing that wetland conditions promote higher moisture, volatile matter, and ash content in castor leaves, while agricultural field conditions favor slightly higher fixed carbon. This visual evidence succinctly captures the environmental influence on the proximate composition of castor leaves, underlining the adaptability of the plant and the pronounced effect of cultivation environment on its basic chemical makeup.

Ultimate Analysis

The ultimate analysis of castor leaves harvested during winter from agricultural land and wetland environments demonstrates significant compositional differences attribuTable to the growing conditions (Table 6). Statistically, the t-test results reveal that elemental carbon, nitrogen, oxygen, and sulphur contents all differ significantly between the two sites, as indicated by their low p-values (all well below 0.05), while hydrogen content does not show a significant difference (p = 0.209). Specifically, leaves from agricultural land have slightly higher carbon (42.1 ± 1.2%) and oxygen (46.8 ± 1.1%) contents compared to those from the wetland (41.5 ± 1.0% carbon, 45.2 ± 1.3% oxygen), suggesting that plants grown with regular groundwater may allocate more resources to structural carbohydrates and other oxygen-rich compounds, possibly due to more stable nutrient availability and less environmental stress.

Table 6: Ultimate Analysis and Elemental Characterization of Castor Leaves from Agricultural Land and Constructed Wetland.

Parameters	**Avg ± SE**		**p-value (as per 2-tailed independent t-test)**
	Agri-Land	**Wetland**	
Elemental Carbon	42.1 ± 1.2	41.5 ± 1.0	4.80E-05
Elemental Hydrogen	6.5 ± 0.4	6.7 ± 0.3	2.09E-01
Elemental Nitrogen	2.1 ± 0.2	2.7 ± 0.2	2.03E-08
Elemental Oxygen	46.8 ± 1.1	45.2 ± 1.3	2.15E-02
Sulphur	0.16 ± 0.01	0.22 ± 0.01	4.95E-13

In contrast, wetland-grown leaves exhibit a significantly higher nitrogen content (2.7 ± 0.2% versus 2.1 ± 0.2%), which may be attributed to the enhanced nitrogen load typically present in rice mill wastewater. This increased nitrogen uptake is consistent with the known ability of castor plants to absorb and utilize nutrients from effluent-rich environments, as supported by literature on phytoremediation and wastewater irrigation. The sulphur content is also markedly higher in wetland leaves (0.22 ± 0.01%) compared to agricultural land (0.16 ± 0.01%), further indicating the influence of wastewater-derived nutrients and possibly reflecting the presence of sulphur-containing compounds or pollutants in the effluent. The only parameter without a significant difference is elemental hydrogen, where both environments yield similar values (6.5 ± 0.4% for agricultural land and 6.7 ± 0.3% for wetland), suggesting that hydrogen content in leaf tissues is less sensitive to environmental or nutrient variations.

Overall, these results reinforce the conclusion that rice mill wastewater-fed wetlands induce substantial physiological and biochemical changes in castor plants, particularly in their elemental composition. The elevated nitrogen and sulphur levels in wetland-grown leaves highlight the plants' capacity to assimilate excess nutrients from effluent sources, which is beneficial for phytoremediation but may also impact the suitability of the biomass for certain uses. The significant reduction in oxygen content in wetland leaves may reflect shifts in metabolic pathways or stress responses. These findings are consistent with previous studies showing that wastewater irrigation can alter the nutrient profile and elemental makeup of crop plants, and they underscore the importance of monitoring and managing such systems for both environmental safety and crop quality.

The Figure 5 visually underscores the compositional shifts observed in the ultimate analysis of castor leaves from agricultural and wetland environments. The most striking feature is the consistently higher nitrogen and sulphur content in the wetland-fed leaves, which stands out in the plot and reinforces the strong influence of rice mill wastewater on nutrient uptake. This visual pattern not only supports the statistical findings but also highlights the plant's ability to assimilate excess nutrients and potentially trace elements from effluent sources, a trait valuable for phytoremediation applications.

Elemental carbon and oxygen, while both prominent in overall leaf composition, show a subtle but clear reduction in the wetland samples compared to the agricultural field. This suggests a shift in the allocation of structural and metabolic compounds, possibly reflecting the altered physiological state of plants grown in nutrient-rich, but potentially more stressful, wetland conditions. The hydrogen content remains nearly identical between the two groups, as depicted by the closely aligned bars, visually confirming its statistical insignificance and suggesting that this element's proportion is relatively sTable regardless of environmental input.

Overall, the graph provides an immediate, emphatic illustration of how cultivation environment can drive elemental changes in plant tissues. The differences, especially in nitrogen and sulphur, are not only statistically significant but also visually compelling, emphasizing the adaptability of castor plants and the pronounced effect of wastewater irrigation on their biochemical makeup. This visual evidence complements the earlier detailed analysis, offering a holistic view of the environmental impact on castor leaf chemistry.

Biological Assessment

The biological analysis (Table 7) of castor leaves harvested from agricultural land and wetland environments during winter reveals highly significant differences across all measured biochemical parameters, as determined by independent t-tests. Leaves from the wetland site, irrigated with rice mill wastewater, consistently show higher levels of total protein (17.4 ± 0.9 mg/g vs. 15.6 ± 0.7 mg/g), amino acids (11.8 ± 0.7 mg/g vs. 10.2 ± 0.6 mg/g), starch content (14.0 ± 0.7 mg/g vs. 13.5 ± 0.5 mg/g), soluble sugars (9.7 ± 0.3 mg/g vs. 9.1 ± 0.4 mg/g), reducing sugars (4.5 ± 0.2 mg/g vs. 4.3 ± 0.2 mg/g), total phenols (2.1 ± 0.1 mg/g vs. 1.6 ± 0.1 mg/g), chlorophyll A (2.2 ± 0.9 mg/g vs. 1.9 ± 0.08 mg/g), and chlorophyll B (1.0 ± 0.05 mg/g vs. 0.8 ± 0.04 mg/g) compared to those from agricultural land. The extremely low p-values for all parameters (ranging from 7.74E-10 to 1.38E-06) confirm that these differences are statistically significant.

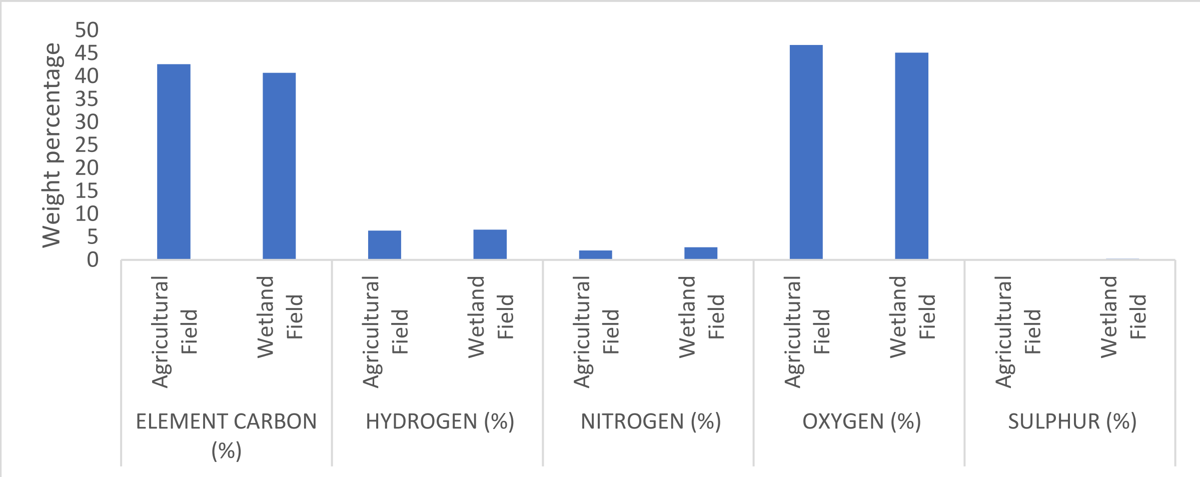

Figure 5 Ultimate Elemental Composition of Castor Leaves from Agricultural Field and Constructed Wetland

Table 7: Biological Assessment of Castor Leaves Harvested from Agricultural Field and Constructed Wetland.

Parameters (mg/g)	Avg ± SE		p-value (as per 2-tailed independent t-test)
	Agri-Land	Wetland	
Total Protein	15.6 ± 0.7	17.4 ± 0.9	7.74E-10
Amino acids	10.2 ± 0.6	11.8 ± 0.7	4.88E-10
Starch content	13.5 ± 0.5	14.0 ± 0.6	6.66E-05
Soluable Sugars	9.1 ± 0.4	9.7 ± 0.3	3.95E-06
Reducing sugars	4.3 ± 0.2	4.5 ± 0.2	5.90E-04
Total Phenols	1.6 ± 0.1	2.1 ± 0.1	4.64819E-10
Chlorophyll A	1.9 ± 0.08	2.2 ± 0.09	2.12416E-06
Chlorophyll B	0.8 ± 0.04	1.0 ± 0.05	1.38484E-06

These findings suggest that the rice mill wastewater provides a nutrient-rich environment, enhancing the biosynthetic capacity of the castor plants. The elevated protein and amino acid levels in wetland leaves likely reflect increased nitrogen availability in the wastewater, which is a critical factor for protein synthesis and overall plant growth. Similarly, the higher starch and sugar contents indicate improved carbohydrate metabolism, possibly due to enhanced photosynthetic activity or altered metabolic pathways in response to the nutrient profile of the effluent. The increased levels of total phenols in wetland-grown leaves may be a plant response to oxidative stress or the presence of organic and inorganic contaminants in the wastewater, as phenolic compounds are known to play a role in plant defence mechanisms.

In fact, the significantly higher chlorophyll A and B concentrations in wetland leaves further support the idea of enhanced photosynthetic potential, likely due to better nutrient availability, particularly nitrogen and magnesium, which are essential components of chlorophyll molecules. These results are consistent with research showing that wastewater irrigation can boost the biochemical and physiological attributes of plants, though it may also induce certain stress responses. Overall, the biological analysis underscores the substantial impact of cultivation environment on the metabolic and physiological status of castor plants, with rice mill wastewater-fed wetlands promoting greater accumulation of key biomolecules. This not only highlights the adaptability and phytoremediation potential of castor but also suggests that such environments can be leveraged to enhance the nutritional and functional quality of plant biomass, provided that contaminant levels remain within safe limits.

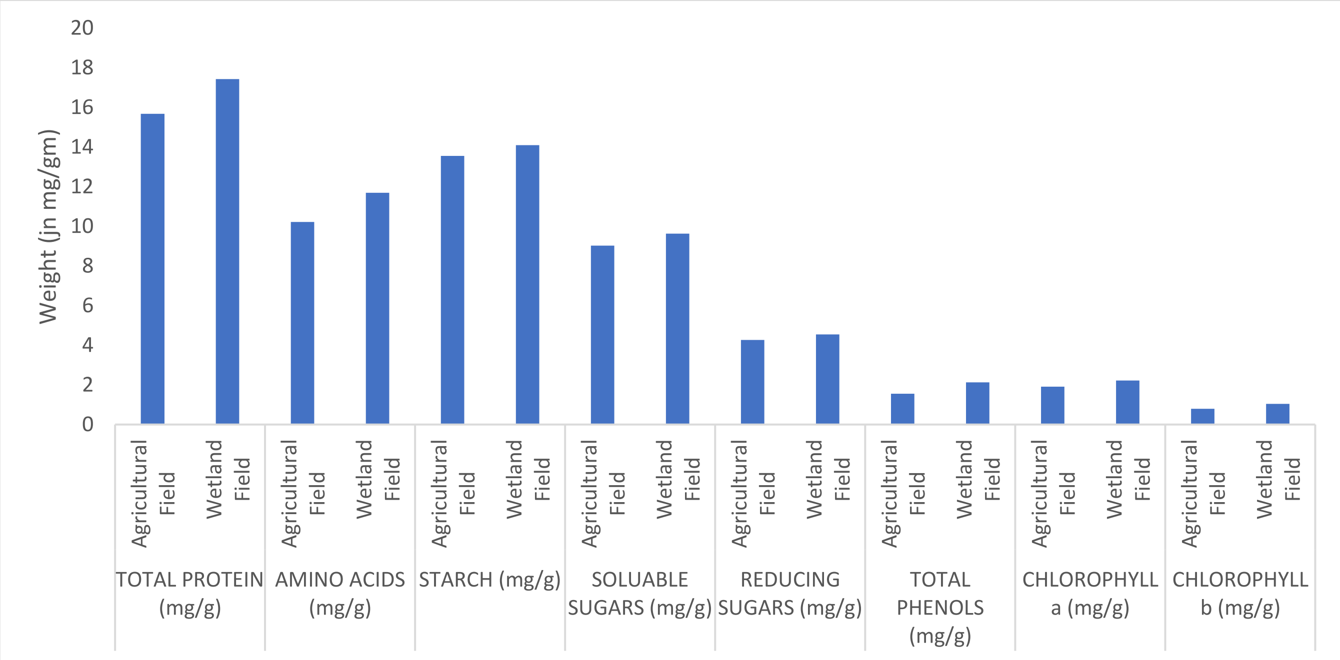

Fig. 6: Biological Composition of Castor Leaves from Agricultural Land and Constructed Wetland.

The Figure 6 depicting the biological assessment of castor leaves provides a clear visual confirmation of the statistically significant differences previously identified between leaves harvested from agricultural land and those from wetland environments. Across all measured parameters-total protein, amino acids, starch, soluble sugars, reducing sugars, total phenols, chlorophyll a, and chlorophyll b-the mean values are consistently higher in the wetland-fed samples compared to those from the agricultural field. This pattern is especially pronounced for total protein and amino acids, where the wetland leaves show a marked increase, underscoring the substantial influence of the nutrient-rich rice mill wastewater on nitrogen assimilation and protein synthesis in castor plants.

The elevated levels of starch and both soluble and reducing sugars in the wetland samples further highlight an enhanced carbohydrate metabolism, likely driven by the improved nutrient availability and possibly by adaptive metabolic responses to the wetland environment. The higher total phenol content in wetland leaves, as shown in the chart, suggests a heightened physiological response, potentially as a protective mechanism against stressors or contaminants present in the wastewater. Similarly, the increased chlorophyll a and b concentrations in wetland-fed leaves visually reinforce the earlier interpretation that wastewater irrigation supports greater photosynthetic pigment accumulation, which is fundamental for robust plant growth and productivity.

Overall, the graphical representation not only corroborates the statistical and biochemical findings but also emphasizes the pronounced effect of environmental conditions on the biological composition of castor leaves. The consistent superiority of wetland-fed leaves across all biological metrics visually encapsulates the adaptability and enhanced metabolic capacity of castor plants in nutrient-enriched, effluent-irrigated systems. This visual evidence, in harmony with the previous analyses, highlights the potential of wetland cultivation for boosting the nutritional and functional quality of castor biomass, while also drawing attention to the importance of monitoring for possible stress-induced changes in secondary metabolites.

Larval growth assessment of Castor Leaves fed from Agricultural Land and Constructed Wetland of the Leaves:

The Table 8 and Figure 7 together provide a comprehensive view of how eri-worm larval growth responds to being fed castor leaves from agricultural land versus wetland environments across progressive instar stages. The data show that during the earliest stage (1st instar), there is no statistically significant difference in weight gain between larvae fed with agricultural or wetland leaves, as indicated by both the close mean values (0.021 ± 0.002 g vs. 0.018 ± 0.002 g) and the high p-value (0.136), which is visually reflected in the overlapping starting points of the growth curves on the graph.

Table 8: Growth Variation in Eri Silkworm Larval Progression Fed with Castor Leaves from Agricultural Land and Wetland.

Stages of eri-worm	Weight Gained by Larvae by all stages (gm)		p-value (as per 2-tailed independent t-test)
	Agricultural fed leaves	Wetland fed Leaves	
1st INSTAR	0.021 ± 0.002	0.018 ± 0.002	0.136092371
2nd INSTAR	0.060 ± 0.003	0.052 ± 0.004	0.04091937
3rd INSTAR	0.252 ± 0.007	0.216 ± 0.007	0.002815383
4th INSTAR	1.217 ± 0.020	1.112 ± 0.027	8.13277E-05
5th INSTAR	4.536 ± 0.050	4.265 ± 0.050	0.000329821

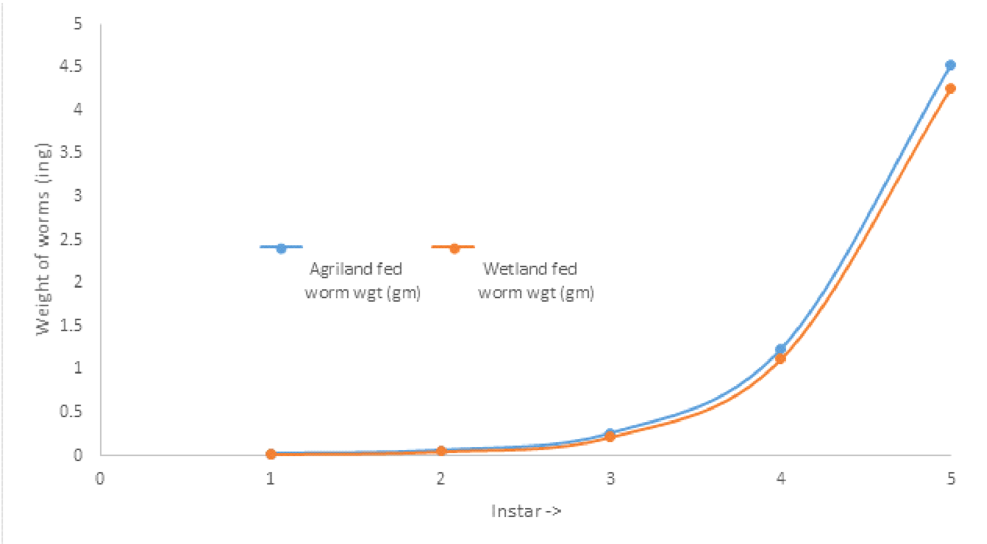

Fig. 7: Comparative Growth Curve of Eri Silkworm Larvae Fed with Agricultural and Wetland Castor Leaves.

However, from the 2nd instar onwards, significant differences emerge. The larvae fed agricultural leaves consistently gain more weight at each subsequent stage, with the differences becoming increasingly pronounced and statistically significant (p-values dropping from 0.041 in the 2nd instar to 0.0004 in the 5th instar). This trend is clearly depicted in the graph, where the blue curve (agricultural fed) remains slightly above the red curve (wetland fed) throughout the later instars, culminating in a noticeably higher mean weight at the 5th instar (4.54 ± 0.05 g vs. 4.27 ± 0.05 g).

The pattern suggests that while the initial nutritional adequacy of both leaf types is sufficient for early larval development, the cumulative effects of leaf quality become more influential as the larvae progress through successive instars. This is consistent with the earlier proximate, ultimate, and biological analyses, which showed that wetland leaves, despite being richer in certain nutrients and secondary metabolites, may differ in ways that subtly impact digestibility or nutrient assimilation for the larvae over time. The slightly lower weight gain in wetland-fed larvae could be due to differences in leaf composition, such as higher phenolic content or altered protein profiles, which might affect larval metabolism or feeding efficiency in later stages.

Overall, the results emphasize the importance of subtle compositional differences in larval diets, which may not be apparent in early growth but become significant as developmental demands increase. The visual and statistical evidence together underscore the need to consider not just the nutrient content, but also the bioavailability and physiological effects of feed sources when evaluating their suitability for insect rearing or similar biological applications.

Cocoon parameters assessment of Castor Leaves fed from Agricultural Land and Constructed Wetland of the Leaves:

The provided data (Table 9 & Figure 8) offer a detailed comparison of cocoon parameters-cocoon weight, pupal weight, shell weight, and shell ratio-between eri-worms fed with castor leaves from agricultural land and those fed with wetland-grown leaves. The results are strikingly consistent: for every parameter measured, worms that consumed agricultural land leaves outperformed those fed with wetland leaves, and these differences are not only visually apparent but also statistically robust, as indicated by extremely low p-values (all < 0.000000002).

Table 9: Variation in Cocoon Parameters of Eri Silkworms Fed with Agricultural and Wetland Castor Leaves.

Parameters	Agricultural fed leaves	Wetland fed Leaves	p-value (as per 2-tailed independent t-test)
Cocoon Weight (gm)	2.1 ± 0.1	1.95 ± 0.1	1.1451E-10
Pupal Weight (gm)	1.6 ± 0.1	1.52 ± 0.08	2.083E-09
Shell Weight (gm)	0.5 ± 0.05	0.43 ± 0.04	5.9235E-10
Shell Ratio (%)	23.8 ± 0.6	22.3 ± 0.5	1.9455E-14

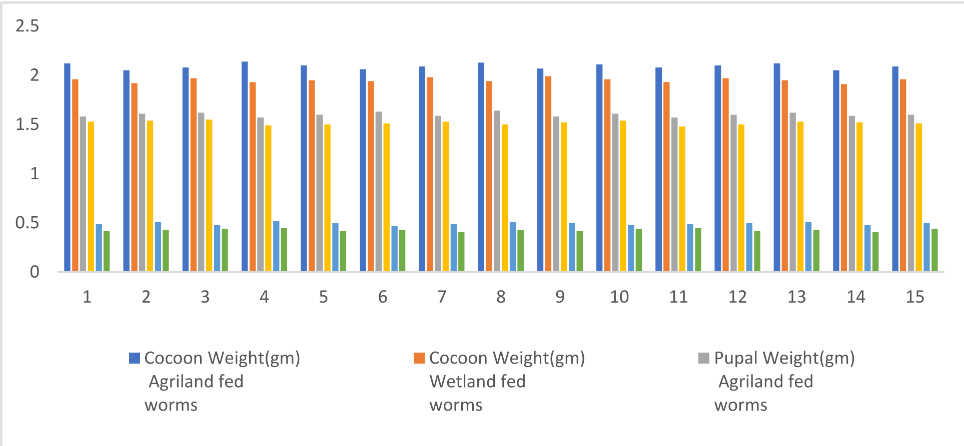

Figure 8 Comparative Analysis of Cocoon Parameters of Eri Silkworms Fed with Agricultural and Wetland Castor Leaves

Cocoon weight is a critical indicator of overall worm health and silk yield. Here, worms fed with agricultural leaves produced heavier cocoons (2.1 ± 0.1 g) compared to those fed wetland leaves (1.95 ± 0.1 g). This difference, while it may seem modest numerically, is significant in the context of sericulture, where even small increases in cocoon weight can translate into substantial gains in silk production at scale. The bar chart visually reinforces this, with the blue bar (agri-fed) extending further than the red (wetland-fed).

Pupal weight follows a similar trend, with agricultural-fed worms yielding heavier pupae (1.6 ± 0.1 g) than their wetland-fed counterparts (1.52 ± 0.08 g). Pupal weight is closely linked to the nutritional reserves accumulated during larval stages and is a good proxy for overall developmental success. The higher pupal weight in agri-fed worms suggests that the nutritional profile or digestibility of agricultural leaves better supports larval growth and physiological development.

Shell weight-the mass of the silk shell spun by the worm-is a direct measure of silk output. Again, agricultural-fed worms have a clear advantage (0.5 ± 0.05 g vs. 0.43 ± 0.04 g). This difference is crucial for silk producers, as shell weight directly affects the yield and economic value of the crop. The bar chart makes this difference immediately apparent, with a visibly longer blue bar for shell weight.

Shell ratio, which expresses the proportion of the cocoon that is silk shell, is higher in the agri-fed group

(23.8% vs. 22.3%). This parameter is particularly important because it reflects the efficiency with which the worm converts its food into silk, not just body mass. A higher shell ratio means more of the cocoon is usable silk, which is highly desirable in commercial sericulture.

CONCLUSIONS

The comprehensive set of studies comparing castor leaves from agricultural land and rice mill wastewater-fed wetlands for eri-silkworm rearing yields several clear conclusions across all stages of the production chain-from leaf yield and quality, through larval growth, to cocoon characteristics.

In terms of leaf yield, both environments supported robust castor growth, but there was no significant difference in the number of tender leaves produced across seasons or sites, indicating resilience in early leaf emergence. However, matured leaf yield was significantly affected by both season and cultivation environment, with agricultural land generally supporting better sustained leaf production. This aligns with research showing that castor cultivars and environmental conditions strongly influence leaf yield and quality, which are critical for successful eri-silkworm rearing.

Leaf characteristics showed marked differences between the two environments. Proximate and ultimate analyses revealed that wetland-grown leaves had higher moisture, volatile matter, ash, nitrogen, and sulphur content, reflecting the nutrient-rich and mineral-laden nature of rice mill wastewater. Conversely, agricultural leaves had slightly higher fixed carbon, carbon, and oxygen content, suggesting a more stable and conventional nutrient profile. Biological analysis further demonstrated that wetland leaves were richer in protein, amino acids, sugars, phenols, and chlorophylls, indicating enhanced metabolic activity and stress adaptation. However, these compositional differences did not uniformly translate into superior performance for silkworm rearing.

When fed to eri-worm larvae, both leaf types supported adequate early-stage growth, but from the second instar onward, larvae fed with agricultural leaves consistently gained more weight at each stage. This trend was statistically significant and became more pronounced as the larvae matured, suggesting that while wetland leaves are nutritionally rich, their composition or the presence of certain secondary metabolites may limit digestibility or nutrient assimilation in later larval stages. This finding is consistent with broader research showing that not just nutrient content, but also nutrient form and bioavailability, are crucial for optimal silkworm development.

The cocoon characteristics reflected these trends even more emphatically. Eri-worms fed with agricultural leaves produced heavier cocoons, pupae, and shells, and had a higher shell ratio-parameters directly linked to silk yield and economic value. The superiority of agricultural leaves for cocoon production underscores the importance of feed quality, especially in the later stages of silkworm development, and confirms that subtle differences in leaf chemistry can have significant downstream effects on Seri cultural productivity.

This integrated study provides a nuanced understanding of how cultivation environment influences not only castor leaf yield and composition, but also the entire sericulture value chain. The results highlight that while wetland (wastewater-fed) castor can produce leaves with high nutrient and secondary metabolite content, these do not necessarily optimize silkworm growth or silk yield. Instead, leaves from conventional agricultural land remain superior for supporting robust larval development and maximizing cocoon and silk production. This has direct implications for sericulture practices, suggesting that while phytoremediation using castor in wetlands is viable, traditional agricultural castor is preferable for commercial eri-silk production. The findings also emphasize the importance of considering both environmental sustainability and economic returns when integrating wastewater reuse with sericulture. Ultimately, this work supports informed decision-making for farmers, policymakers, and researchers aiming to optimize both environmental management and silk industry productivity.

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SOLID WASTE MANAGEMENT IN UBAN AREAS; A CASE OF JCMC AREA, JALGAON, MAHARASHTRA, INDIA

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ABSTRACT

This study carried out within the Jalgaon City Municipal Corporation in Maharashtra State, India, concentrating on the prevailing practices, challenges, and strategies pertinent to solid waste management. Initial field assessments indicated that the average solid waste generation rate of household in the city stands at 0.25 kg per capita per day, culminating in an estimated total waste output of around 54 tons daily. A thorough examination was conducted to analyze the processes involved in the sourcing, quantity produced, collection, transportation, storage, treatment, and disposal of Municipal Solid Waste (MSW). Data pertaining to Solid Waste Management within the Municipal Corporation was gathered through the distribution of questionnaires, individual site visits, and interviews with pertinent municipal officials. Furthermore, photographic evidence and documentation were amassed to depict the various stages of generation, storage, collection, transportation, treatment, and disposal of Municipal Solid Waste.

The study's outcomes advocate for the adoption of sanitary landfills as a substitute for current open dumping practices, aiming to reduce reliance on waste incineration, notwithstanding the challenges and issues that may arise from this transition. The paper proposes an urgent shift from the existing waste collection and disposal methodologies employed by the government to a newly recommended framework that prioritizes waste-to-wealth or trash-to-treasure initiatives through recycling and community involvement, which are considered vital for attaining sustainability and effective solid waste management in the region under study.

No. of Pages: 10 **References: 18**

Keywords: Municipal Solid Wastes, Jalgaon area, Landfill, Recycling Waste.

INTRODUCTION

Effective waste management is crucial for promoting sustainability in Jalgaon. The strategies employed for the disposal of solid waste, including landfill operations and recycling initiatives, play a significant role in minimizing environmental impact. By focusing on these key areas, Jalgaon can enhance its waste management practices and contribute to a more sustainable future. Municipal Solid Waste Management (MSWM) represents a significant challenge to public health and environmental sustainability in Indian urban areas. Despite allocating 20-55% of their budgets to solid waste management, these cities manage to collect only 40-80% of the generated waste. Legislation mandates that each state and local government establish its own environmental protection agency to oversee the safeguarding and enhancement of the environment within their jurisdictions. The management of municipal solid waste and pollution is a primary obligation of these state and local environmental agencies, which are tasked with the responsibilities of handling, processing, disposing of solid waste, and mitigating pollution (Ogwueleka et. al., 2009). The

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concept of municipal solid waste encompasses the solid refuse generated from residential areas, roadways, public spaces, commercial establishments, healthcare facilities, and administrative offices. This type of waste is frequently managed by municipal and governmental entities. In contrast, solid waste produced by industrial activities is typically not classified as "municipal." Nevertheless, it is essential to consider industrial waste in the context of municipal solid waste management, as it often inadvertently contributes to the municipal waste stream (Zurbrugg, 2003).

Improper management of waste including its handling, storage, collection, and disposal poses significant risks to both environmental integrity and public health. In urban areas with high population densities, the effective and safe management of municipal solid waste and pollution is crucial for fostering a healthy living environment for residents (Mosler et. al., 2006). Research indicates that between one and two-thirds of generated solid waste remains uncollected. Consequently, this uncollected waste, frequently contaminated with human and animal feces, is often disposed of haphazardly on land, leading to issues such as flooding, the proliferation of insect and rodent vectors, and the transmission of diseases. Even the waste that is collected is frequently disposed of in an uncontrolled manner at dumpsites or incinerated, resulting in the pollution of air and water resources as per the Zurbrugg, 2009. Recently, several developing nations have come to the realization that their existing policies regarding solid waste and pollution management do not align with the goals of sustainable development (Abhijit et.al, 2024). This recognition underscores the necessity for a fundamental shift in the approach to municipal solid waste and pollution management challenges (Agamuthu, 2003). Emphasis is placed on the technical dimensions of various collection and disposal methods. Effective management of municipal solid waste and pollution transcends mere technological concerns; it encompasses institutional, social, legal, and financial dimensions (Sonawane et. al., 2010). This complexity necessitates the coordination and management of a substantial workforce, as well as collaboration with numerous stakeholders and the broader community. Furthermore, it requires contributions from diverse academic disciplines and a thorough understanding of local conditions (Zurbrugg, 2009). The aim of this research study is to provide a comprehensive overview of the issues and challenges encountered in the waste management sector, particularly concerning basic waste disposal and pollution control methods. Additionally, the study seeks to develop strategies that can be effectively implemented within the Jalgaon Municipal Corporation of Maharashtra State.

The recommendations derived from this study address various dimensions of municipal solid waste and pollution management, including institutional, political, social, financial, economic, and technical factors. Furthermore, it emphasizes the importance of information dissemination and training regarding innovative approaches such as waste-to-wealth and recycling, which are essential for achieving sustainability and enhancing solid waste management practices in the JCMC area of Maharashtra State.

MATRERIAL AND METHODS:

2.0: Study Area: Jalgaon city is positioned at a latitude of 21°0077^{0}'N and a longitude of 75.5626^{0}' E, located on the right bank of the Girna River. It is strategically situated along the Dhule-Nagpur National Highway No. 6 and is connected by the Mumbai-Bhusawal-Delhi, Mumbai-Bhusawal-Kolkata, and Bhusawal-Surat railway lines. According to the 2001 census, the population of Jalgaon was recorded at 368,579 individuals, an increase from 242,193 in 1991, encompassing an area of approximately 62.29 square kilometers as shown in Fig. 1. It is estimated that around 72% of the urban population resides in informal or unplanned settlements. The management of solid waste is overseen by the city cleansing section within the Environmental Health Service department.

2.1: Data Collection: The data necessary for the current study was obtained from a variety of primary and secondary sources. This included information sourced from several government entities, such as the Census Bureau, Municipal Corporation, Town Planning Department, as well as from newspapers and academic journals. Additionally, data was gathered using questionnaires, fieldwork, and personal interviews. The collected data was systematically organized, classified, presented, compared, and analyzed using various suitable statistical techniques. Graphs, diagrams, and maps were employed where relevant, and their interpretations contributed significantly to the findings of this study. This research integrates both theoretical frameworks and empirical investigations, providing comprehensive insights into the issues and challenges associated with municipal solid waste and pollution management. Solid waste from diverse societal segments was collected, mixed, and a one-kilogram (1kg) sample was prepared utilizing the quartering method. The waste was subsequently characterized, and the proportion of each component was calculated. Secondary data sources included municipal records, direct observations, photographs of selected sites, and personal interviews. A questionnaire was distributed to assess the involvement and collaboration of various ministries and agencies in Solid Waste and Pollution Management (SWPM) regarding solid waste collection services, disposal methods, and the generation of waste.

3.0: Solid Waste Generation Rates: The quantity of solid waste produced per capita daily in Jalgaon City Municipal Corporation (JCMC) was assessed to estimate the total volume of domestic solid waste generated each day. The measurement of waste generation in the city was conducted weekly on Fridays over a span of ten months, and the mean value was calculated. The results obtained from these studies are displayed in Graph-2, Waste Generation 305.66MT and Collection 298.82 and Uncollected 06.83 in Jalgaon City Municipal Corporation (JCMC) shown in Graph-3.

RESULTS AND DISCUSSION:

3.0: Solid Waste Generation Rates: The quantity of solid waste produced per capita daily in Jalgaon City Municipal Corporation (JCMC) was assessed to estimate the total volume of domestic solid waste generated each day. The measurement of waste generation in the city was conducted weekly on Fridays over a span of ten months, and the mean value was calculated. The results indicate that the waste generation rate in household in JCMC was approximately 0.25 kg/ca/day. The results obtained from these studies are displayed in Graph-2, Waste Generation 305.66MT and Collection 298.82 and Uncollected 06.83 in Jalgaon City Municipal Corporation (JCMC) shown in Graph-3 suggests that income level is a significant factor inducing domestic solid waste generation rates, as demonstrated by the high waste production rates observed in (JCMC) area.

3.1: Factors Affecting Solid Waste Management in JCMC, Jalgaon: In the realm of solid waste management and development, numerous factors that influence the process differ from one location to another and must be considered during the design phase. Among these factors are:

3.1.1: Waste Quantity and Composition: The domestic waste generated in industrialized nations typically contains a significant amount of packaging materials such as paper, plastics, glass, and metals, resulting in a low density of waste. Conversely, in many developing countries, including Jalgaon city in India, the waste comprises substantial quantities of fillers like sand, ash, dust, and stones, along with elevated moisture levels due to the high consumption of fresh fruits and vegetables (Sonawane and Thorat, 2010). These characteristics contribute to a higher density of waste. Consequently, the weight and abrasiveness of the sand, coupled with the corrosive nature of the water content, can lead to the rapid degradation of equipment. In such circumstances, incineration is not an appropriate method; instead, recycling or salvage operations should be utilized to minimize the amount of combustible paper and plastic in the waste prior to its treatment stage.

3.1.2: Awareness and Attitudes: Public awareness and attitudes towards waste significantly influence the entire solid waste management system. Every aspect of solid waste management, from the storage of household waste to waste segregation, recycling, collection frequency, the prevalence of littering, the willingness to pay for waste management services, and the resistance to the establishment of waste treatment and disposal facilities, is contingent upon public awareness and engagement. Therefore, this issue is vital in determining the effectiveness or ineffectiveness of the solid waste management system within the Jalgaon City Municipal Corporation, Jalgaon.

3.1.3: Access to Waste for Collection: Numerous sources of waste may only be accessible via roads or alleys that could be unsuitable for certain transportation methods due to their width, slope, congestion, or surface conditions (Sonawane and Thorat, 2010). This situation is particularly critical in unplanned settlements, such as slums or low-income neighbourhoods within the Jalgaon City Municipal Corporation, Jalgaon, and it significantly impacts the choice of equipment used for waste collection.

3.1.4: Institutions and Legislation: Institutional challenges encompass both existing and proposed legislation, as well as the degree to which such legislation is enforced. Standards and restrictions may constrain the technological options available for consideration. Additionally, governmental policies regarding the involvement of the private sector, both formal and informal, must be considered. The strength and concerns of trade unions can also play a crucial role in shaping waste management practices.

3.1.5: Collection and Storage: The solid waste in Jalgaon City Municipal Corporation is gathered from various sources and establishments through multiple methods. This process encompasses primary collection, which involves transporting waste from households to designated collection points, as well as secondary collection, which entails gathering waste from household levels, collection centres, open spaces, and illegal roadside dumps, ultimately leading to final disposal (Abhijit Thorat, et. al., 2024). Approximately 2,653 dust bins are strategically placed throughout Jalgaon City Municipal Corporation to facilitate primary collection. These bins come in cylindrical, semi-cylindrical, and rectangular shapes, with capacities ranging from 2 to 10 m^3, and are located in various settings such as Hospitals, and Schools. The waste collection from these dust bins is organized based on the frequency at which the containers reach capacity, as noted during this study. Within the Jalgaon City Municipal Corporation, door-to-door waste collection is partially executed in affluent neighborhoods, while communal collection is also somewhat practiced. In this scenario, households dispose of their waste using handcarts to transport it either to the primary collection points or to the municipal collection sites from these locations, the waste is eventually transported to the two chosen garbage dump sites.

3.1.6: Disposal System: In India, like many developing nations, waste is frequently discarded in open dumps, which are uncontrolled landfills where waste collection services are organized. These dumps are typically situated along or adjacent to major roadways (Ogwueleka et. al., 2009). Within the Jalgaon City Municipal Corporation in Jalgaon, Maharashtra State, there exist two (2) dumpsites located 3 km from the city along the City Municipal Corporation, Jalgaon road and City Municipal Corporation, Jalgaon Road, with disposal operations commencing in 1991; currently, these sites are either filled or exhausted. The practice of open dumping cannot be regarded as a sustainable environmental disposal method. Furthermore, refuse often spills onto roadways, obstructing traffic and culverts within the urban area, and waste is frequently burned openly at the roadside. Various methods exist for waste disposal; however, sanitary landfills represent the sole land disposal option that allows for the control and effective mitigation of severe emissions and contamination of surface and groundwater. Sanitary landfills necessitate significantly higher initial investments and, consequently, incur greater operating costs compared to controlled dumps (Abhijit et.al, 2024). Although sanitary landfills are not implemented in Maharashtra State, open dumping remains the predominant practice. There is an absence of landfill regulations or standards that establish a framework for compliance and monitoring. Waste in open dumps is often burned to reduce its volume. By considering each fundamental element separately, it is possible to: Identify the essential components and when feasible, establish measurable relationships to facilitate engineering comparisons, analyses, and evaluations.

3.1.7: Characteristics of Solid Waste: The amount and characteristics of solid waste differ across various locations. Factors that affect both quantity and composition include average income levels, sources of waste, population dynamics, social behaviors, climate conditions, industrial output, and the market for waste materials. Research has linked waste generation to the economic status of society by examining the volume of domestic solid waste produced across three socio-economic categories: Low Income Group (LIG), Middle Income Group (MIG), and High-Income Group (HIG). A positive correlation was noted between higher income levels and increased waste generation. Individuals in the HIG category tend to dispose of significantly more plastic, metal, and glass waste, as well as hazardous materials, which constitute 25.3% of the solid waste in Jalgaon City Municipal Corporation, Jalgaon. The studies indicated that the composition of solid waste in Jalgaon City Municipal Corporation, Jalgaon consists of 28% organic materials, followed by 12% rubber and leather products, and 2.6% textiles and rags. This suggests that the municipal solid waste in Jalgaon City Municipal Corporation, Jalgaon contains a substantial proportion of biodegradable materials. The typical composition of municipal solid waste generated in percentage is shown in Graph 4. Conversely, the percentage of non-biodegradable waste, such as metals and plastics, is notably high, indicating significant consumption of packaged plastic and rubber/leather products (Abhijit et.al, 2024).

3.1.8: Transport and Transfer: In recent years, the implementation of small transfer stations in various cities across developing nations has gained traction (Moghadam et. al., 2008). Currently, due to advancements in technology, there are only a limited number of transfer stations within the Jalgaon City Municipal Corporation, Jalgaon. The primary objective of establishing a transfer station is to mitigate the incidence of open dumping in proximity to residential areas and commercial hubs, which are characterized by narrow streets and aged alleys

(Abhijit Thorat, et.al., 2024). The specific type of transfer station utilized in Jalgaon City Municipal Corporation is a direct load system. Waste collected by smaller vehicles (e.g., vans) is unloaded into different categories of collection dumper trucks, which are equipped with specialized mechanisms for the removal and disposal of waste at designated sites.

Environment Problems Resulting from Solid Wastes Traditionally, the government served as the exclusive provider of nearly all essential services, including water supply, electricity, road infrastructure, and health services, with solid waste management being part of this framework. This reliance on a conventional model has resulted in insufficient infrastructure and service delivery (Kyessi, and Victoria, 2009). Despite the implementation of various intervention strategies since the early 2000s, such as collaborations with private contractors and civil society organizations, numerous challenges persist in the realm of solid waste management within the Jalgaon City Municipal Corporation, Jalgaon (JCMC), which include: Insufficient service coverage (some individuals not receiving service); Lack of authority to make financial and administrative decisions; Insufficient financial resources; Shortage of trained personnel; Deficiency of vehicles and equipment/existing ones frequently break down; Inability to maintain/repair vehicles and equipment; Absence of legislation to enforce measures and capabilities.; Rapid urbanization exceeding service capacity; Uncontrolled growth of squatter settlements; Challenges in locating and acquiring landfill sites; Poor public cooperation; Shortage of qualified private contractors; Difficulty in managing contractual services.

Regrettably, at the site, scavengers informally collect valuable components of municipal solid waste (MSW). Furthermore, various animals such as dogs, goats, sheep, and cows consume organic components of the waste (Akinwale, 2005). These inadequate disposal methods and practices result in issues that negatively affect both human and animal health as per Sheet one pictures figure 1: Picture of a dumpsite at Jalgaon city municipal corporation (JCMC) area; figure 2: Dumpsite along Jalgaon city municipal corporation main road; figure 3: Chandu annanagar dumping site; figure 4: Dumping site solid waste segregation building; figure 5: Samta nagar road Jalgaon.; figure 6: 100 feet shiv-colony road, Jalgaon.; figure 7: Krushna marble store road Jalgaon; figure 8: Dumping ground in chandu anna nagar, Jalgaon; figure 9: Hari-Vithal nagar, shiv-colony Chau fully Jalgaon.; figure 10: Wagh nagar stop area, Jalgaon. Environmental issues arising from MSW include Lack of action to control insects, rodents, and other vectors; no measures for leachate control; unpleasant odors at sites; air pollution due to waste burning, etc. Ultimately, the accumulation of garbage on streets, in open spaces, and on private properties presents another challenge associated with municipal solid waste management (MSWM). Despite some initiatives aimed at enhancing solid waste management in various areas of the metropolis, there remain significant levels of uncollected solid waste.

In Jalgaon today, it is a frequent occurrence to observe piles of decaying waste in our neighborhoods. The peripheries of residential buildings, drainage systems, highways, and the corners of both major and minor streets, as well as undeveloped land, have all transformed into waste repositories for numerous households. This situation results in waste accumulation increasing at a geometric rate, while collection and disposal occur at an arithmetic rate (Sonawane, et.al., 2010).

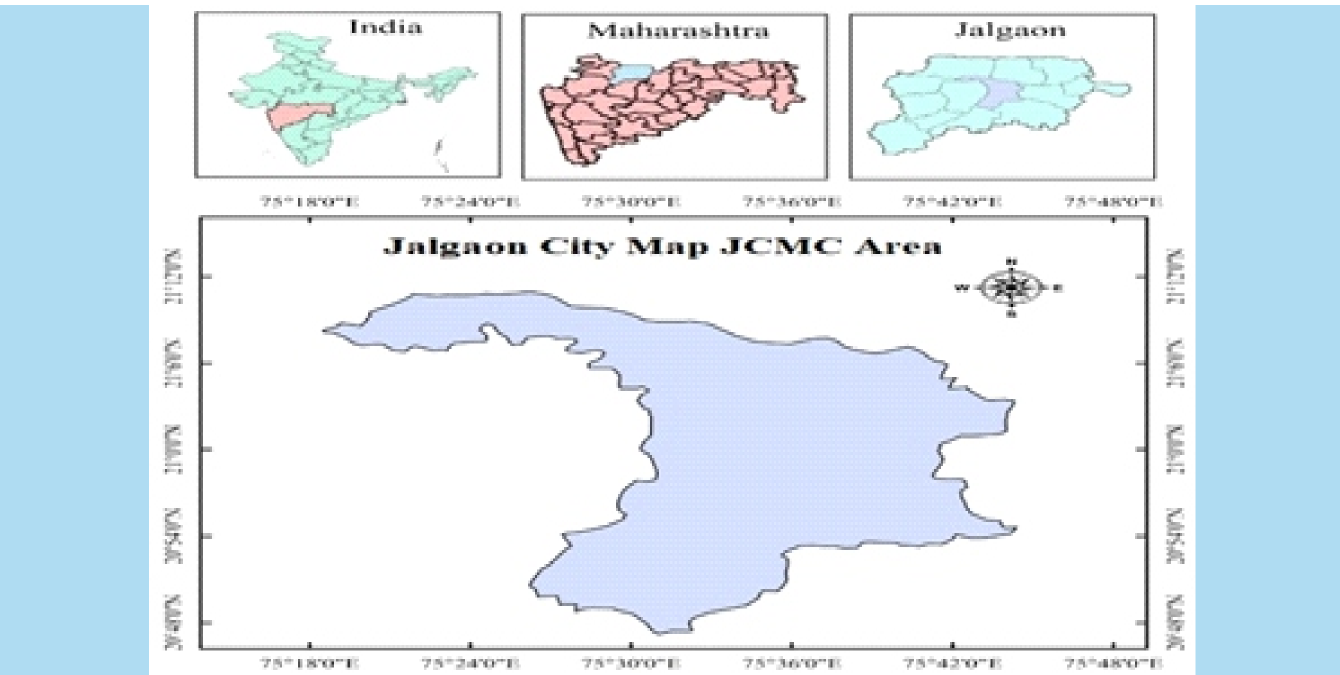
3.1.9: Solid Waste Reduction and Recovery: There exist a few formal systems for material recovery in Jalgaon. Nevertheless, there is extensive reuse of plastics, bottles, paper, cardboard, and cans for domestic applications. This practice is particularly prevalent among the economically disadvantaged in the city. The primary challenge lies in the absence of local or national markets for recyclable materials (Yhdego, 1995; Abhijit Thorat, et. al., 2024). The waste generated in developing nations contains a significant amount of moisture, necessitating the addition of fuel to initiate and sustain combustion. This results in a low calorific value and combustible components of solid waste in India, rendering incineration economically unfeasible, especially when considering the high costs associated with construction and maintenance (Ogwueleka et. al., 2009). Therefore, it is suggested that composting could serve as a highly viable recovery alternative that is practically implementable within the Jalgaon City Municipal Corporation (JCMC). Most rural regions in Maharashtra State utilize household food waste to feed livestock, where the waste is composted at home and subsequently used to enrich the soil. The composted material can serve as fertilizer. It has been noted that composting programs are not well established in Maharashtra, including within the Jalgaon City Municipal Corporation; instead, backyard composting is more commonly practiced. Composting involves the decomposition of organic materials under controlled conditions of temperature, humidity, and pH through an aerobic biological process.

3.2: Challenges in Solid Waste and Pollution Management: The difficulties encountered by waste management departments, particularly in municipal waste and pollution control, are a global phenomenon. This assertion is substantiated by evidence such as the rise in global population, financial constraints, and the scarcity of resources and land, all of which significantly affect the necessity for and the extent of waste minimization within waste management practices. To effectively tackle the backlog in waste services, several issues must be addressed, including: Political commitment; Increasing volumes of waste; Institutional challenges; Financing and fees for waste services; Education and public awareness; Illegal dumping and littering; ; Legislative measures and enforcement; Waste minimization strategies; The involvement of the private sector in waste management services; Data collection and information dissemination; Inefficient collection systems and fleet management; Scavenging activities at landfill; Source separation and Insufficient land for new landfills; Emergence of new waste streams from innovative products and processes.

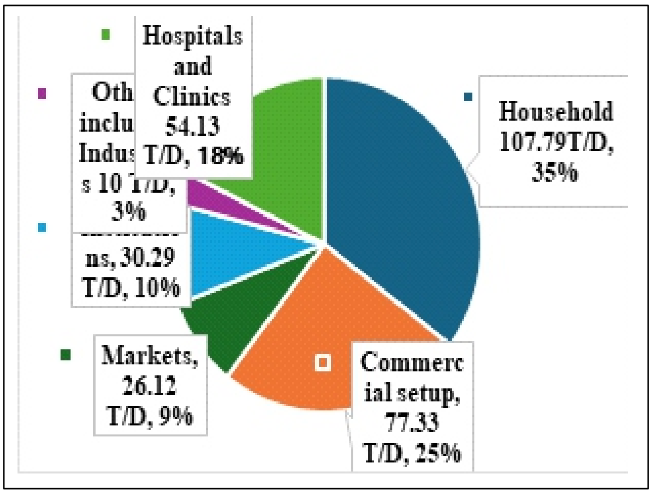
These challenges further amplify the necessity for enhanced environmental management and greater resource protection at an integrated level. Collectively, this demands ongoing innovation in waste management technologies, waste minimization strategies, and resource management to maintain a balance between costs both direct and indirect to society, service providers, and environmental impacts, alongside the imperative for sustainable development (Coetzee, 2006). Thus, the challenges confronting the waste sector or department of the state can be succinctly summarized as: Modifying consumption habits to minimize waste production, adjusting behaviors to promote waste segregation at the source, incorporating recycling systems into both current and future waste management frameworks, disassociating economic growth from the environmental consequences of waste, exploring alternative waste treatment methods to lessen reliance on landfill disposal. The volume of solid waste generated has been on the rise due to an increase in population, particularly over the past 15 years.

3.3: Insufficient Funding, Human Resources, and Equipment: Household hazardous waste, such as paint, used batteries, and pesticide containers, is not collected separately. Plastic waste, particularly thin plastics used for packaging and PET bottles, has become a significant challenge in waste management across nearly all areas of the Jalgaon City Municipal Corporation, Jalgaon.

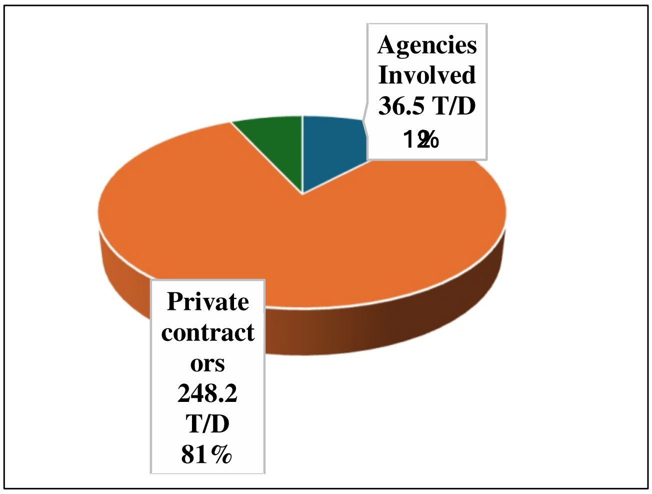
In many developing countries, regulations have been established or are being formulated. Nonetheless, there is a pressing need for stringent controls and enforcement mechanisms to ensure effective implementation (Sonawane and Thorat, 2010).



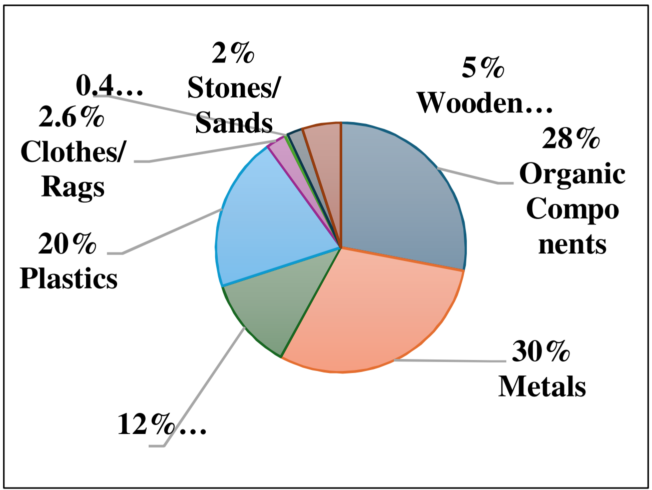
Graph 1: Detailed Map of Jalgaon City Municipal Corporation, Jalgaon.



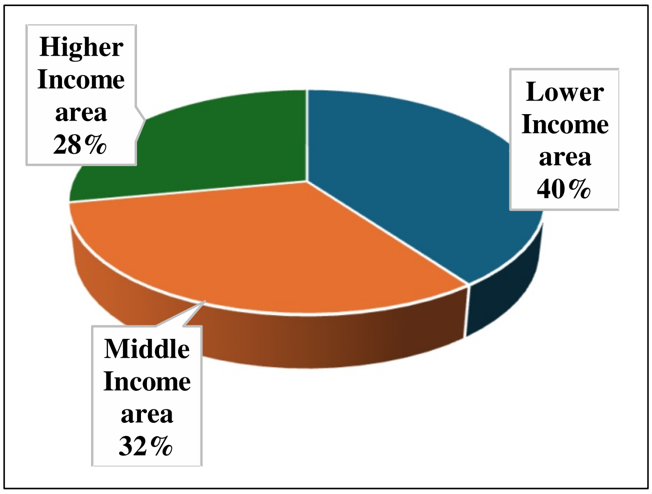
Graph 2: Solid Waste Generation in (JCMC) Jalgaon City Municipal Corporation, Jalgaon.



Graph 3: Waste Collection and Disposal by Ministry of Environment and Urban Development.



Graph 4: Composition of Municipal Solid Waste in Jalgaon City Using Quartering Method of 1kg.



Graph 5: Solid waste generation percentage at Jalgaon City (JCMC) Area.

The Jalgaon City Municipal Corporation, Jalgaon also contends with legal requirements concerning environmental matters, particularly in solid waste management (Moghadam et al., 2008). The operational efficiency of solid waste management relies heavily on the active involvement of both the municipal agency and the community. Given the low social regard for solid waste management in many developing nations, there is a pressing need for increased awareness. Therefore, there is a pressing need for significant apathy towards the issue, as evidenced by the accumulation of uncollected waste in numerous locations and the decline in both aesthetic and environmental standards at uncontrolled disposal sites (Shekdar and Tanaka, 2004). Fortunately, public engagement in Maharashtra, particularly concerning municipal solid waste, has seen improvements over the past decade due to the efforts of NGOs and media involvement.

CONCLUSION

The rise in solid waste production within the metropolis can primarily be attributed to population growth and various commercial and industrial activities. The recorded generation rate of 0.34 kg/capita/day is nearly equivalent to the 0.39 kg/capita/day reported by Kaseva and Gupta (1996) and falls within the range of 0.4-0.6 kg/capita/day for developing nations as noted by Smith (1997). An analysis of waste management by the Jalgaon City Municipal Corporation indicates a significant enhancement in solid waste collection efforts over the last ten years. This improvement is largely due to the active participation of government agencies and citizens in the waste collection process within the metropolis. However, the primary obstacles to effective municipal solid waste management include a lack of resources, inadequate infrastructure, insufficient planning, leadership deficits, and low

Sheet 1: Pictures showing present scenario of Jalgaon City Municipal Corporation (JCMC), Jalgaon area.

Figure 1: Picture of a dumpsite at Jalgaon city municipal corporation (JCMC) area; figure 2: Dumpsite along Jalgaon city municipal corporation main road; figure 3: Chandu annanagar dumping site; figure 4: Dumping site solid waste segregation building; figure 5: Samta nagar road Jalgaon.; figure 6: 100 feet shiv-colony road, Jalgaon.; figure 7: Krushna marble store road Jalgaon; figure 8: Dumping ground in Chandu anna nagar, Jalgaon; figure 9: Hari-Vithal nagar, shiv-colony Chau fully Jalgaon.; figure 10: Wagh nagar stop area, Jalgaon.

public awareness. In light of the study's findings, the following recommendations are proposed to effectively address the current challenges faced by the Jalgaon Municipal Corporation (JCMC) in managing municipal solid waste: The establishment of enclosed community depots or secondary collection centers in remote locations, the encouragement of recycling and composting programs, the formulation of appropriate policies, legal frameworks, and financial management strategies for municipal waste management, the execution of landfill liners, leachate collection systems, roll-on/roll-off control systems, final covers, groundwater monitoring systems, and gas collection systems, as well as the proper fencing of waste. The government should embrace innovative methods for waste collection and disposal, such as Waste-to-Wealth or Trash-to-Treasure, which are collectively referred to as Integrated Solid Waste Management (ISWM).

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EFFECT OF NAPTHA CONTAMINATION ON THYRIOD AND CORPUSCLES OF STANNIUS HISTOLOGY OF *HETEROPNEUSTES FOSSILIS*

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ABSTRACT

Naptha are comprised of normal, ISO cycloparaffins and aromatic hydrocarbon C_4 to C_{12} for H. fossilis LC50 value found to be 23.24 PPM for Naptha and mature fish were exposed for 4 weeks to LD50 value to find out prime changes in Histology of thyroid and corpuscles of stannius. The basic principal of toxicology is that a compound seek entry into the body of an animals, it is corporate into blood and ones it has reached. The circulatory stream through out the body and easily transcend through the plasma membrane the variation of the Thyroid follicles regarding their staining was possible a result of highly effected activity of thyroid but the occurrence of variation all the follicle were effected. Behaviour of thyroidal epithelium was unifor initial stage and appeared as not much district thyroidal follicles started secretion the colloid the development of the vascular at the colloidal mass, the corporates of stannius observed the renal vasculature much filled up with the blood indicating an extra ordinary rise in renal blood supply. The cells were shrunken clumbed loss of staining properties loss of cytoplasmic contents nuclei are more prominent their in early case of female. Naptha toxicity was indicating to be leas effected on male then in female.

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Keywords: Fishes, corpuscles of stannius thyroid, Naptha.

INTRODUCTION

Extremely high level exposure to gasoline kerosene vapour which are primary mix of aromatic hydrocarbons as well as aromatic variety of branched and unsaturated Naptha which is petroleum product has after been referred to as mixture of kerosene and gasoline. It has fair changes of being discharged into the fresh water bodies which are an important resource of fisheries diseases. Roubal et al. (1977) Verma et al. (1975).

In H. fossilis the thyroid gland (follicles) is scattered in a group ground the ventral aorta and its efferent branches and thus its belong to the intermediate stages in between compact type and scartted type. In *H.fossilis* hypofunction of thyroid during not breeding periods. Oliveria et al,(2011): Fish thyroid and stress responses Mishra et al. (2002), Toxicity and behaviour responses in catfish. Khan, M. (2025) effect of sub lethal concentration in cat fish.

Zatshi (2005) studies of pituitary and testis under the fenthion toxicant during breeding session in Hammer fish. The younger follicles are more dominant than the older ones the thickness of thyroidal epethelium wall proceeding from a flat to the cuboidal phase.

The sexes in this fish are widely distributed and also in the kidney ranging from anterior to posterior ends. The maximum corpuscles of stannius was mostly restricted to the middle of kidney and some types extended for back as ureter. It has been common several corpuscles of stannius young various location and the dorsal and ventral side of fully partially

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embedded and lateral margins of kidney the toxicological effect of Naptha on corpuscles of stannius was largely damaged like cells cords was protein mostly were swollen most have not seen fine grain. Basophilia aggregation was noticed the cords of corpuscles cells were damaged at the ventral area of corpuscles.

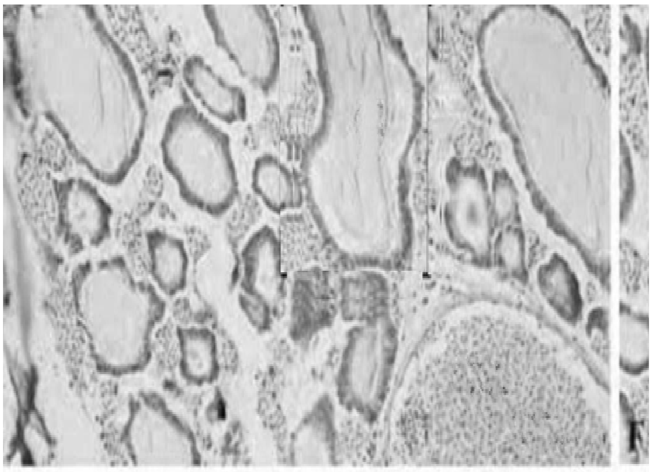
More paper published indicated highly morality of juvenile fish Pradhan and Hota (1993). *H. fossilis* in a carnivorous fish in order cypriniformas. The accessory respiratory organ for which is quite hard and is usually in muddy water. It grow in the estuarine water Srivastava (1968). Fish is an Omega -3 fatty acid and rich of protein and various minerals that the men need to stay meal. However potentially dangerous toxicant are observed into the body tissue of fish transferred to human being when the take fish in their diet. Fish has great economically value in their direct or indirect pathway of toxicant. The present histopathological work carried out response of thyroid and corpuscles of stannius (endocrine gland) system to their Naptha and the species used as model is Heteropneustes fossilis.

MATERIAL & METHOD

Live and mature specimens of both sexes of the fish H. fossilis were obtained from the local fish market and put for the acclimatization for duration of 4 weeks the animal fed only boiled egg albumin and kept in well aerated glass and bath in 1% of $KMNO_4$ solution the size of glass Aquaria was 75x75x18 cm that contained in the laboratory at the water ambient long 262^{0}C at the water in period value of water PH=7.1 both group of male and female were selected for the experiment evolving exposed to LC_{50} value found to for Naptha and completed the exposure the fishes were anesthetized to MS 222 (0.01%) or fromanaldehyde (1.5%) solution and such specimens were dissected and to take out the organs such as corpuscles of stannius (Kidney) thyroid (jaw) which were in 10% naturals formalin or bouins fluid solutions cell at 4.7 mm thickness the paraffin section of (Kidney) corpuscles of stannius and thyroid were stains the Harish Haemotoxyline eosin, OFG Durey et. at. (1987).

HISTOPATHOLOGY OF THYROID

Thomas Addison is father of Endocrinology. It is messenger system of hormones released by internal gland direct connect into blood circulatory system hypothalmus is the mural control centre for all end ovine system the Thyroid gland and its associated endovins hormones is growing area of regulatory toxicant due to the important role of metabolism low potential for thyroid hormone affect from exposure to Naptha stream, especially where the aromatic content is low regulatory studies for most chemical do not inducts.

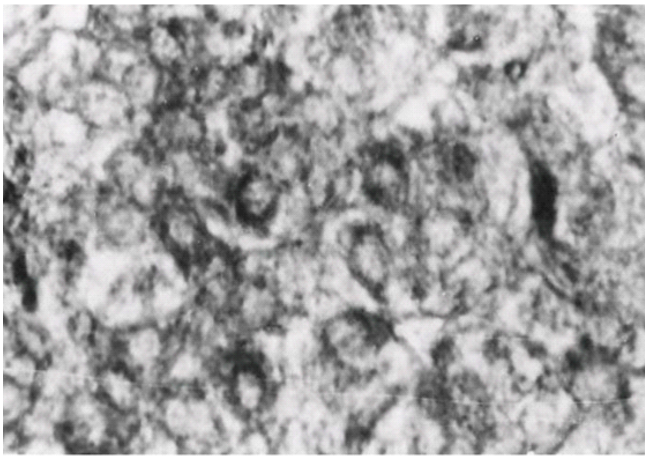


T.S. of Fish Thyroid under the exposure of Naptha 100X.

In H. fossilis the thyroid gland is scattered in a patches around the ventral arota and afferent branches it belonged intermediate stage in between compact type and scattered type. Through very small numbers of follicle gene rare not exceeding that follicles enclosing the colloid of highly variable histochemical nature were record. Some of the appeared that reabsorption vacuoles which actually they were not close to closer examination revealed. That on the colloidal mass of such follicles were only patches of different standings some time producing a short mosic vision suggested that due to coming colloid as was caused by outgoing quanta the thyroid has been given an department place for the purpose of judgement of the toxicological interference Chung et al. (2019). Sexes specific effect hormones and their function. Simon, J. (1944) comparative anatomy of the gland. Giles et al. (1968) effect of hyper and hypocalcemia in the thyroid calcitonin. Haya (1989) toxicity of parathyroid in fishes the colloid was vacoulated but in the both case epithelium remained flat, these vacuoles were close to epithelial liaing and most of the follicles were stained uses the orange, G.

HISTOPATHOLOGY OF CORPUSCLES OF STANNIUS (CS)

The C.S. of fish are widely distributed on and also in the kidney ranging from anterior to posterior ends the large concentration of the C.S. was usually restricted to middle kidney.



T.S. of Fish Corpuscles of Stannius under the exposure of Naptha 100X.

The toxicant effect on kidney the renal vasculature was too much filled up with the blood i.e. indicating an extra ordinary rise in the orenal blood supply implicating to the fact of the rise blood pressure many of blood vessels had come in usually thick, Swaroop et al. (1980) responses of calcitonin cells administrate, the cells were shurken to that extent that instead of appearing as normal chords at time there was sufficient loss of staining property and such features mean the loss of cytoplasmic content as possible for such strong concentration cell and places the cell cord were broken the C.S. in these moles had a weak and reduced fibrous covering and weak staining of nucleus of their corpuscular cells were more prominent their in earlier case of female i.e. is toxicity of Naptha was indicating to be less effective on male then in female. Nand Karni et al. (1966) structure of C.S. in normal and Thyroparathyroidectomized.

DISCUSSION

All vertebrates and invertebrates perform all of teristrial ones respire acirially and so the aquatic concentrate that it has live an water to respire through water excrete in water which head to peculiar situation of being contacted with chemicals which contaminate the only medium being used and inhabited by the fish both physically and physiologically for the such reason H. fossilis was selected for the present study because the under present experiment Nand Karni et al. (1966), Tiwari (1993) endocrinal regulation Correa et al. (2021) occurrence of contaminates. If there were clear cuts chances of double exposure the complete influences of the toxicant could be noticed as the responses of different organs system in present course for the H. fossilis. Stagant water Ram et al. (1983) effect of Mercuric chloride in reproductive cycle in teleost fish Green Wood et al. (2002) coted the corpuscles of stannius is calcium sensing receptors. The basic principal of toxicology is that one compound seek entry into the body of an animal. It is containely in corporated into the blood and ones it has reached the circulatory stream. It circulate through out body as per general rate that compound have higher affinity with lipids through the plasma membranes as well as the Naptha compound easily get a transfer from blood to the tissue they cannot remain with in blood also for the reason that a opposed to blood proteins tissue. Like brain which are such in phospholipids can be larger entry. It has been noticed to during hypophitic substances as Naptha induced enlargement of mitochondria both in liver and other tissue.

The variation of the thyroid follicles regarding their staining was highly effected activity of thyroid for the reason of all the follicles were effected. Follicle of thyroid have responded in different way behaviour of thyroid follicles epethelium started secretion the colloids the development of the vascular very appeared at the periphery of the colloidal mass.

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