Cherishing Human-Elephant Landscapes with GIS-LBS: A LUCIS-Based Negotiation Framework for Human-Elephant Coexistence in Sri Lanka

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1 ABSTRACT

Conflicts over land and ecological heritage increasingly require planners to treat plans not as fixed blueprints but as negotiated agreements over space, values, and future risk. Collaborative and communicative planning traditions emphasise that durable spatial decisions emerge through iterative bargaining – where maps, scenarios, and design proposals act as shared "boundary objects" that help parties externalise trade-offs and explore mutually beneficial solutions (HEALEY, 2020; BAR-SINAI, 2013). However, while negotiation is widely discussed in planning theory, it is still weakly operationalised in everyday practice, especially in multi-stakeholder settings shaped by power asymmetries, competing mandates, and contested evidence (RUMING, 2012; KARTZIOS et al., 2022).

A further challenge is that many land–ecology conflicts behave as complex systems: outcomes emerge from interacting processes, feedback loops, and adaptation across actors and environments, often producing nonlinear change and shifting hotspots over time. In urban science and complexity perspectives suggest that such contested socio-ecological landscapes require an Urban Informatics stance – integrating big data, sensing, and computing to support dynamic, evidence-updated decision-support systems and applications, rather than relying solely on conventional land-use allocation logic and periodic plan revisions (BATTY, 2013; SHI, GOODCHILD, BATTY et al., 2021).

Methodologically, many planning support tools remain oriented toward spatial optimisation or impact assessment, rather than negotiation itself. Multi-criteria frameworks (e.g., AHP) can formalise stakeholder priorities, yet weights often remain expert-driven and opaque. Game-theoretic approaches offer a complementary lens by representing stakeholders as strategic actors with distinct objectives and utilities, enabling systematic testing of stability (e.g., near-equilibrium outcomes) and efficiency (e.g., Pareto-improving compromises) across alternative spatial strategies (ZARREH & GROGAN, 2025). Importantly, negotiation-oriented modelling must remain participatory and transparent, supporting learning and trust rather than acting as a technocratic "black box" (CUHADAR, 2004).

Human-Elephant Conflict (HEC) in Sri Lanka is a particularly urgent arena for such negotiation-capable, informatics-oriented planning support. HEC is not only a conservation challenge but also a land-use and spatial justice problem in mixed agricultural–settlement landscapes that overlap elephant home ranges and corridors (GUNAWANSA et al., 2023). These landscapes are continuously reshaped by cultivation cycles, settlement expansion, infrastructure, and seasonal resource conditions – interacting with elephant movement to create persistent yet evolving conflict patterns – thereby reinforcing the need for dynamic, evidence-driven planning beyond static master-plan prescriptions. This paper advances a GIS-LBS–enabled negotiation framework that couples (i) LUCIS-based suitability and conflict mapping (CARR & ZWICK, 2007) with (ii)

LBS-derived GPS elephant movement as an empirical validation lens, and (iii) game-theoretic analysis to evaluate negotiated outcomes across three strategy families: coexistence, partial separation, and full separation. By explicitly linking spatial modelling, movement evidence, and negotiation analytics, the framework provides a transparent basis to "cherish heritage" through evidence-based, politically feasible landscape sharing – supported by adaptive, data-informed planning applications – rather than purely separation-oriented interventions.

Keywords: Spatial Planning, Landuse Conflict, Human-Elephant Coexistence, Geographic Information System, Participatory Planning and Negosation

2 METHOD OF STUDY

2.1 Conceptual and Methodological Framework

Across Sri Lanka, the struggle between protecting endangered Asian elephants and sustaining rural livelihoods has become one of the most acute land-use planning challenges. Around 40% of the country's population lives within the elephant home range, where more than half of the land is classified as non-forest wildlife area, including extensive agriculture and dispersed human settlements. Each year, 300–400 elephants and 120–140 people are killed due to Human-Elephant Conflict (HEC), giving Sri Lanka one of the highest per-capita elephant and human death rates from HEC globally.

This study conceptualises HEC not merely as a conservation or law-and-order problem, but as a profound land-use and spatial justice issue situated at the interface of heritage conservation, rural development, and climate-resilient planning. Elephants represent both ecological heritage and cultural identity, while smallholder agriculture and village settlements provide the socio-economic backbone of rural regions. The central question is: how can GIS and Location-Based Services (LBS) – particularly GPS tracking of elephant movement – support planners in negotiating spatially explicit, politically feasible strategies for coexistence?

The study develops an integrated decision-support framework that combines:

- GIS- and LBS-based movement analysis of elephants using GPS records to delineate empirical home ranges and movement corridors;
- A GIS-based land suitability model for elephants, agriculture and human settlements;
- The Land Use Conflict Identification Strategy (LUCIS) to identify compatible uses and conflict zones;
- Stakeholder-driven weighting via Analytic Hierarchy Process (AHP); and
- Game-theoretic negotiation to evaluate coexistence, partial separation and full separation strategies.

The key innovation are i.) the explicit use of LBS-derived GPS elephant tracks not only as an input dataset, but as a validation lens – home ranges extracted from GPS data are compared against modelled suitability, revealing where planning assumptions match or diverge from elephants' actual space-use behaviour – and ii.) the use of game-theoretic negotiation to obtain stakeholder-driven weighting when implementing LUCIS-based scenarios.

2.2 Study Area and Data

The analysis is conducted at national scale in Sri Lanka. The GIS database includes land cover, topography, climate, soils, water bodies, protected areas, vegetation structure and existing infrastructure were obtained from open-source data-based and grovment agINCes.

LBS is operationalised through:

- GPS records from collared elephants and field tracking.
- Delineation of home ranges and movement corridors (e.g. kernel density and home-range analysis);
- Overlay of these empirical patterns with the elephant suitability model to refine factor weights and thresholds, and to identify under-protected high-use areas and "misclassified" suitable zones.

2.3 GIS–LBS, LUCIS and Game-Theoretic Negotiation

Following LUCIS, the method unfolds in three phases:

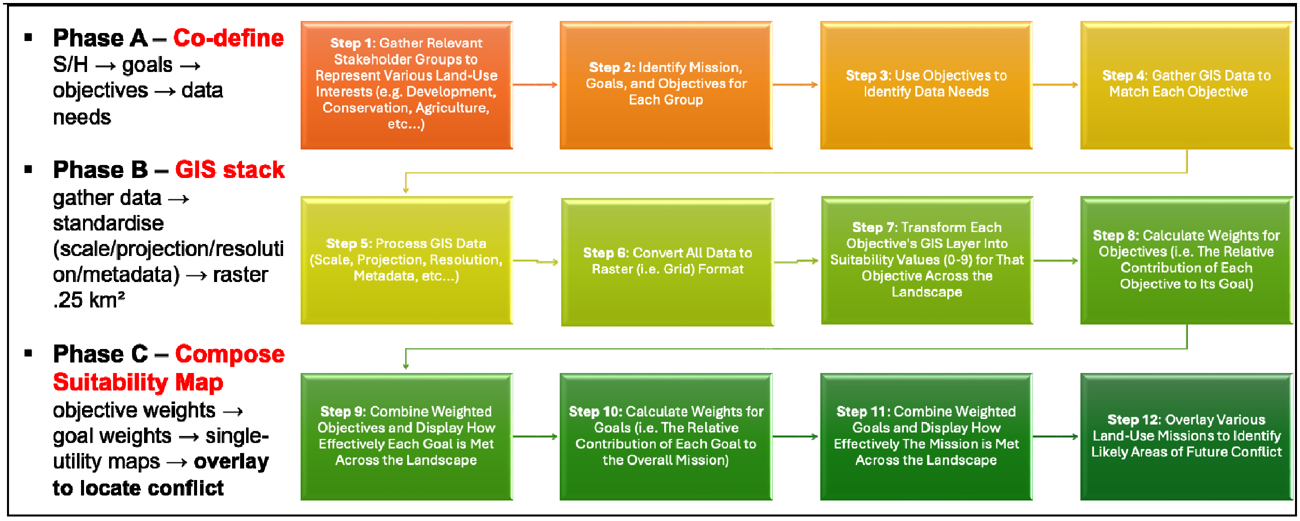

Fig. 1: GIS–LBS–LUCIS negotiation workflow

(1) Co-definition of missions and objectives: Missions such as securing elephant landscapes, safeguarding productive farmland and ensuring safe settlements are decomposed into measurable spatial objectives and indicators.

(2) Suitability mapping with GPS validation: Indicators (e.g. distance to forest, slope, rainfall, access to water, vegetation density, infrastructure) are standardised into 0–9 suitability scores. AHP is used to derive initial weights for objectives and goals for elephants, agriculture and settlements. GPS-based home ranges and corridors are then overlaid on the elephant suitability surface to validate and refine these weights, exposing mismatches between modelled suitability and actual elephant use.

(3) Conflict mapping and game-theoretic negotiation: Composite suitability maps are overlaid to classify land into single-use, compatible multi-use and high-conflict zones. Alternative strategies – coexistence, partial separation, full separation – are spatially implemented. Stakeholder utilities for each strategy, reflecting their weighted objectives, are then analysed using game theory (Nash equilibria and Pareto efficiency) to identify robust compromise solutions. Here, game-theoretic negotiation is used to iteratively adjust and stabilise stakeholder-driven weights and preferences when applying LUCIS.

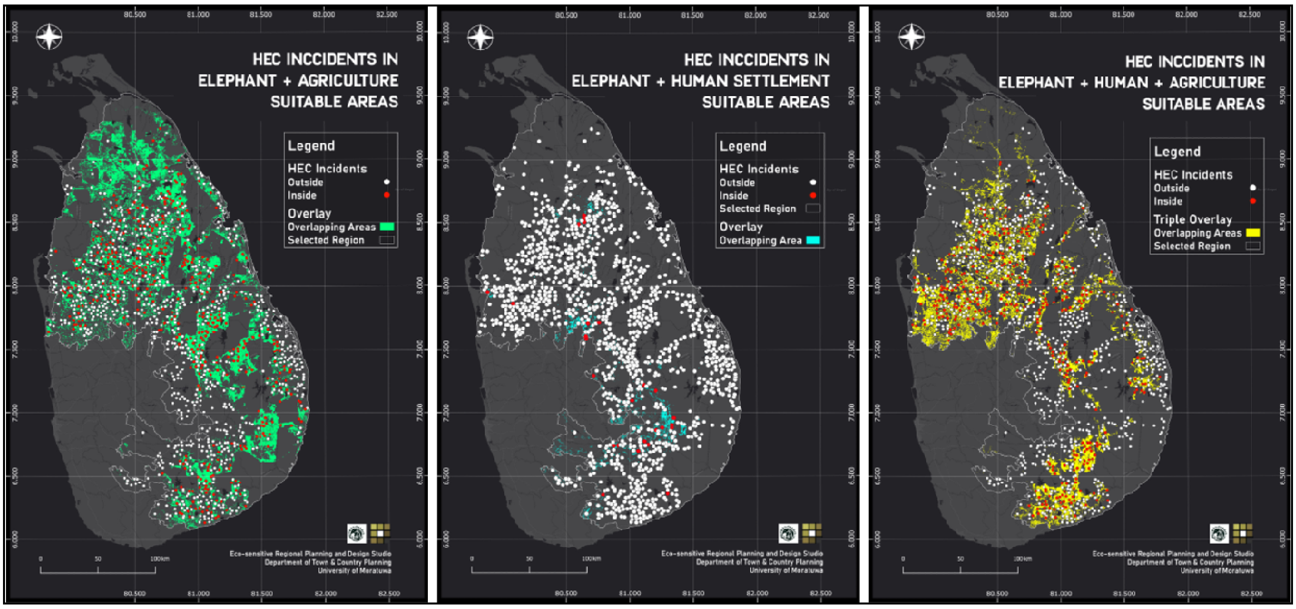

Fig. 2: National-scale overlap of suitability surfaces for elephants, agriculture, and human settlements, highlighting compatible-use zones and high-conflict hotspots where GPS-confirmed elephant use intersects high agricultural/settlement suitability

3 KEY FINDINGS

3.1 GPS–Suitability Compatibility and Conflict Hotspots

GPS-based home ranges confirm that elephants intensively use several zones currently dominated by agriculture or mixed land uses, and highlight high-use areas underrepresented in existing protected networks. Conflict hotspots cluster where:

- GPS-confirmed home ranges intersect areas of high agricultural suitability; and
- Movement corridors are constricted by settlement growth and infrastructure.

Comparing GPS tracks with the suitability model improves habitat prioritisation, helps avoid designating "paper habitats" that elephants seldom use, and sharpens the delineation of critical corridors and buffer zones.

3.2 Planning Strategies and Negotiated Weighting

Three strategy families are tested:

- Full separation (strict elephant/human–agriculture segregation);
- Partial separation (Elephant Conservation Areas allowing seasonal agriculture and eco-tourism);
- Coexistence (habitat restoration, corridor protection, targeted agriculture, compensation and livelihood diversification).

Strategy	**Core planning logic**	**Typical spatial instruments**	**Governance & livelihood instruments**	**Expected strengths**	**Key risks/failure modes**
Coexistence	Share landscapes by reducing risk and improving compatibility where overlap is unavoidable	Corridor protection; habitat restoration; buffer zoning; micro-siting of settlements/infrastructure; land-use guidance in mixed mosaics	Compensation/insurance; early warning; crop switching; livelihood diversification; community stewardship	Often higher multi-stakeholder acceptability; flexible and adaptive; can protect "working corridors"	Requires sustained institutions/funding; uneven benefits may trigger distrust; needs strong participation to avoid perceived imposition
Partial separation	Prioritise elephants in defined conservation areas while allowing limited/seasonal compatible use	Elephant Conservation Areas (ECA); controlled agriculture zones; seasonal access rules; corridor widening	Co-management agreements; conditional permits; eco-tourism and benefit-sharing	Clearer spatial structure than coexistence; can reduce peak-risk encounters in hotspots	Boundary disputes; leakage of settlement expansion; may displace risk to edges if enforcement is weak
Full separation	Minimise contact by spatial segregation of humans/agriculture and elephants	Fencing; strict exclusion zones; relocation/resettlement; hard barriers along corridors	Enforcement-heavy management; resettlement packages; strict land controls	Fast visible action in specific sites; may reduce encounters locally if maintained	High social cost and political resistance; barrier maintenance failures; can fragment habitat and intensify conflict at fence lines

Table 1: Summary comparison of HEC strategy families.

Preference elicitation shows overall support for coexistence-oriented options. Game-theoretic negotiation, grounded in stakeholder-driven weights, indicates that GPS-informed coexistence scenarios yield higher combined utilities for farmers, conservationists and state agencies than fencing-only or relocation-centric approaches, and emerge as Pareto-efficient in many settings.

4 DISCUSSION

The proposed GIS–LBS and LUCIS-based framework reshapes Human-Elephant Conflict from a predominantly technical or sectoral problem into a structured arena of spatial negotiation. A central contribution lies in treating LBS-derived GPS elephant tracks not merely as another input layer, but as a validation lens on top of the suitability model. By overlaying empirical home ranges and movement corridors with modelled suitability, the framework forces planners to confront where their assumptions diverge from elephants' actual space-use behaviour. This is particularly important in Sri Lanka, where conservation and land-use decisions have often relied on generalised habitat notions rather than movement-informed landscape functionality. The GPS-based perspective exposes "phantom suitability" areas that look ideal on paper but are rarely used by elephants, as well as overlooked "hot habitats" and corridors that demand higher protection or more sensitive management.

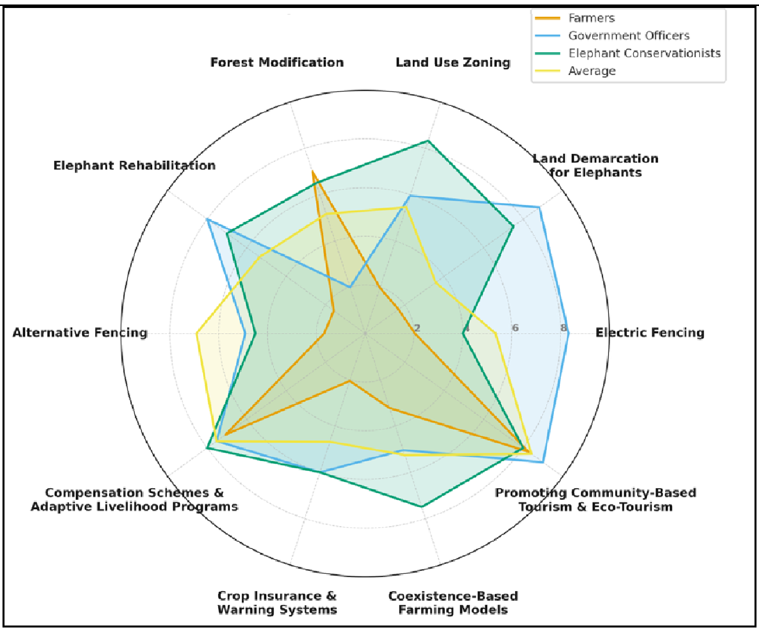

Fig. 3: Stakeholder preference distribution across strategy families (coexistence, partial separation, full separation), summarised by stakeholder group and used to parameterise utility-based scenario comparison.

Equally important is the shift from purely expert-led weighting of criteria towards a game-theoretic, negotiation-centred approach to stakeholder-driven weighting. LUCIS has proven powerful for conflict identification, but in many applications, weights and priorities remain largely in the hands of experts or single institutions. In contrast, this study combines initial AHP-derived weights with an explicit game-theoretic layer, where alternative scenarios – coexistence, partial separation, full separation – are evaluated as strategic options with utilities for farmers, conservationists, and state agencies. Through this, weighting is no longer a hidden technical step: it becomes contested, negotiated, and iteratively adjusted until more stable, Pareto-efficient outcomes emerge. This responds directly to the discourse on whether digital tools and AI truly revolutionise planning: here, technology is not the driver of decisions but an enabler of more transparent bargaining over space, risk, and heritage.

The framework also highlights the promise and the limits of relying on digital evidence in deeply political conflicts. GIS–LBS tools can clarify trade-offs, show where fences or resettlement are unlikely to work, and visualise where coexistence is spatially feasible. Yet they cannot, by themselves, resolve power asymmetries, ensure compensation is fair, or guarantee that communities trust institutions. There is a risk that highly technical models may be used to legitimise predetermined decisions if participation is superficial. Thus, the value of the approach depends on how genuinely stakeholders are engaged in defining missions, interpreting maps, and shaping strategies, rather than merely being shown “finished” products. The work also underscores a broader insight for digital urbanism: AI, LBS and advanced models are most transformative when they illuminate shared problems and create common ground for negotiation, not when they are treated as black-box optimisation engines.

5 CONCLUSION

The GIS–LBS, LUCIS and game-theoretic negotiation framework presented in this study offers a transparent and transferable approach to planning for Human-Elephant coexistence in Sri Lanka. By integrating GPS-based movement data as both input and validation, it grounds conservation and land-use strategies in elephants’ lived geographies, revealing where protected areas, agricultural expansion and settlement growth are misaligned with actual home ranges and corridors. Through LUCIS-based suitability and conflict mapping, it provides a clear spatial language to distinguish compatible-use zones from structural hotspots of conflict. Game-theoretic negotiation adds a governance layer, turning stakeholder preferences and weights into an explicit object of discussion rather than a hidden technical choice. In practical terms, the results indicate that well-designed coexistence strategies – supported by habitat restoration, corridor protection, controlled agriculture, compensation, and livelihood diversification – can deliver higher joint benefits than rigid separation or fencing-and-resettlement approaches alone. More broadly, the study demonstrates the effectiveness of an Urban Informatics approach – combining complexity science, sensing, data integration, and spatial computing – to support dynamic, evidence-updated planning decisions, in contrast to static land-use master plans that struggle to respond to shifting risk and dayanmics.

Limitations include partial coverage and temporal bias in collaring datasets, sensitivity of suitability outputs to indicator selection and AHP weights, and the coarse national grid that may miss micro-scale barriers and local land-management practices. Future work should: (i) add uncertainty and sensitivity analysis to identify "no-regret" corridors and interventions; (ii) incorporate temporal dynamics (seasonality, crop calendars, rainfall variability) beyond static suitability; (iii) deepen participation through facilitated negotiation workshops to refine utilities, test coalition stability, and address power asymmetries; and (iv) operationalise the framework as an adaptive planning application linked to monitoring, early warning, and compensation targeting. These steps would strengthen robustness and uptake while maintaining transparency and stakeholder ownership.

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