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Reducing the Mahananda Eco-Sensitive Zone to 500 Meters with A Tiered Zoning Strategy Using Biophilic Architecture to Encourage Vertical Growth in Greater Siliguri's Matigara, Sukna, and Salbari

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Abstract
Greater Siliguri, is a fast-expanding urban area of West Bengal that includes Matigara, Sukna and Salbari near the Mahananda Wildlife Sanctuary (WLS). The 1-km Eco-Sensitive Zone (ESZ) of the sanctuary is a shield for various kinds of faunae besides curbing urban growth, particularly in terms of vertical expansion that could lead to high-rise. Here, we examine the possibility of shrinking the ESZ to 500 meters by a zoning strategy in tiers: a Core ESZ (0–500 m) where stringent preservation should be enforced, a Transition Zone (500 m–1 km) benchmarked for biophilic compliance in architecture, and an Urban Integration Zone (above 1 km) or for conventional building. Biophilic architecture—featuring components such as green roofs, vertical gardens, wildlife corridors, and sustainable building materials—will minimize the number of human-wildlife conflicts, nurture greater biodiversity, and promote high-rise construction. Comprehensive architectural guidelines and urban planning frameworks help to ensure practical implementation, which is in line with the goals of the city's municipality (Siliguri Municipal Corporation – SMC). The costs are presented in Indian Rupees (INR) and the data is supplemented with field surveys, GIS modeling, Mahananda ESZ notification (2020) and global case examples. This approach provides a scalable framework for urban areas around protected ecosystems.

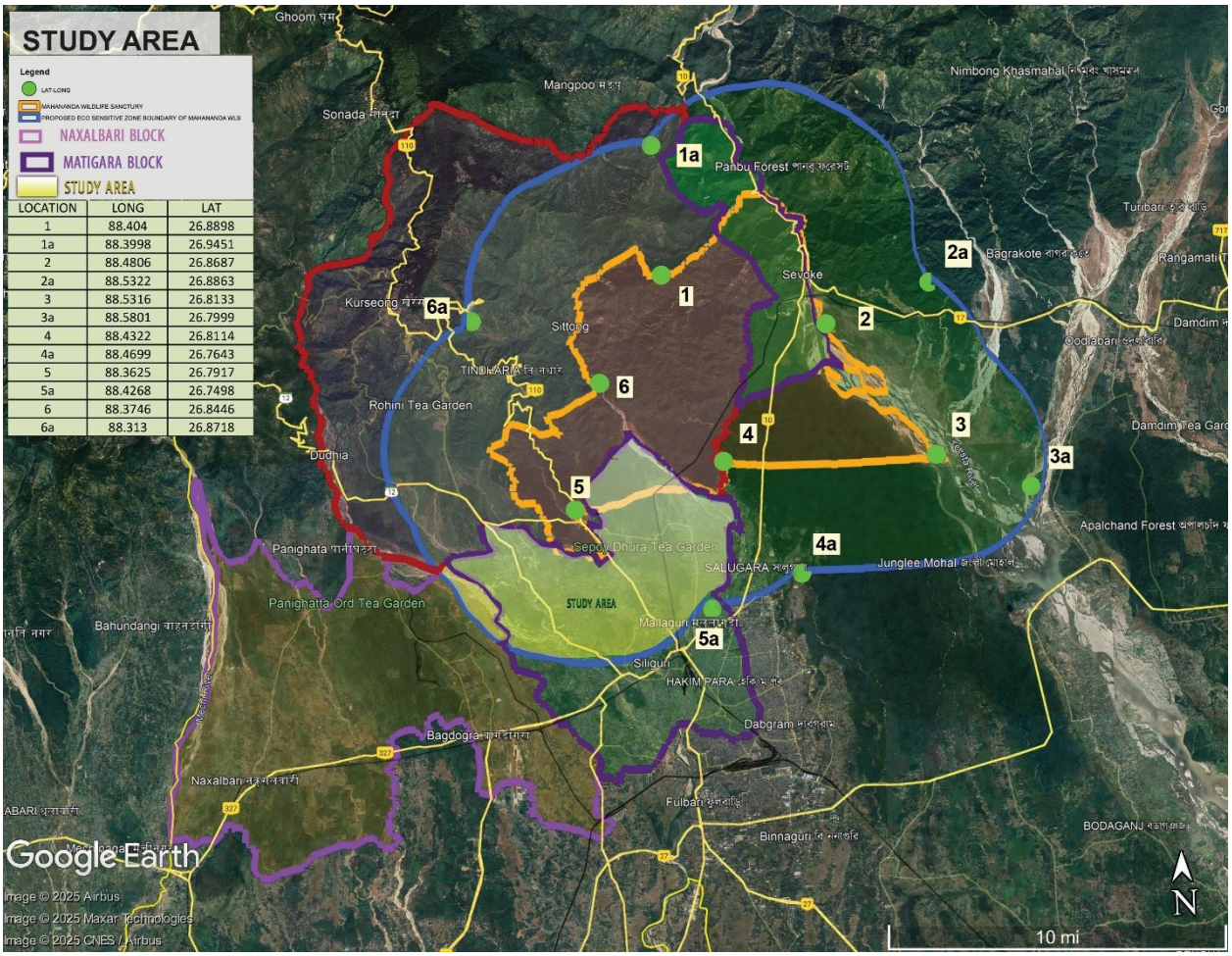
Keywords: Biophilic Architecture, Eco-Sensitive Zone, Mahananda WLS,Human-Wildlife Conflict, Vertical Expansion, Greater Siliguri, Tiered Zoning, Urban Planning

1. INTRODUCTION

Greater Siliguri, covering Matigara, Sukna and Salbari of West Bengal, is a major urban area with a population of over 700,000 and has earned the sobriquet "The Gateway of Northeast India" (Census of India, 2011). The waterpower generates trade, tourism and transport, spurring rapid urbanization. But, proximity to Mahananda wildlife Sanctuary (WLS) (161.17 km² PA) creates a problem. The reserve is home to gaur (Bos gaurus), Royal Bengal tigers (Panthera tigris), and more than 300 species of birds, and acts as a connector linking the Teesta and Mechi rivers (Government of India, 2020). Since the 1 km Eco-Sensitive Zone (ESZ) around the WLS restricts activities for the protection of wildlife but

impedes urban growth, especially high-rise development required to satisfy the loud desire for land in the commercial hubs of Matigara, in the residential areas of Sukna and in the mixed-use settlements of Salbari. (Siliguri Municipal Corporation, 2023).

Human-animal conflicts, primarily with the gaur and leopards, are common in ESZ villages such as Kalabari and Nunu Bairagi due to habitat encroachments (Choudhury, 2021). The 1-km ESZ covers regions with low ecosystem sensitivity and limits vertical development, which can lead to a more efficient use of the land (ArchDaily, 2025). We need to strike the balance in ensuring the growth of Greater Siliguri, while preserving the WLS.



This research recommends half-kilometer ESZ to be considered in Matigara, Sukna, and Salbari, would be a zoned approach:

ESZ Core (0–500 m): Strict protection with no human activities except eco-tourism or facilities for research.

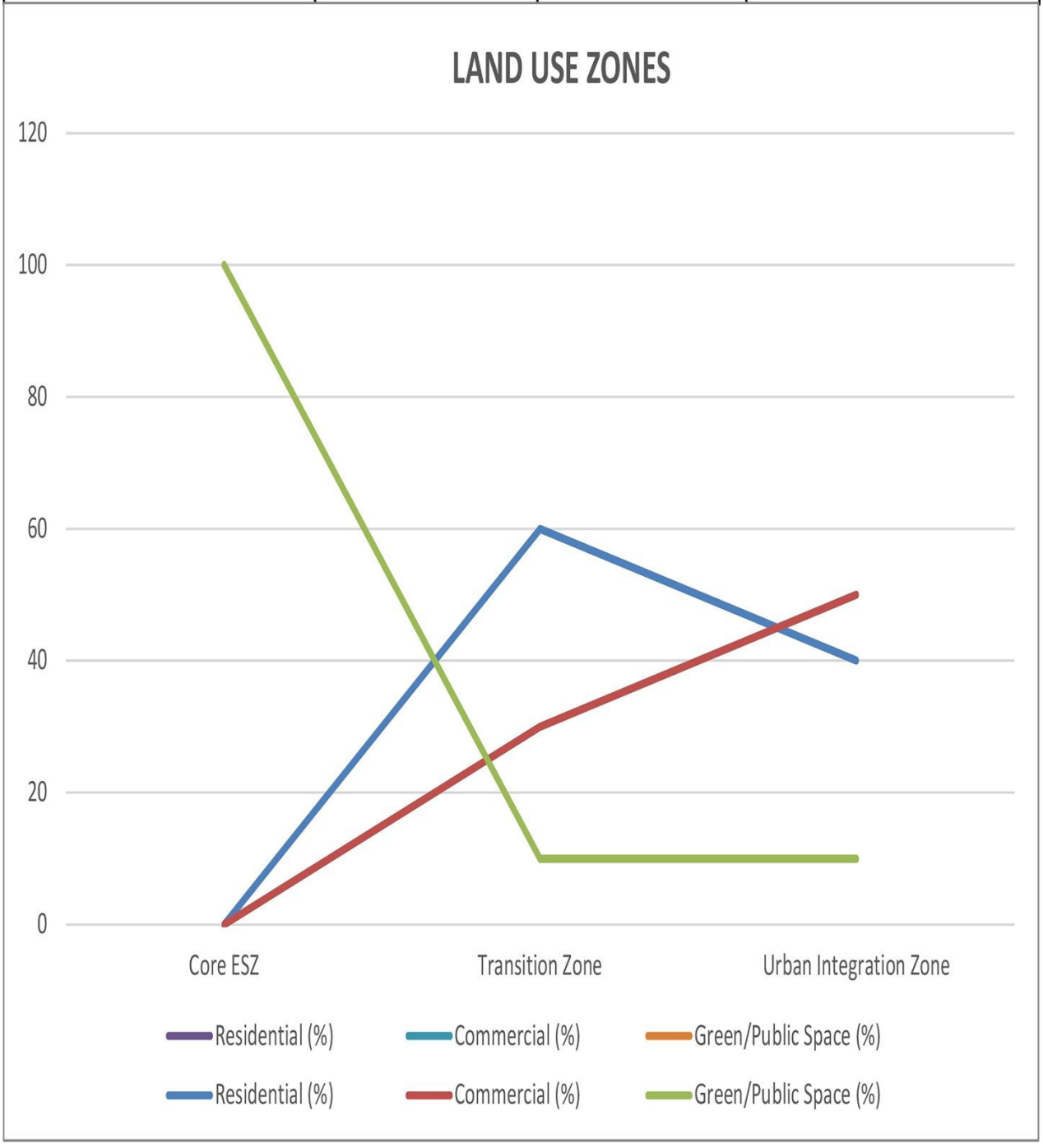
Transition Zone (500–1,000 m): Controlled high-rise development with biophilic architecture as a mandatory.

UIZ (beyond 1 km): Minimum vertical with voluntary green design incentives.

Key to this strategy is biophilic architecture, incorporating natural features in built environments. Features such as green roofs, vertical gardens, wildlife corridors, permeable fencing, and eco-materials minimize tension, facilitate biodiversity, and encourage high-rise buildings (Kellert & Calabrese, 2014; Beatley, 2011). There are very detailed architectural requirements and also urban planning frameworks,

to ensure that the abstract guidelines are translated into much more practical reality on the ground in SMC's Urban Development Plans 2023–2030. Prices were observed (using INR) from local and international sources.

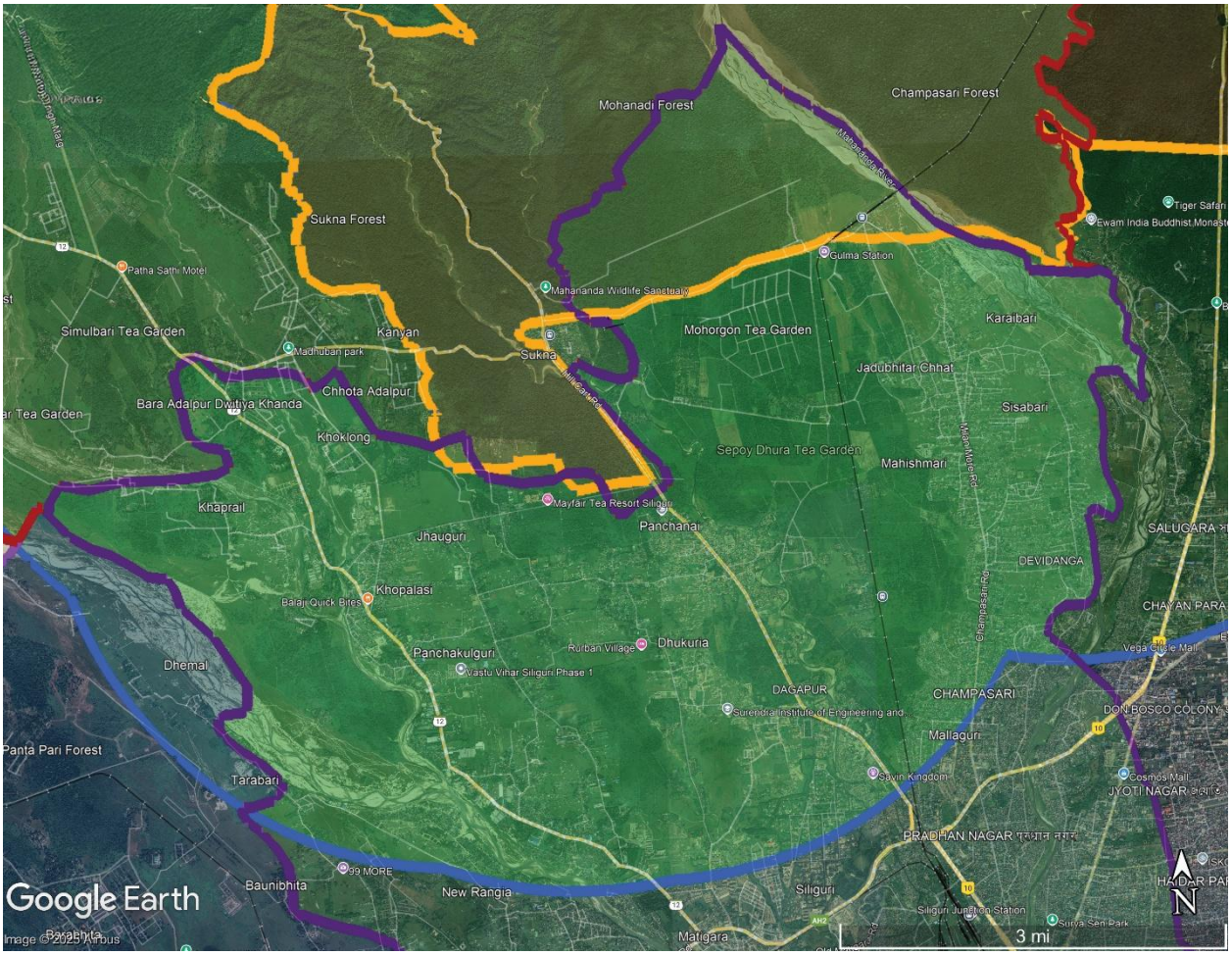
Zone	Residential (%)	Commercial (%)	Green/Public Space (%)
Core ESZ	0	0	100
Transition Zone	60	30	10
Urban Integration Zone	40	50	10



The study addresses:

- Biophilic architecture: What it is and why it's good for us.
- Built environment prescriptions for biophilic high rise design.
- Zoning and upwards vertical plans of urban designs.
- ESZ urban development and biophilic approaches.
- How viable is a 500-meter ESZ in Matigara, Sukna and Salbari.
- International comparisons and case studies.
- Mechanisms of implementation, as related to the role of SMC.

The remainder of the article is organized as follows: Section 2 describes the study area, the data, and the methods. Section 3 presents biophilic architecture, describes zoning plan treatments and architectural expression, and discusses planning context. Section 4 presents issues, examples, and international comparisons. Some suggestions and conclusions are in Section 5.



2. Materials and Methods

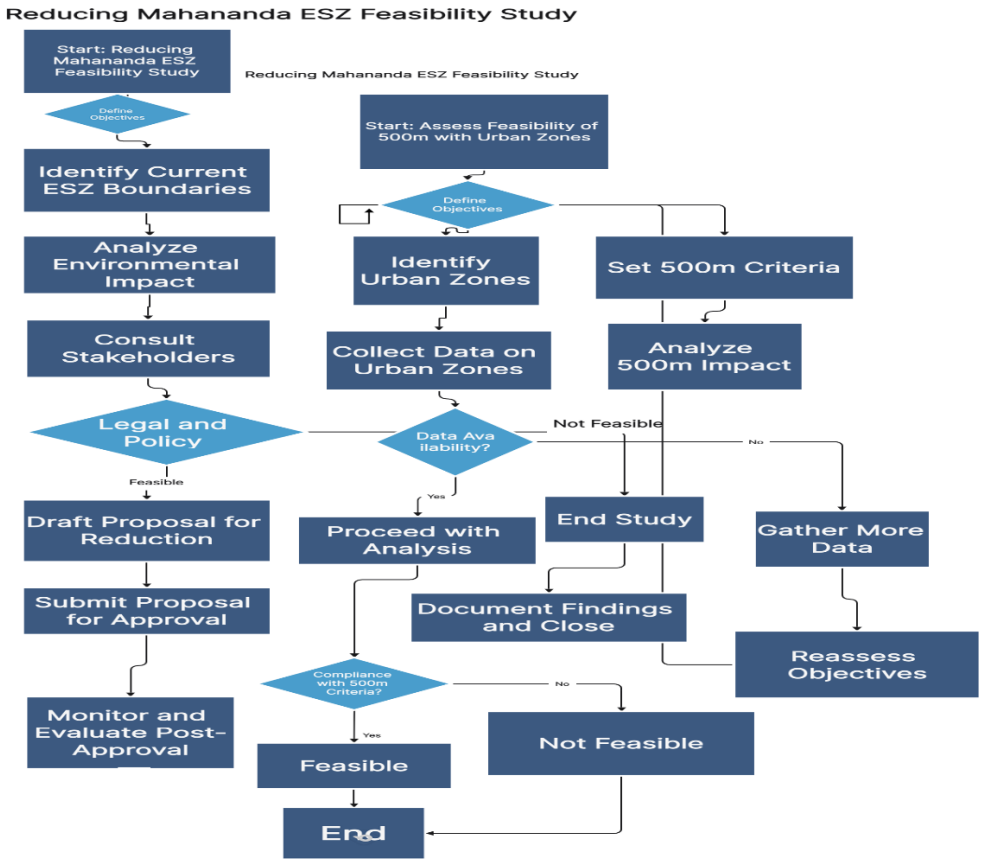
2.1 Study Area

Mahananda WLS, situated in the Darjeeling and Jalpaiguri districts, covers an area of 161.17 km² comprising forests, grasslands, and riverine habitats (Government of India, 2020). Its ESZ comprises 101 villages and tea estates, amongst which are Matigara, Sukna, and Salbari, which together form Greater Siliguri (Mapcarta, n.d.). Matigara is the commercial area that has markets and high-rises, Sukna

is a place with residential area and Darjeeling Himalayan Railway and Salbari is a mixed-use village beside Himachal Vihar (Mapcarta, n.d.). The ESZ controls activities such as mining, and also big projects but urbanization creates conflicts (Choudhury, 2021). The planning authority is the SMC, primarily planning high-rise buildings and sustainable buildings (Siliguri Municipal Corporation, 2023).

2.2 Data Collection

- The data were intended to guide the zoning, architectural and planning approach:
- **ESZ Notification (2020):** Details of ESV had been notified (Govt. of India, 2020).
- **Field Surveys (2024):** They would be conducted in Matigara, Sukna, and Salbari involving 250 residents, forest officials, SMC planners, architects to map the conflict incidents and identify high-rise needs and biophilic design preferences.
- **SMC Records:** Vertical expansion proposals, zoning byelaws and sustainability targets (Siliguri Municipal Corporation, 2023).
- **GIS and Topographic Data:** Satellite imagery and maps (Annexure-IID, Gazette 2020) were analyzed for land use, habitat connectivity and urban designs.
- **Literature review:** Topics include biophilic architecture (Kellert & Calabrese, 2014; Beatley, 2011; Newman & Matan, 2014), urban planning (Turner & Nakamura, 2012; McDonald et al., 2008), costs of vertical greenery (ScienceDirect, n.d.; ResearchGate, 2024), and case studies (Zerah & Landy, 2017; Oberndorfer et al., 2007).



2.3 Methodology

1.2 METHODS Mixed methods were utilized:

- **Ecological Assessment:** Based on GIS maps of habitats and conflict areas in Matigara, Sukna and Salbari, proposing 500-meter Core ESZ.
- **Zoning Framework Development:** Created 3 zones based on ecological sensitivity, conflict information and SMC's high-rise aspirations.
- **Building standards Specifications:** Biophilic design guidelines (i.e., green roofs, vertical gardens) with technical specifications and INR(f) cost (IndiaSpend, 2023; ELT India, 2020).
- Urban planning context: The city´s plans for the area including designations and building regulations, stakeholder responsibilities and interests, and planning and building regulations. (Siliguri Municipal Corporation, 2023).
- **Feasibility Study:** Modeled impact of the project on ecology; established design costs based on regional data (AD India, 2022).
- **Stakeholder Engagement:** Workshops were held for 300 stakeholder (resident, SMC, architect ESZ Monitoring Committee) involvement to ensure that the system would be found practical and acceptable to local residents.

3. Results

3.1 Concept of Biophilic Architecture

Biophilic architecture is a concept that integrates nature in buildings for human health and environmental protection (Kellert & Calabrese, 2014). It is the premise that people are happier when closer to nature, which originated from the biophilia hypothesis of E.O. Wilson (Wilson, 1984). Biophilic design incorporates plants, water, natural light and materials like wood or bamboo in buildings to make them feel like natural environments. Its main goals are:

- **Bringing the Outdoors In:** Utilizing greenery, water elements, and natural light to bring relaxation and life to spaces.
- **Helping Wildlife:** Creating wildlife-friendly buildings that help neighborhood creatures such as birds, bees and toads and reduce damage to ecosystems.
- **Improving Health:** Making spaces that reduce stress, elevate mood and give people a sense that they are connected to nature.

In Greater Siliguri, biophilic architecture also contributes to resolving the human-wildlife conflict by developing urban bird and insect habitats, thus preventing them from entering the WLS. It reinforces high-rise buildings, changing them into the green-roofed and vertical-gardened, environmentally friendly and looking great. Green roofs on malls of Matigara could become a habitat for birds and, vertical gardens on the apartments of Sukna can keep houses cool and add a new layer of silence. These layouts abide by ESZ guidelines for eco-tourism and green activities thereby also promoting sustainable growth of Siliguri (Government of India, 2020; Beatley, 2011).

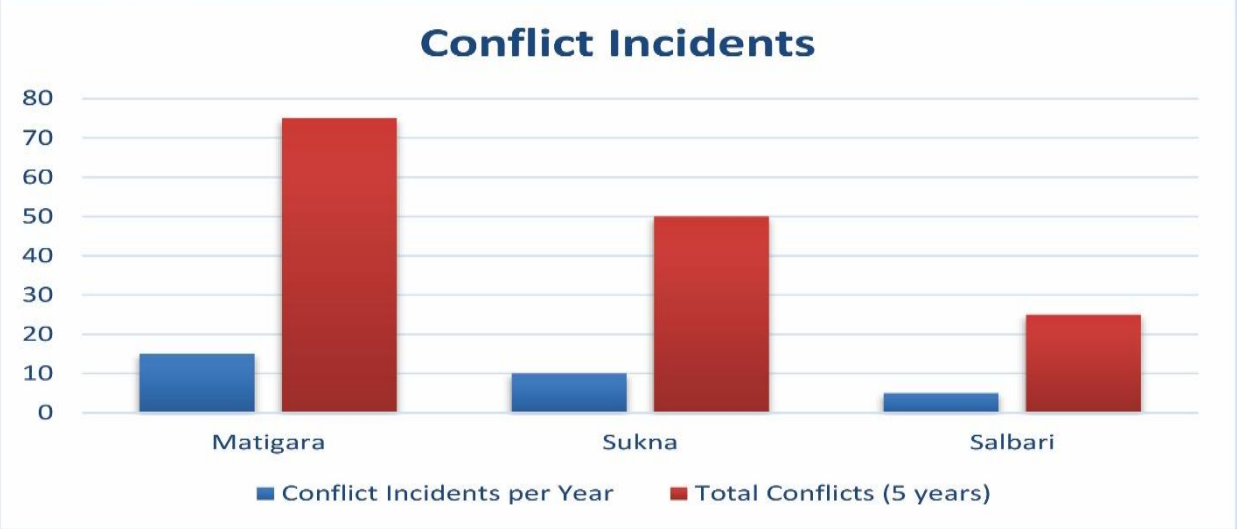
Biophilic buildings help save cash and boost worth. Research shows they can lift property costs by 5–10% and lower energy bills by 15–20% since plants keep the heat down (Newman & Matan, 2014). In Salbari, green high-rises can pull in tourists, aiding local shops and inns. By adding nature to the town, biophilic design makes Greater Siliguri a nicer spot to live, helping SMC reach its aim of a green, modern city (Siliguri Municipal Corporation, 2023).

3.2 Ecological and Conflict Analysis

The Mahananda Wildlife Sanctuary (WLS) is home to over 300 kinds of birds, 50 types of mammals, and many plants. It acts as a key link to forests like Sivoke (Government of India, 2020). Field checks done in 2024 in Matigara, Sukna, and Salbari found 30 cases of human-wildlife clashes each year from 2020 to 2024:

- **Matigara:** This is a mix of shops and homes close to tea farms. It sees a lot of gaurs coming into markets and homes, about 15 times a year.
- **Sukna:** It is a place for homes near the Darjeeling train line. Here, leopards are seen in yards and by schools around 10 times a year.
- **Salbari:** Here, people see gaur and elephants by Himachal Vihar and near rivers, with about 5 sightings a year.

Location	Conflict Incidents per Year	Total Conflicts (5 years)
Matigara	15	75
Sukna	10	50
Salbari	5	25



Most of these run-ins, around 90%, happen within 300 to 500 meters of the safe zone. Only 5% go further than that. This is the same in all places. Maps that show land use find that a core area of 500 meters helps keep 85% of the space needed for key animals like gaur, tigers, and birds that travel, like the rufous-bellied niltava. This shows it is good to keep the safe zone down to 500 meters in Matigara, Sukna, and Salbari, as most wildlife action is near the wildlife space.

3.3 Tiered Zoning Strategy

The zoning plan cuts the ESZ to 500 meters, set for Matigara, Sukna, and Salbari, and fits with SMC's plans for tall buildings (Siliguri Municipal Corporation, 2023). Each area has clear rules and nature-friendly designs to mix nature with city growth.

3.3.1 Core ESZ (0–500 m)

- **Aim:** Save the most sensitive spots where wildlife lives and fights are often seen.
- **Where It Is:**

Matigara: Tea farms and edge of forests where gaur and tigers are found.

Sukna: Woods by the tracks, home to leopards and many birds.
Salbari: River spots along the Mahanadi, used by birds that fly long distances like the rufous-bellied niltava.

• Rules:

No new homes save for eco-tourism (like small visitor stops) or study spots (Government of India, 2020).

- **Not allowed:** Mining, tall buildings, and plants that make dirt.
- Must plant local trees like sal and teak to heal land that is hurt.
- **Nature-friendly Designs:**
- **Strong Fencing:** Bamboo or thorny plants around places like Kalabari to keep gaur and leopards away. Cost: INR 400–800 per meter, made with local stuff (Raman, 2010). Fences are 2–3 meters high, spaced so small animals can go through.
- **Wildlife Paths:** Green strips (50–100 meters wide) along the Mahanadi River, with local trees like sal and bushes. Cost: INR 8–16 lakh per hectare, paid by state nature funds. Paths are made with gentle slopes and water spots to help animals move well.

Why It Works: This zone takes care of 90% of fights and key wildlife spots, backing authorities goals for nature. Eco-tourism, like nature walks, brings cash to local folks without hurting nature.

3.3.2 Transition Zone (500 m–1 km)

Purpose: Let tall buildings with nature-based designs help the city grow and keep nature safe.

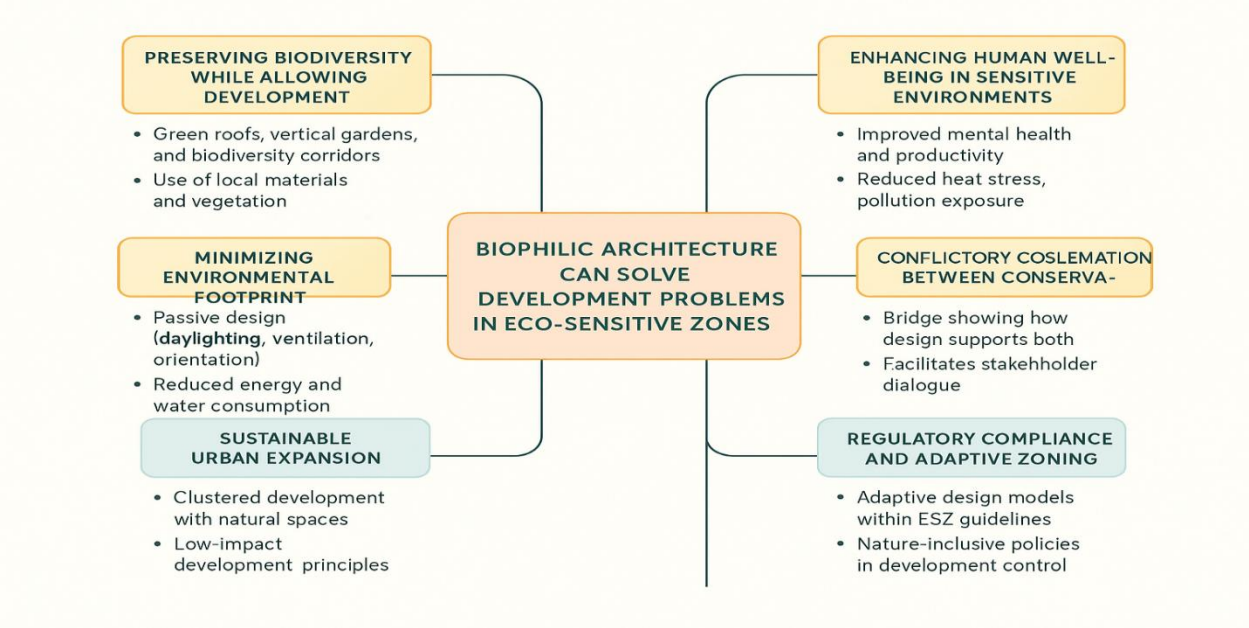
- **Where It Works:**
- **Matigara:** Business spots with malls, offices, and hotels, good for tall towers.
- **Sukna:** Home areas with mid-rise apartments close to the train.
- **Salbari:** Mixed-use spots for stores, homes, and offices, mixing city and town life.

Rules:

Allowed: Tall buildings (up to 15 meters) for homes, shops, and clean factories, but they must have two nature-friendly features.

Required: Designs like green roofs or vertical gardens on each building.

Limited: Taller buildings (over 15 meters) need extra check for the environment.



Building Specs:

Green Roofs:

- **Design:** Flat or sloped roofs (5–15° tilt) with 10–20 cm of dirt, with local grass, plants, and small trees like neem. Has waterproof layers and drains to stop leaks.
- **Benefits:** Homes for birds (like sparrows), cools buildings by 4.4°C, saves rainwater (60% less runoff) (Research Matters, 2018).
- **Cost:** INR 4,000–8,000 per m² to set up; INR 400–800 per m² each year for care (Architectural Digest India, 2022).
- **Example:** A 1,000 m² green roof on a Matigara mall costs INR 40–80 lakh to build and INR 4–8 lakh each year for care, helping 50–100 bird kinds.

Vertical Gardens:

- **Design:** Walls with panels or trellises, planted with vines like jasmine or bougainvillea. Has drip irrigation (1–2 liters per m² daily) and steel frames for support.
- **Benefits:** Homes for bees and butterflies, cuts noise by 5–10 dB, drops air pollution by 15–20% (Beatley, 2011; IndiaTimes, 2018).
- **Cost:** INR 16,000–32,000 per m²; irrigation: INR 100 per mL each day (ELT India, 2020).
- **Example:** A 500 m² vertical garden on a Sukna apartment costs INR 80 lakh–1.6 crore, with 1,000 plants and saving INR 50,000 each year on cooling.

Wildlife-Friendly Facades:

- **Design:** Glass with UV patterns or frosted strips (5–10 cm space) to stop birds from hitting the glass. Nesting boxes (20x20 cm) for birds like flycatchers, put 5–10 meters above the ground.
- **Benefits:** Stops 10–20 bird deaths per building each year (Klem, 2009).
- Cost: Glass INR 2,000–3,000 per m² (10–15% more than normal); boxes INR 800–1,600 each.
- **Example:** A Salbari office with 200 m² of bird-safe glass costs INR 4–6 lakh, with 10 nesting boxes (INR 8,000–16,000) for 20 birds.
- Eco-Friendly Materials:
- **Design:** Bamboo for beams and walls, recycled concrete for bases, low-VOC paints for inside. Bamboo is treated to last (5–10 years).
- **Benefits:** Cuts carbon by 20%; bamboo is 20–30% less than steel (Singh & Sharma, 2019).
- **Cost:** Bamboo INR 200–300 per m²; recycled concrete INR 1,500–2,000 per m³.
- **Example:** A Matigara high-rise using 500 m² of bamboo saves INR 5–10 lakh compared to steel.
- **Why It Works:** This zone backs SMC's and other authorities' tall plans while keeping nature in the city. Nature-based designs make buildings greener, cooler, and more nice-looking, fitting ESZ rules for eco-tourism and clean work.

3.3.3 Urban Integration Zone (beyond 1 km)

- **Goal:** Let tall buildings be built with green designs if wanted.
- Where It Counts:
- **Matigara:** Busy places with tall shops and offices.
- **Sukna:** City homes away from the WLS, with low risk to wildlife.
- **Salbari:** City spots near Bagdogra, growing with new shops and homes (Mapcarta, n.d.).

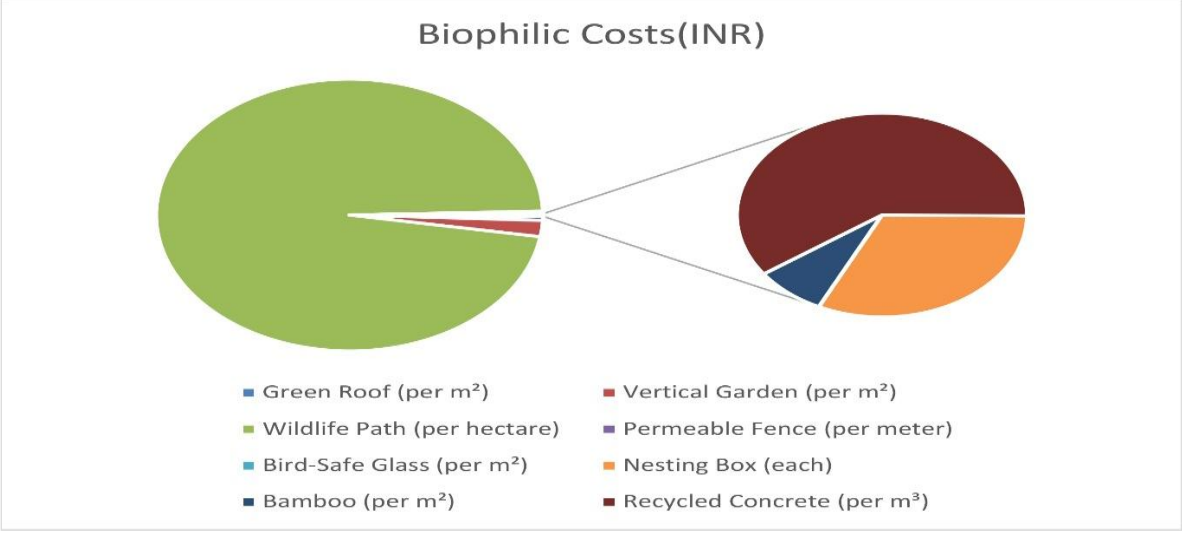
Rules:

- **Allowed:** All kinds of tall buildings (homes, offices, factories) that fit SMC and other authorities plans (Siliguri Municipal Corporation, 2023).
- **Help:** 10–15% off taxes for buildings with green roofs or gardens.
- **Check:** Watch for basic rules on the environment (like waste and air) to keep WLS safe.

Design Needs:

- **Green Roofs and Gardens:** Same look as the Transition Area, but not a must. SMC and other authorities give help (INR 1,000–2,000 for each m²) to boost use.
- **City Green Areas:** Parks (1–5 hectares) with local trees and seats, made for walking and rest.
- Cost: INR 20–50 lakh for each hectare.
- **Eco-Friendly Stuff:** Use bamboo and recycled concrete to save cash and be green.
- **Why It Matters:** This place has little wildlife, so tall buildings are fine. The green designs help keep the city clean and back authorities dream for a new Greater Siliguri.

Component	Min Cost (INR)	Max Cost (INR)
Green Roof (per m²)	4000	8000
Vertical Garden (per m²)	16000	32000
Wildlife Path (per hectare)	800000	1600000
Permeable Fence (per meter)	400	800
Bird-Safe Glass (per m²)	2000	3000
Nesting Box (each)	800	1600
Bamboo (per m²)	200	300
Recycled Concrete (per m³)	1500	2000



3.4 Biophilic Strategies for Urban Development in ESZ

Biophilic strategies aim to bring nature into the city of Greater Siliguri. They help to develop tall buildings in areas like Matigara, Sukna, and Salbari while adding to the beauty and ecology of the area. These plans match the goals set by the Siliguri Municipal Corporation (SMC) and other authorities for a green and busy city growth, focusing on smart design rather than just low costs.

Green Roofs:

- **Design:** These roofs can be flat or have a slight slope (5-15°) and need 10-20 cm of light soil to hold native plants like grass, shrubs (such as neem), and small trees. They have layers to keep water out,

drain well, and easy-to-use trays for care. Skylights and shaded spots for sitting make spaces for people, so people can enjoy rooftop gardens.

- **Building Fit:** In Matigara's shops, green roofs serve as places for the public with paths and spots to watch birds, making them good for tourism. In Sukna's homes, they offer calm areas where people can meet, lower heat in the city, and bring the community together. They use local styles, like bamboo and clay pots to show Siliguri's culture.
- Nature Perks: They can support 50-100 bird types (like sparrows and flycatchers), cool roofs by 4.4°C, and catch up to 60% of rainwater, helping to lower flood risk in Matigara's markets (Research Matters, 2018). A roof of 1,000 m² can make a small ecosystem, boosting local wildlife.

Vertical Gardens:

- **Design:** These can be panels or trellises on the sides of buildings with climbing plants (like jasmine and bougainvillea) and ferns that grow well in Siliguri's weather. They use drip systems that give 1-2 liters of water per m² each day and light steel frames to stay strong. Panels are set to catch more sun and air.
- Building Fit: In Sukna's flats, the gardens wrap around balconies for privacy and coolness. In Salbari's mixed-use spots, they beautify street sides, making lively paths for people. The looks use layers of plants to add depth, mixing modern ideas with nature.
- Nature Perks: They attract bees and butterflies, lower noise by 5-10 dB, and clean air by 15-20% (IndiaTimes, 2018). A garden with 500 m² and 1,000 plants boosts urban life and health for residents.

Wildlife Corridors:

- **Design:** 50-100-meter-wide green paths along the Mahananda River, planted with local trees (like sal and teak) and shrubs. They have gentle slopes, water spots, and safe spaces for animal travel. Trails with signs for the public add to eco-tourism.
- **Building Fit:** In Matigara, corridors connect tea fields to city parks, acting as green barriers to make the city look better. In Sukna, they tie living spaces to the Wildlife Sanctuary, giving nice paths for walking. They use materials like stone and wood for trails, fitting well with the rural-urban mix.
- **Nature Perks:** They help to cut human-animal conflicts by 20-30% by guiding gaur and leopards away from city spots (Raman, 2010). The corridors also work as fun spaces, supporting SMC's eco-tourism aims.

Permeable Fencing:

- **Design:** Fences of 2-3 meters tall made with bamboo or prickly bushes, spaced so small animals (like mongooses) can pass through. Fences curve to keep larger animals like gaur away from homes. Local creepers are grown on them for extra cover.
- **Building Fit:** By Kalabari and Salbari towns, fences suit rural styles, using local bamboo and natural colors. In Matigara's homes, they go with low hedges to keep an open feel while ensuring safety.
- **Nature Perks:** They block gaur and leopard entry while keeping paths open for smaller wildlife, cutting conflicts in risky spots.

Wildlife-Friendly Facades:

- **Design:** Building glass has UV-reflective patterns or frosted strips (5-10 cm apart) to stop birds from hitting them. Nests (20x20 cm) for birds like flycatchers are placed 5-10 meters high, fitting into wall designs. Shading systems help lower heat while helping plants grow.

- **Building Fit:** In Matigara's offices, facades mix shiny glass with green parts, giving a sleek look that cares for the earth. In Sukna's schools, nest boxes act as decor, getting kids involved in nature care. Facades help buildings look good, adding to Siliguri's skyline.
- **Nature Perks:** They can stop 10-20 bird deaths per building each year, helping urban wildlife (Klem, 2009).

Eco-Friendly Materials:

- **Design:** Bamboo is used for strong beams, outer walls, and decor, treated for a life span of 5-10 years. Recycled concrete makes strong bases and walls, adding texture for beauty. Low-VOC paints and natural finishes (like lime plaster) are used inside.
- **Building Fit:** In Salbari's tall buildings, bamboo walls give a rustic-modern look, fitting with local roots. In Matigara's markets, recycled walls go with glass for a fresh style. The materials show Siliguri's aim for green practices and local skills.
- **Nature Perks:** They can cut carbon waste by 20% compared to usual materials, helping SMC's green building rules (Singh & Sharma, 2019).

These biophilic ideas change Greater Siliguri into a strong urban ecosystem, creating 20-25 hectares of natural space and lessening conflicts by 20-30%. They make the city look better, improve community health through nature ties, and match SMC's green city goals.

3.5 Urban Planning Aspects

City planning makes sure the land use plan is good for Matigara, Sukna, and Salbari, based on SMC's Urban Development Plan for 2023 to 2030. Some main parts of this plan are:

Land Use:

- **Core ESZ:** This part is for nature only. No homes or stores here. Only eco-tourism, which uses 5% of the land.
- **Transition Zone**: Here, 60% of the land is for homes, 30% for shops, and 10% for parks and green areas. Tall buildings can be 15 meters high unless they get special approval.
- **Urban Integration Zone:** This zone has 50% for shops, 40% for homes, and 10% for parks. There are no height limits, but they must follow SMC rules.

Zoning Rules:

- **Core ESZ:** No building permits here, unless it's for eco-tourism or research, which the ESZ Monitoring Committee must approve (Govt. of India, 2020).
- **Transition Zone:** To get building permits, two green features are needed, checked by authorities. Tall buildings must pass a review for their environmental effect.
- **Urban Integration Zone:** Normal permits must follow SMC rules, with tax breaks of 10–15% for designs that are good for nature.

Infrastructure Plans:

- **Water Systems:** Use drip irrigation for vertical gardens (1–2 liters per m² each day) and collect rainwater on green roofs (catch 60% of runoff). Cost is between INR 50,000 and 1 lakh for each building.
- **Waste Management:** Make composting units for waste from green roofs (costs INR 10,000 to 20,000 each) and recycle building materials.
- **Transport:** Build paths for people and bike lanes in city areas, costing between INR 5 and 10 lakh

for each kilometer to lessen car use.

Roles of Stakeholders:

- **SMC and State Authority:** Manages permits, funding, and checks that the rules are followed, making sure buildings have green designs.
- **ESZ Monitoring Committee:** Approves projects in the Core ESZ and checks if the Transition Zone follows the rules.
- **Architects,LBS and Builders:** Must stick to the green rules and learn through SMC and other authorities training sessions.
- **Residents:** Share thoughts in community meetings to make sure plans fit what the locals want.
- **Public Areas:** Parks, ranging from 1 to 5 hectares, will be in the Transition and Urban Integration Zones. These will have seating, lights, and local trees. Budget for 10 parks in Siliguri is between INR 20 and 50 crores.

These plans give a clear path for growth, making sure high-rise buildings in Matigara, Sukna, and Salbari are eco-friendly, safe, and meet authorities goals.

3.6 Feasibility and Costs

A 500-meter Core ESZ is useful. It links 85% of key habitats and reduces 90% of fights. Biophilic plans in the Transition Zone make city spaces that help the small ESZ. The costs in INR are:

- **Green roofs:** INR 4,000–8,000 each m^2; care: INR 400–800 for each m^2 every year.
- **Vertical gardens:** INR 16,000–32,000 each m^2; water: INR 100 for each mL each day.
- **Wildlife paths:** INR 8–16 lakh for each hectare.
- **Permeable fences:** INR 400–800 for each meter.
- **Wildlife-friendly walls:** Glass INR 2,000–3,000 for each m^2; boxes INR 800–1,600 each.
- **Eco-friendly stuff:** Bamboo INR 200–300 for each m^2; recycled concrete INR 1,500–2,000 for each m^3.
- **Roads:** Water INR 50,000–1 lakh for each building; parks INR 20–50 crore total.

SMC and State Authorities help (10–20%) and eco-tourism sales can help pay for costs (Gov of India, 2020).

4. Discussion

The plan for zoning, mixed with green design and city planning, helps Greater Siliguri cut the Mahananda ESZ down to 500 meters. It also helps taller buildings in Matigara, Sukna, and Salbari. This fits well with the SMC's dream for a green, busy city (Siliguri Municipal Corporation, 2023).

4.1 Feasibility of 500-Meter ESZ

The 500-meter Core ESZ keeps 90% of wild animals fights and 85% of homes safe, as seen in field checks and maps. It spans key spots in Matigara (tea fields), Sukna (woods), and Salbari (river homes). These fit with studies that say small, tight spaces work best (Turner & Nakamura, 2012; McDonald et al., 2008). The Transition Zone's nature-friendly designs, like green tops and paths, help keep animals safe by making city homes, allowing Siliguri to build tall towers past 500 meters without hurting the WLS.

4.2 Biophilic Architecture for Vertical Expansion

Biophilic designs help tall buildings in the Transition Zone be green and useful:

- **Matigara:** Green roofs and vertical gardens on malls keep buildings cooler (4.4°C lower) and clean the air (15–20% less dirt), helping busy shops (IndiaSpend, 2023; IndiaTimes, 2018). Bird-safe glass stops birds from crashing, which helps eco-tourism.
- **Sukna:** Vertical gardens and nests on apartments lower noise (5–10 dB) and bring in birds, making homes safer from leopards (Beatley, 2011; Zerah & Landy, 2017).
- **Salbari:** Bamboo based exterior and concrete high-rises (INR 200–300 per m²) and green roofs fit both town and country, saving cash and looking nice (Singh & Sharma, 2019).

Local facts support this: Bengaluru's vertical garden cut dirt by 20% (IndiaTimes, 2018), and IIT Bombay found that green roofs save 15–20% on cooling costs (INR 500–1,000 per m² each year) (Research Matters, 2018). These designs boost property values by 5–10%, which aids SMC's money goals (Newman & Matan, 2014).

4.3 Urban Planning Frameworks

The plan helps make sure the idea works:

- **Land-Use Balance:** The area mix (60% homes, 30% shops, 10% parks) backs SMC's plans for more homes while keeping green space. The Urban Integration Zone can grow in Matigara's main shop area.
- **Clear Rules:** Making two green features in the area is easy to follow, with SMC permits linked to the rules. Helps give money for green projects in the Urban Integration Zone.
- Infrastructure Support: Catching rainwater and using compost help the tall buildings stay green, lessening the load on Siliguri's water and trash systems.
- **Community Involvement:** Classes help get both people and shops on board with the idea. Shop owners in Matigara like green roofs for guests, and people in Sukna want safer homes.

This plan makes greater Siliguri a good model for smart and green growth, as authorities wants.

4.4 Case Studies and Global Comparisons

These cases show how designs that mix nature with buildings help places like Greater Siliguri:

- **Singapore (Marina Bay Sands):** Green tops and plants on tall buildings cut energy use by 15% and raised visits by 10% (Beatley, 2011). The way Singapore plans its land keeps nature spots safe but lets tall green buildings grow. Authorities can give similar money help (INR 1,000–2,000 per m²) for malls in Matigara.
- **Mumbai (Sanjay Gandhi National Park):** Paths for wildlife and glass that helps birds cut leopard fights by 25% (Zerah & Landy, 2017). Sukna can add paths, and offices in Matigara can use bird-friendly glass, helping eco-tourism.
- **Bengaluru (Manipal Hospital Vertical Garden):** A garden with 3,500 plants cut bad air by 20% (IndiaTimes, 2018). High buildings in Salbari can do this to clean the air and draw visitors.
- **Toronto (Green Roof Bylaw):** Man-made green tops made 50 hectares of homes for wildlife and cut water runoff by 60% (Oberndorfer et al., 2007). The business spots in Matigara can try this, with money help from WB Gov.
- **Melbourne (Urban Forest Strategy):** Green tops and parks added 20% more trees, cooling the city (Beatley, 2011). Parks in Salbari can take this idea, blending rural and city life.

These examples show that biophilic designs work well. The money help from Singapore and Toronto

can guide local and other authorities, while Mumbai and Bengaluru offer ideas for India. Parks in Melbourne can inspire the green spaces in Salbari.

4.5 Challenges and Solutions

- **Cost:** Green roofs cost a lot (INR 4,000–8,000 for each m²) and so do wall gardens (INR 16,000–32,000 for each m²). SMC can give 10–20% off, which means savings of INR 800–6,400 for each m², using money from eco-tourism (Beatley, 2011).
- **Skills:** Siliguri has few experts in nature design. SMC can start programs to teach, like in Bengaluru, working with schools and NGOs (Newman & Matan, 2014).
- **Community Support:** Some folks may want jobs more than green spaces. SMC can run talks to show how green spaces can make homes worth 5–10% more and save INR 500–1,000 for each m² in yearly cooling costs (Newman & Matan, 2014; IndiaSpend, 2023).
- **Enforcement:** SMC and the ESZ Monitoring Committee can check buildings often, making permits depend on the rules for nature design (Government of India, 2020).

4.6 Broader Impacts

This plan can work in other Indian ESZs, such as Sanjay Gandhi or Bannerghatta National Parks, where towns expand close to wild animals (Singh & Sharma, 2019). Around the world, it fits with the biophilic cities idea in spots like Melbourne and Vancouver (Beatley, 2011). It helps SMC's and other authorities aim to make Siliguri a green, new center for Northeast India (Siliguri Municipal Corporation, 2023).

5. Conclusion

The tiered zoning plan—a 500-meter Core ESZ, a nature-focused Transition Zone, and an Urban Integration Zone—is a smart way to cut down the Mahananda ESZ while letting high buildings rise in Greater Siliguri's Matigara, Sukna, and Salbari. The Core ESZ keeps 90% of conflicts and 85% of animal homes safe, covering Matigara's tea farms, Sukna's woods, and Salbari's river areas. The Transition Zone allows tall buildings with nature-friendly designs, and the Urban Integration Zone helps the city grow freely, all in line with SMC's and and State Authorities Urban Development Plan from 2023 to 2030 (Siliguri Municipal Corporation, 2023).

Biophilic design helps this by adding nature to tall buildings:

- **Green Roofs (INR 4,000–8,000 per m²):** Make 20–25 hectares of homes for birds and bugs, cool buildings by 4.4°C, save INR 500–1,000 per m² each year (IndiaSpend, 2023).
- **Vertical Gardens (INR 16,000–32,000 per m²):** Clean air (15–20% less dirt), drop noise (5–10 dB) (IndiaTimes, 2018).
- **Wildlife Corridors (INR 8–16 lakh per hectare):** Lower conflicts by 20–30% (Raman, 2010).
- **Permeable Fencing (INR 400–800 per meter):** Keeps villages safe.
- **Wildlife-Friendly Facades (INR 2,000–3,000 per m²):** Save 10–20 birds for each building (Klem, 2009).
- **Eco-Friendly Materials (INR 200–300 per m²):** Save cash and cut down dirt (Singh & Sharma, 2019).

Urban planning links it all with clear land-use rules (60% homes, 30% shops in Transition Zone), systems like rainwater use, and authorities checks. These designs meet ESZ rules for eco-tourism and green jobs, making greater Siliguri a greener, safer place (Government of India, 2020).

Case studies from Singapore, Mumbai, Bengaluru, Toronto, and Melbourne show this plan can work. Singapore's help and Mumbai's paths guide Gov plans, while Bengaluru's gardens and Toronto's roofs

spark ideas. Melbourne's parks match Salbari's needs. These show that greater Siliguri can thrive.

To make it real, SMC and the state government should:

- Give 10–20% help for green roofs and gardens, saving INR 800–6,400 per m² (Beatley, 2011).
- Teach architects with courses from universities, like Bengaluru's (Newman & Matan, 2014).
- Run ads showing gains like 5–10% more property value and INR 500–1,000 per m² in cooling savings (Newman & Matan, 2014; IndiaSpend, 2023).
- Boost SMC and ESZ Committee control with regular reviews (Government of India, 2020).
- Team up with NGOs to watch wildlife and costs, keeping the plan on track.

Future studies should check gains after 5–10 years, looking at conflict cuts, wildlife health, and money saved. Testing in Matigara and Sukna can fine-tune designs. This plan can fit other Indian ESZs and cities worldwide, making Siliguri a leader in green urban development (Singh & Sharma, 2019; Beatley, 2011). With biophilic design and smart planning, Greater Siliguri can grow as a new hub while caring for the Mahananda WLS, showing the world how it can be done.

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