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FIELD FRAGMENTATION AND GEOMETRIC COMPACTNESS FOR LAND-USE PLANNING: A SINGLE-LAYER GIS FRAMEWORK AND A PASTDARG‘OM STUDY DESIGN

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Abstract

Agricultural land-use planning requires field subdivision, geometric shape and internal boundary structure to be evaluated separately. This paper develops a single-layer GIS framework for a proposed 2 × 2 km study window in Pastdarg‘om District, Samarkand Region. The quantitative component consists of deterministic geometric experiments rather than a survey of local fields. Methods specify stable field identifiers, non-overlapping area and compactness classes, edge treatment, unique-boundary accounting and a 250 m reporting grid. Four fully specified synthetic 400-ha layouts provide the analytical results. With 64 fields and 6.25 ha per field held constant, changing a 4:1 rectangular layout into squares increases compactness from 0.5027 to 0.7854 and reduces internal boundary density from 9 to 7 km/km². Increasing the number of square fields from 64 to 256 leaves compactness unchanged while boundary density rises from 7 to 15 km/km². Each full 250 m cell represents 6.25 ha, so one uniquely assigned field corresponds to 16 fields per 100 ha. A 5% overstatement of perimeter lowers

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compactness by 9.30% at fixed area. These analytical findings explain why counting rules and boundary quality must accompany fragmentation assessment. They do not establish local field counts, class areas, ownership fragmentation or consolidation benefits. Application in Pastdarg‘om requires authenticated field polygons, imagery metadata and independently verified management information. A regional location map and five map-design illustrations accompany the methodological specification; they are not inputs to the numerical analysis.

Keywords: field fragmentation; geometric compactness; land-use planning; GIS; internal boundaries; 250 m grid; Pastdarg‘om; analytical benchmark.

1. Introduction

A land-use plan must describe how agricultural land is arranged, not merely how much land is present. Small fields, elongated fields and fields separated by many internal boundaries represent different planning conditions. Their interpretation also depends on irrigation, access, working direction and rights. Land evaluation therefore concerns a specified use and its constraints, rather than a single geometrical score [1].

The study asks three linked questions: how should field subdivision be mapped, how should shape be distinguished from field size, and how can local boundary concentration be reported without double counting? The contribution is a traceable analytical specification linking these questions to one field layer and explicit geometric controls. The paper reports these controls and a proposed empirical workflow; it is not a completed district survey.

2. Study design and evidential scope

The proposed regional setting is Pastdarg‘om District, with Juma used as the district-centre reference in the original author-supplied location map (Figure 1).

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The design specifies a 2,000 × 2,000 m window, equivalent to 400 ha or 4 km². A georeferenced site polygon has not been supplied, so no specific study-window position is claimed. Roads, channels, buildings and other excluded surfaces would reduce the agricultural area within an actual window.

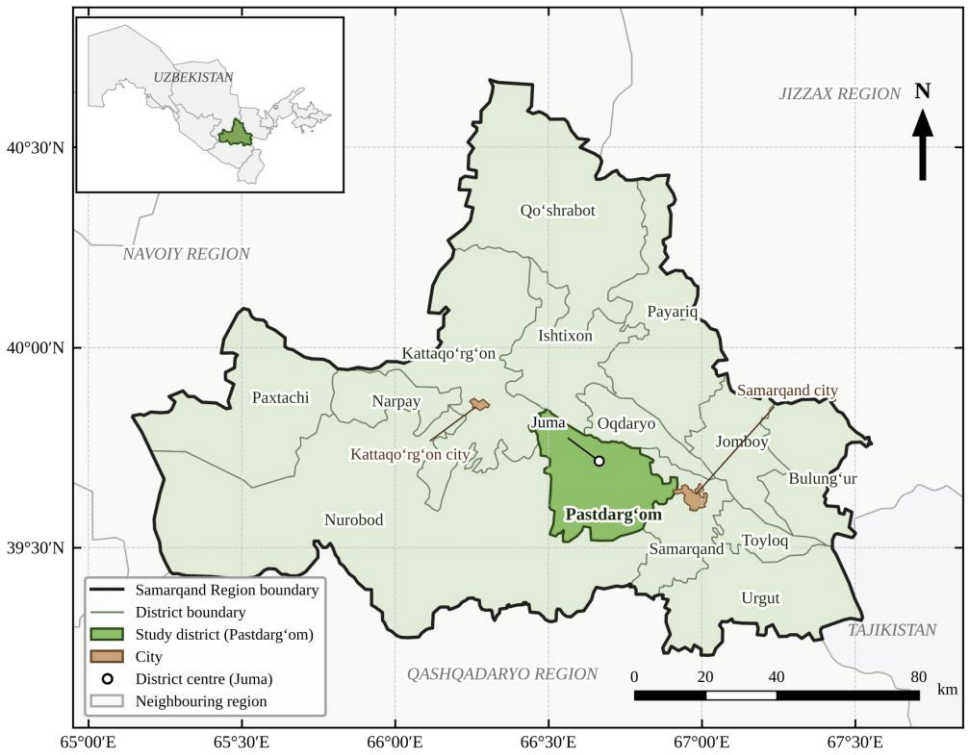

Figure 1. Location of Pastdarg‘om District and Juma within Samarkand Region.

The intended map suite comprises regional orientation, field boundaries, area classes, compactness classes, a two-panel density grid and a conditional aggregation comparison. Figures 2–6 illustrate the proposed presentation only. The analytical object is an operational field; a legal cadastral parcel or ownership holding may contain several such units. The study does not infer ownership fragmentation from illustrated boundaries [4,5].

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Figure-production statement. Figures 2–6 were produced with a generative image model during manuscript preparation. They are not outputs of an ArcGIS 10.8 analysis or of digitisation from authenticated imagery. Embedded coordinates, scale bars, provider labels, class colours and farm groupings are unverified. No authenticated fields layer or Farm_ID register accompanies them. The illustrations are retained to show the proposed presentation; no local measurement or numerical result is derived from them.

3. Materials and methods

3.1. One authoritative field layer

A reproducible implementation would maintain one authoritative fields layer and derive every map and graphic from its stable Field_ID. Changing symbology must not change geometry. Area classes, compactness classes and grid summaries should be joined to the same version of the field register. The image date, digitising scale and boundary-confidence convention must be recorded before analysis. This follows the distinction between spatial objects and the measurements made from them [2–4].

Table 1. Required attributes and quality controls for the proposed fields layer.

Attribute	Purpose	Quality control
Field_ID	Persistent identifier of one operational field	Unique, non-missing; kept in every output
Area_m2, Area_ha	Full field area; hectares = m² / 10,000	Positive values; projected metric units
Perim_m, K, E	Perimeter, compactness and elongation	Valid polygon; holes and edge rule documented
Edge_flag, Area_in	Intersection with the window edge	Full-field shape kept separate from clipped area
Image_ref, Confidence	Source image and digitising confidence	Image date recorded; uncertain edges flagged
Farm_ID, Access, Water	Optional aggregation scenario	Verified membership; barriers and irrigation checked

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3.2. Measuring subdivision and shape

Field area is calculated in square metres in an appropriate documented metric coordinate system and converted to hectares. Perimeter is measured on the same geometry and in the same system. The proposed primary shape statistic is circularity-based compactness; elongation provides complementary information on the ratio of the long and short axes of a minimum bounding rectangle [2–4].

$$A_{ha,i} = \frac{A_i}{10\,000}, \quad K_i = \frac{4\pi A_i}{P_i^2}, \quad E_i = \frac{L_i}{W_i}. \qquad (1)$$

For valid non-degenerate planar polygons, K is positive and at most one. A square has K = π/4 ≈ 0.7854, not one. Compactness is scale-invariant: uniformly enlarging a field changes area and perimeter but leaves K unchanged. Consequently, a low K does not by itself mean that a field is small, and a high K is not a verified agronomic suitability rating.

Figure 1 is the original regional location map supplied by the author. The separate image-production statement in Section 2 identifies the origin of Figures 2–6. No colour counting, assumed pixel-to-hectare conversion or printed-scale measurement is used to estimate local area, shape or density. The earlier methodological manuscript supplies the benchmark structure [6]; the controls below use an explicitly specified 400-ha local-coordinate domain.

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3.3. Image-supported field delineation and edge treatment

Map 2. Digitized Field Boundaries over Satellite Imagery in the 2 × 2 km Study Area

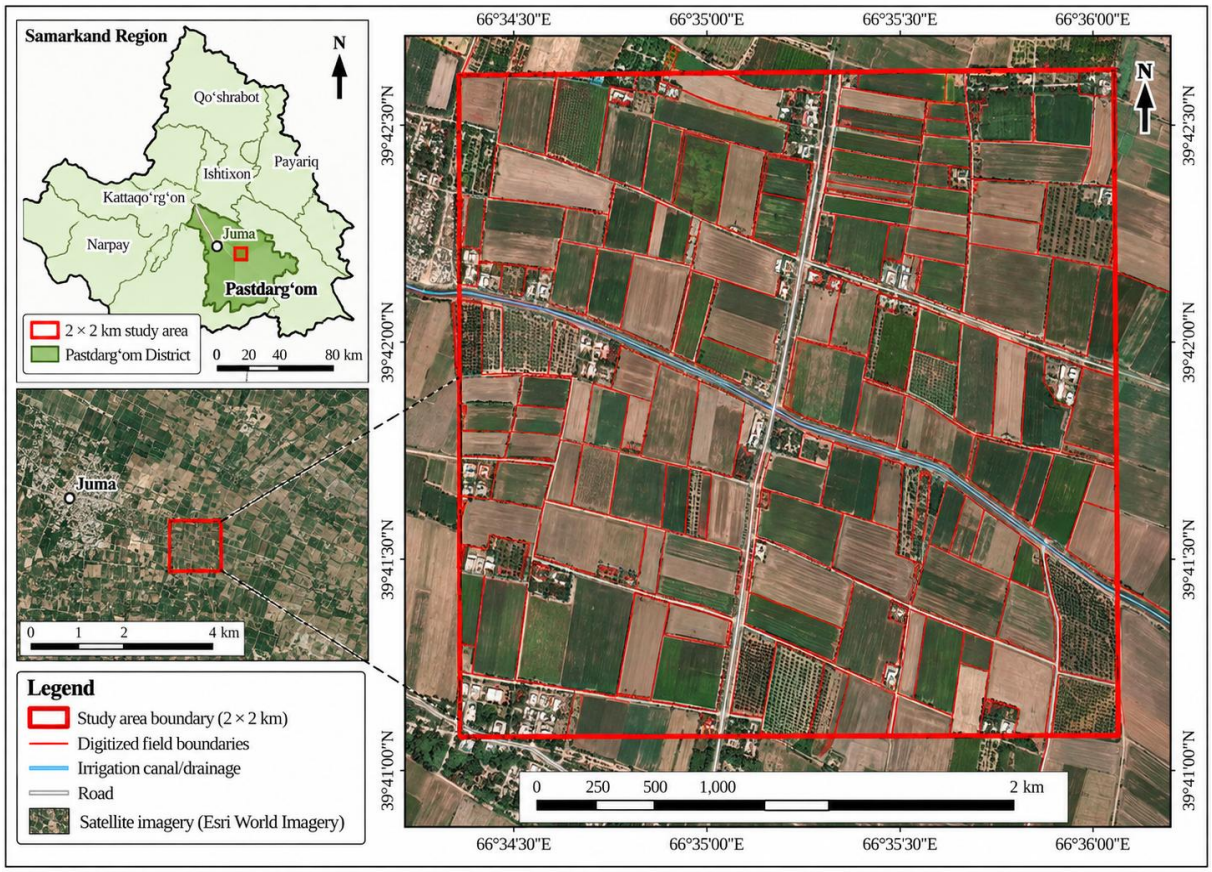

Figure 2. Illustrative field-boundary layout, not a digitised field survey.

A measured field-boundary overlay must be exported from a dated, georeferenced image and the single fields layer. Its study-window polygon must be identical in the main map, locator insets and every derived map. Visible field edges must be distinguished from crop-colour changes, roads, canals and legal boundaries. Figure 2 cannot verify the source imagery, the site's direction relative to Juma or the dimensions of the window.

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Fields crossing the study boundary require special treatment. Full boundaries should be digitised beyond the window wherever source coverage allows; their full-field area and K should be retained. A clipped geometry may be used for display and within-window area accounting, but it must not silently replace the full geometry for shape analysis. Edge-affected records should carry a flag, and the valid record set used by each summary must be reported.

A common Field_ID permits all graphics to use the same declared sample. Where perimeter is uncertain, local revisions should be documented rather than smoothing boundaries merely to improve compactness. A map image without the underlying polygons is insufficient to reproduce these checks.

3.4. Classification and reporting denominators

The requested five area classes and four compactness classes are retained. Table 2 resolves shared endpoints so that no field is counted twice. These boundaries define the cartographic design; they are not legal standards or thresholds calibrated to local productivity. Classes must be assigned using unrounded values, with rounding applied only to displayed statistics.

Table 2. Exact class definitions used in the proposed map specification.

Area label (ha)	Unambiguous rule	K label	Unambiguous rule
< 1	$0 < Aha < 1$	< 0.50	$0 < K < 0.50$
1–2	$1 \leq Aha < 2$	0.50–0.65	$0.50 \leq K < 0.65$
2–5	$2 \leq Aha < 5$	0.65–0.75	$0.65 \leq K < 0.75$
5–10	$5 \leq Aha \leq 10$	≥ 0.75	$0.75 \leq K \leq 1$
> 10	$Aha > 10$	Invalid / missing	Flag separately; do not force into a class

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Aha denotes area in hectares. The four valid K classes are distinct from any quality-control exclusion.

Count shares and area shares answer different questions. The share of fields in class c is nc/N, while the share of mapped field area is $\Sigma A_i,c / \Sigma A_i$. Neither denominator is automatically the gross 400-ha window. The two shares coincide in an equal-area model, but need not coincide in a heterogeneous agricultural landscape. Actual histograms should therefore accompany the class table rather than being inferred from map colour coverage.

3.5. A 250 m grid and unique internal boundaries

The 2 km window contains 8 × 8 = 64 cells of 250 m, each covering 6.25 ha. Each field is assigned to one cell by an interior representative point, so that no field is counted twice. The field density of cell j with n_j assigned fields is

$$D_{N,j} = \frac{100 n_j}{6.25} = 16 n_j \tag{2}$$

in fields per 100 ha. For the boundary measure, each boundary shared by two fields is counted once, while the window edge, grid lines and clipping lines are excluded. With L_j the shared boundary length in metres within cell j, the boundary density in km/km² is

$$D_{B,j} = \frac{L_j/1000}{0.0625} = \frac{L_j}{62.5} \tag{3}$$

For a complete partition without gaps or overlaps, the total internal boundary length follows from the field perimeters and the perimeter of their union:

$$L_{int} = \frac{\sum_i P_i - P_{union}}{2} \tag{4}$$

because each shared edge appears twice in the sum of field perimeters and the outer boundary appears once.

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3.6. Controlled calculations

Four complete rectangular partitions are evaluated in a local 2,000 m square. They contain either 64 or 256 equal-area fields with aspect ratios of one or four. All geometries are computationally valid, their union is 4 km² and their overlap area is zero. Calculations are deterministic: no sampling significance tests, district estimates or local confidence intervals are produced.

4. Analytical results and methodological discussion

4.1. Field-size mapping: subdivision, not ownership

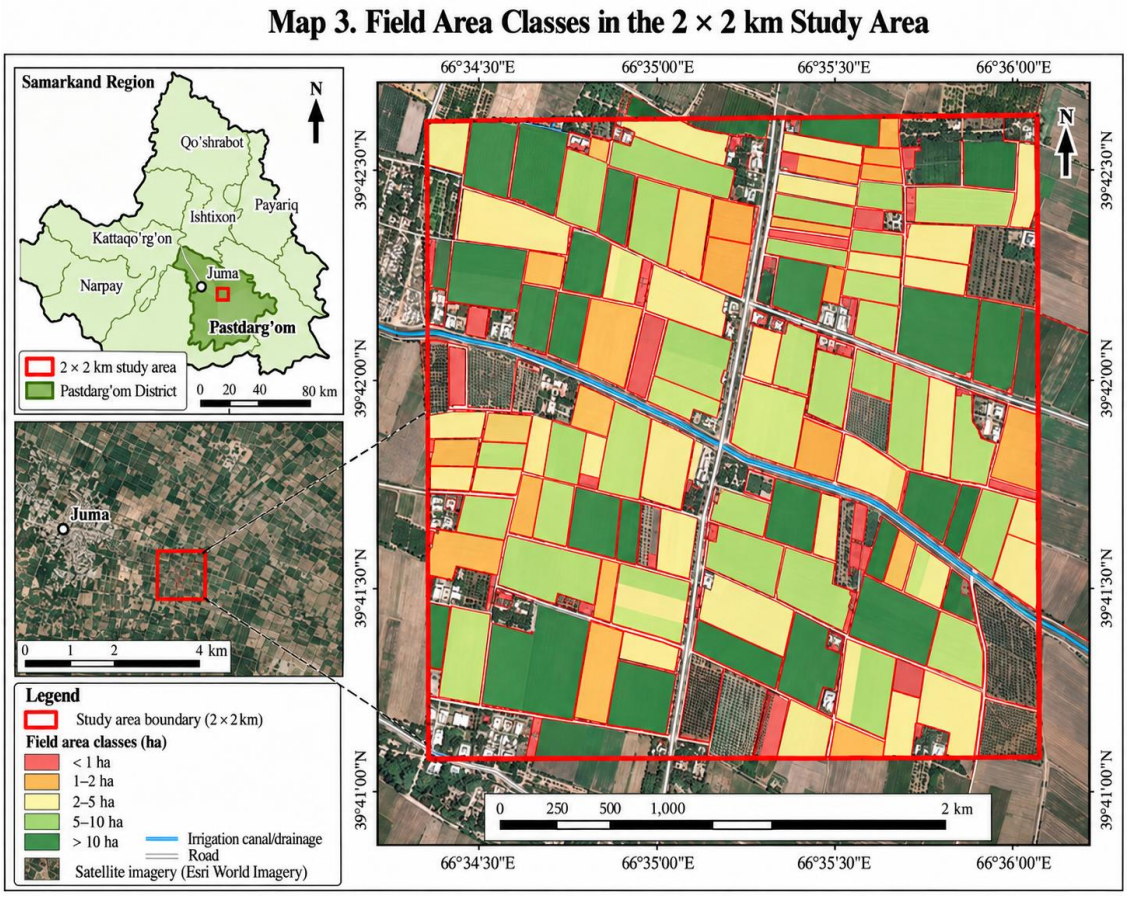

Figure 3. Illustration of field-area class presentation.

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A measured field-area map should identify every Field_ID and display its class from a calculated Area_ha attribute. Figure 3 illustrates that presentation but does not supply verified class areas. A 180 × 220 m rectangle has an area of 39,600 m² or 3.96 ha and belongs to the 2–5 ha class, not the >10 ha class. This arithmetic example explains the need for geometric checks; it is not an accepted measurement of a real field.

A concentration of small fields would not, by itself, prove inefficient land ownership or justify consolidation. Field definitions, crop arrangements and management boundaries may differ from cadastral units. The proposed class table should therefore report field count, count share, summed area and area share together. The mean alone can conceal a skewed size distribution, whereas a median and a histogram would reveal whether a few large fields dominate the area denominator.

No field count or class-area total is recoverable as a verified local result from this plate. Apparent size differences motivate the required measurements but do not replace them. The three requested empirical graphics—an area histogram, a K histogram and an area–K scatterplot—must eventually be generated from the same eligible Field_ID sample. The analytical diagrams later in this paper are explicitly different products, not substitutes labelled as observations.

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4.2. Compactness: separating size, elongation and irregularity

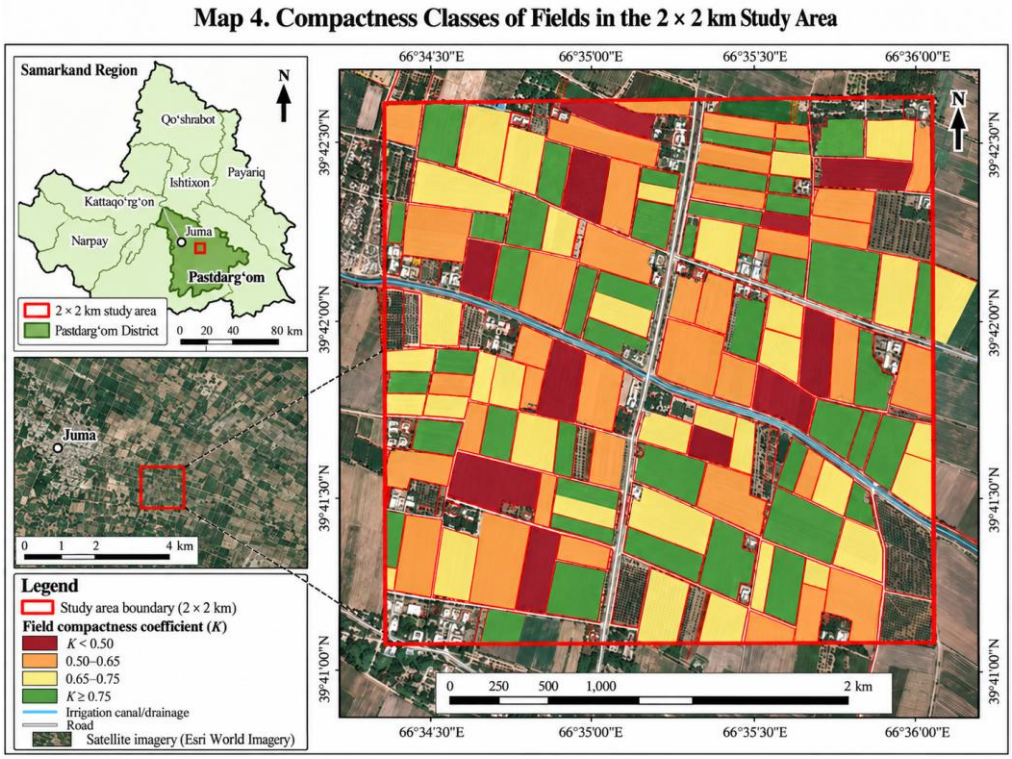

Figure 4. Illustration of compactness-class presentation.

Measured area and compactness maps must be based on identical fields, but should not be expected to reproduce the same pattern. The defining equation contains both area and perimeter. A small square and a large square have the same K, while two fields of equal area can have substantially different perimeters. The two attributes answer different questions; their apparent colours in Figures 3 and 4 do not establish a measured relationship.

For a rectangle with aspect ratio $r \geq 1$, substitution into Equation (1) gives $K = \pi r/(r + 1)^2$. The requested thresholds K = 0.75, 0.65 and 0.50 correspond approximately to aspect ratios 1.54, 2.42 and 4.04. These values are calculated geometric equivalents for rectangles only; they are not direct elongation estimates

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for irregular polygons. A 4:1 rectangle has K = 0.5027 and lies just above the 0.50 boundary.

Low K can arise from elongation, indentations, holes or excessively detailed digitisation. These mechanisms have different planning implications. A bounding-rectangle ratio and a boundary-quality check should accompany K before describing a field as elongated. Likewise, maximizing circularity is not an agricultural design objective: an elongated field may be appropriate to irrigation direction or field operations.

4.3. Grid density: resolving counting and support effects

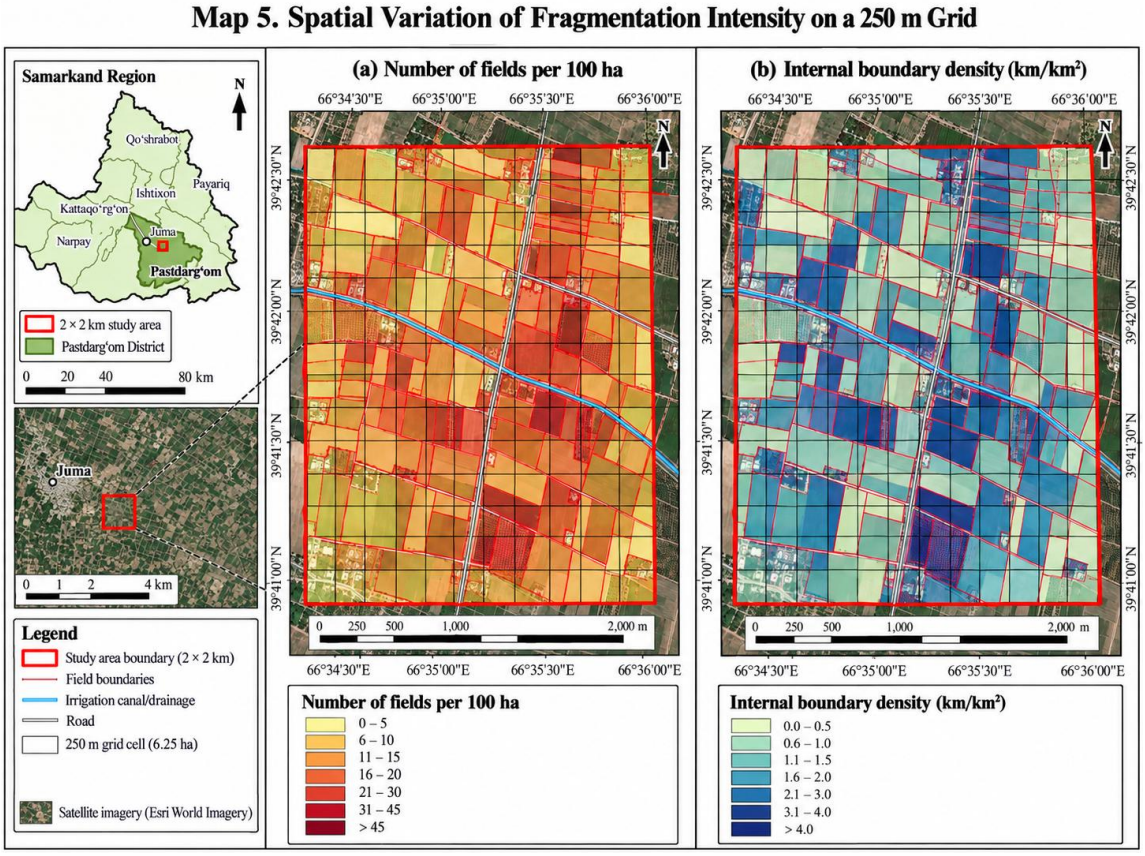

Figure 5. Illustration of two-panel density reporting, not a calculated grid.

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An analytical density map must be rebuilt from exactly the same 64-cell grid in both panels, using a documented metric origin, 250 m cell size and 2,000 m extent. One summary value is joined to each Grid_ID; shading individual fields is not grid-density mapping. Under unique representative-point counting, full-cell densities occur in multiples of 16 fields per 100 ha. All shared internal boundaries are counted once. The irregular mesh and colours in Figure 5 are illustrative, not calculated values.

Table 3. Exact conversions for a full 250 × 250 m cell.

Assigned fields, n	Fields per 100 ha	Shared line (m)	Boundary density (km/km²)
0	0	62.5	1.0
1	16	125	2.0
2	32	250	4.0
3	48	500	8.0

An intersection-count grid may be useful, but its legend must state that a field can contribute to more than one cell. A field-location density and a boundary-length density are complementary rather than interchangeable. Their apparent agreement in a drawing cannot establish correlation or a local fragmentation hotspot.

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4.4. Aggregation: an explicit conditional scenario

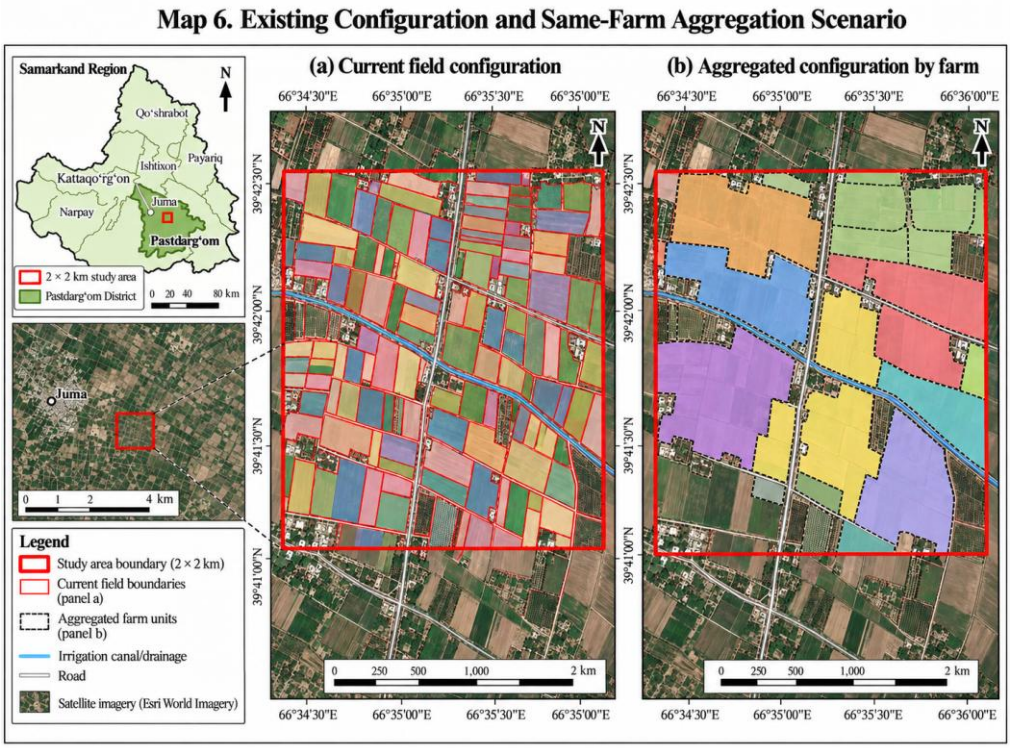

Figure 6. Illustration of existing and aggregated field layouts.

The proposed aggregation comparison concerns existing fields and eligible connected units. Figure 6 illustrates the comparison format but cannot identify same-farm units because Farm_ID values and authenticated field geometries are absent. A measured replacement is conditional on verified common management and contiguity. Roads and canals can prevent operational combination, and a shared boundary segment is required rather than point contact.

A defensible procedure would construct a graph of eligible adjacent fields, retain only pairs with confirmed common management and compatible constraints, and dissolve connected components. Multi-part results would be separated into their connected units for reporting. The union area should remain unchanged, unless

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an explicitly documented redesign allocates or removes land. Access and irrigation features must be checked before a shorter boundary is interpreted as an improvement.

No local aggregation gain is calculated from the supplied plate. The separate benchmark in Table 5 shows the mathematics of specified merges without assigning ownership or Farm_ID values to Pastdarg'om fields. This distinction is important because geometric dissolution, cooperative field operations and legal parcel consolidation are different actions. A scenario map can propose an option, but it cannot establish permission, engineering feasibility or economic benefit.

4.5. Analytical benchmark: fixed count, different shape

Table 4. Recalculated results for four synthetic 400-ha layouts.

Model	Grid	N	Mean area (ha)	K	Internal line (km)	D_B (km/km²)
C1	8 × 8	64	6.2500	0.7854	28	7
C2	16 × 4	64	6.2500	0.5027	36	9
C3	16 × 16	256	1.5625	0.7854	60	15
C4	32 × 8	256	1.5625	0.5027	76	19

C1 and C2 hold both field count and mean field area constant at 64 and 6.25 ha. C1 contains 250 × 250 m squares; C2 contains 125 × 500 m strips. Changing C2 into C1 raises K by 0.2827, equivalent to 56.25% relative to C2, while unique internal boundaries decrease from 36 to 28 km. Boundary density falls from 9 to 7 km/km², a 22.22% reduction. No field has become larger and no field count has changed.

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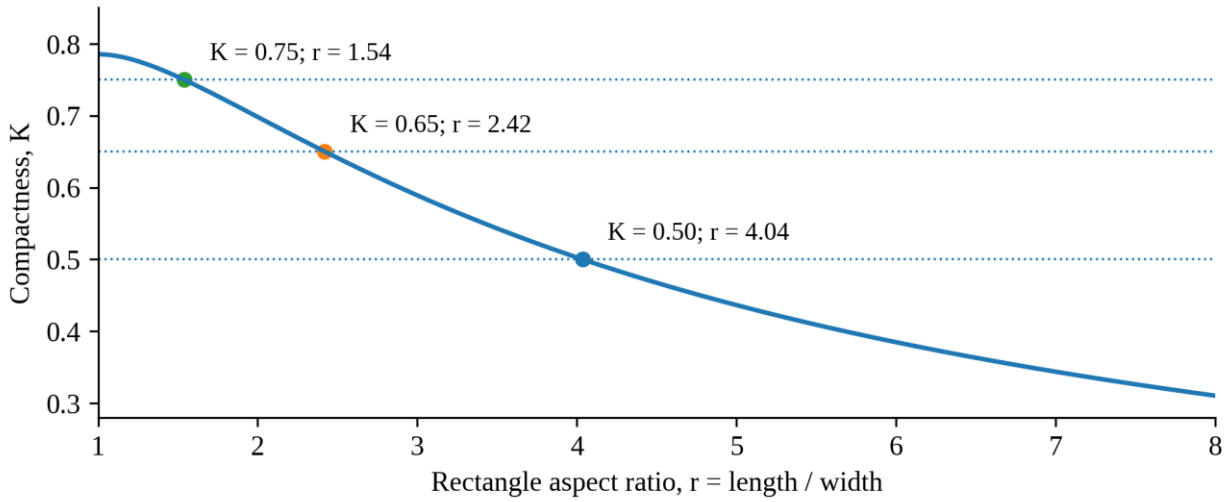

Figure 7. Exact compactness–aspect-ratio relationship for rectangles.

The comparison isolates shape rather than fragmentation by number. It provides a direct test for the interpretation of the area and compactness maps: two field layers may have identical area-class tables yet different shape distributions. Conversely, different field sizes can have identical shape scores. A single combined priority label would conceal these separate mechanisms unless its construction and validation were reported.

$$L_{int} = \frac{\sum_i P_i - P_{union}}{2} \quad (4)$$

For these complete, non-overlapping partitions, Equation (4) counts each common edge once. The outer perimeter is 8 km in every model. Applying it to C2 gives (80 − 8)/2 = 36 km; C1 gives (64 − 8)/2 = 28 km. These identities verify the boundary totals and show why simply summing field perimeters would overstate internal-boundary length.

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4.6. More fields do not necessarily imply lower compactness

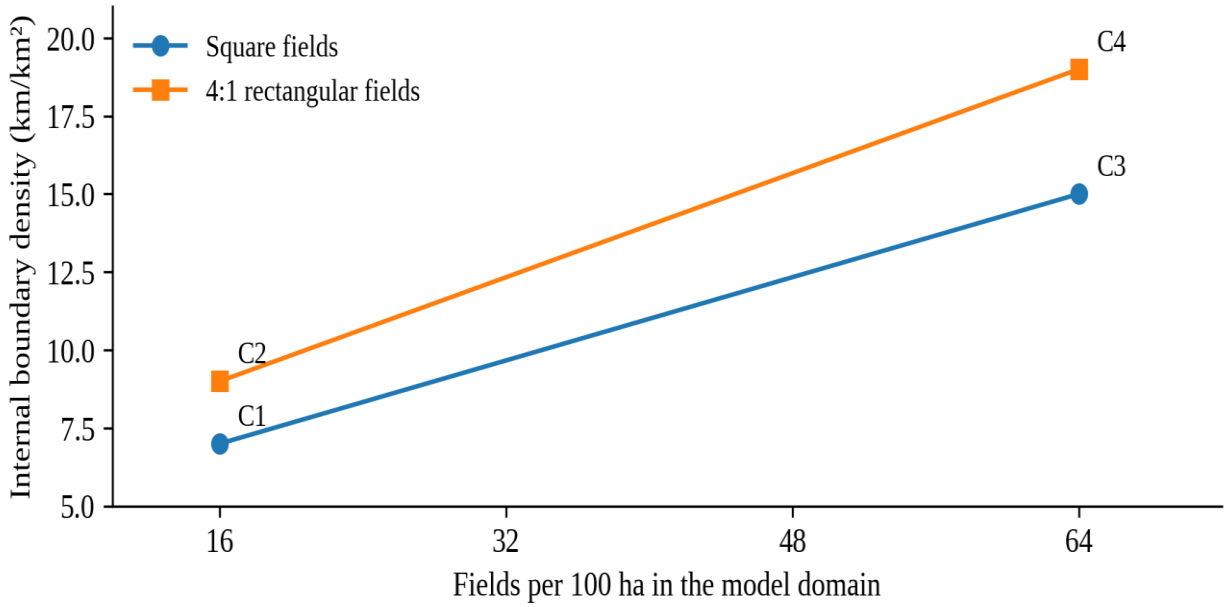

Figure 8. Field-count density and internal-boundary density in the four exact model layouts.

C1 and C3 contain square fields, so both have K = 0.7854. Subdivision from 64 to 256 fields reduces mean area from 6.25 to 1.5625 ha and increases boundary density from 7 to 15 km/km². This is a 114.29% increase in boundary density without any decrease in compactness. In the strip controls, C2 to C4 likewise keeps K at 0.5027 while boundary density increases from 9 to 19 km/km². The benchmark therefore rejects an automatic equivalence between smaller fields and less compact shapes.

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Table 5. Idealised merging alternatives in the same synthetic 400-ha domain.

Alternative	Fields	Mean area (ha)	K	Internal line (km)	Reduction (%)
M0: 4:1 strips	64	6.25	0.5027	36	0.00
M1: merge pairs	32	12.50	0.6981	20	44.44
M2: merge four	16	25.00	0.7854	12	66.67

Pairwise merging changes field count as well as shape: 64 fields become 32, mean area doubles to 12.5 ha, K rises to 0.6981 and internal lines decrease by 44.44%. Four-strip merging gives 16 square units of 25 ha and a 66.67% boundary reduction. These percentages apply only to the stated model. They cannot be assigned to Figure 6 or used as a prediction of an actual farm-level outcome.

The merging contrast also exposes the effect of classification. All M0 fields lie in the 5–10 ha class, while all M1 and M2 units exceed 10 ha. A movement into a larger class is therefore a consequence of the chosen grouping rule, not proof that the underlying agricultural system has improved. Operational evidence would be needed to decide whether the removed boundaries are unnecessary or perform an important irrigation, access or management function.

4.7. Boundary quality and window clipping can change classes

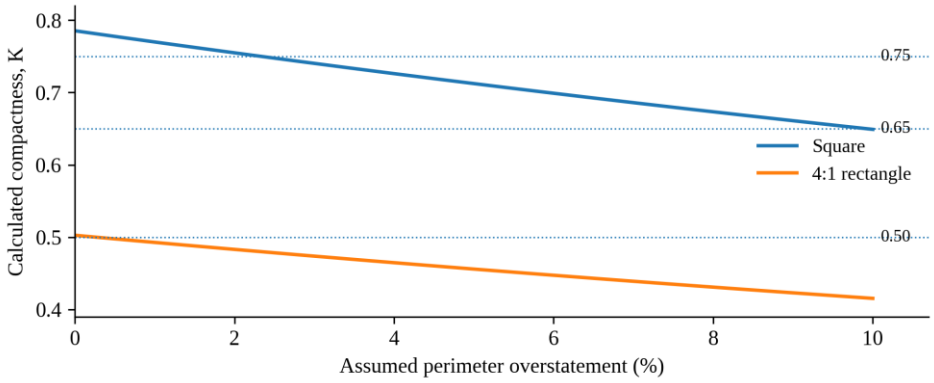

Figure 9. Deterministic sensitivity of K to an assumed perimeter overstatement at fixed area.

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$$K_* = \frac{K}{(1+\varepsilon)^2},$$

where P* = P(1 + ε) and area is fixed. (5)

Table 6. Compactness sensitivity and two independent clipping examples.

Test	Original K	Modified K	Interpretation
Square; perimeter +5%	0.7854	0.7124	Class changes without an area change
4:1 rectangle; perimeter +1%	0.5027	0.4928	Crosses the 0.50 boundary
50 × 400 m rectangle clipped to 50 × 200 m	0.3103	0.5027	K increases by 62.00%
250 × 250 m square clipped to 250 × 125 m	0.7854	0.6981	K decreases by 11.11%

A 5% perimeter overstatement lowers any fixed-area K by 9.30%. A square then moves from the highest requested class to 0.65–0.75, even though its intended usable shape has not changed. The 4:1 rectangle is more vulnerable to the lowest threshold: only a 1% overstatement moves K below 0.50. Reporting rounded K alone would conceal the closeness to that decision boundary.

Window clipping has no single directional effect. Shortening a long rectangle makes it more compact, whereas cutting a square into a narrower rectangle makes it less compact. The examples in Table 6 therefore support explicit Edge_flag treatment rather than a universal correction factor. For real fields, the primary statistics should retain full-field geometry and provide a separate edge-affected comparison where required.

These results explain why visual agreement among attractive map plates is insufficient for validation. Common coordinates, identical field identifiers, a

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defined boundary convention and sensitivity checks must precede interpretation. A detailed outline is not necessarily a more accurate one, particularly when digitisation follows image noise or shadows.

5. Implications for the land-use-planning methodology

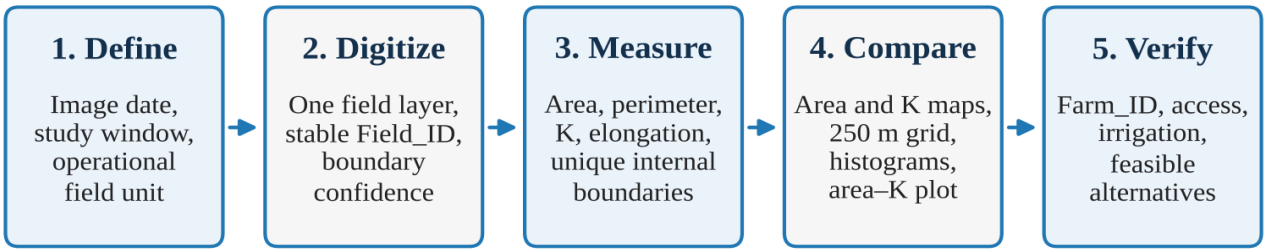

Figure 10. A single-layer workflow linking cartographic output to a reproducible land-use-planning decision.

5.1. Translating the three diagnostics into a planning decision

The proposed workflow separates diagnosis from intervention. Field-size composition identifies the structure of subdivision; K and elongation describe shape; shared-boundary density identifies concentrations of internal edges. None of them independently specifies a consolidation project. A planning record should preserve the original field identifier, the triggering diagnostic, the relevant physical or legal constraint and the alternative considered. This connects mapped evidence to a decision that can be reviewed rather than to an unexplained colour ranking [4,5].

The control comparisons are relevant precisely because they hold selected factors constant. C2 versus C1 isolates shape at fixed count and area. C1 versus C3 isolates subdivision while preserving square shape. M0–M2 demonstrate the additional consequences of merging. Together they provide a structured basis for interpreting the requested map suite: a planner can distinguish a shape problem from a field-count problem and avoid presenting every geometric change as the

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same improvement.

5.2. Empirical validation and the requested statistical graphics

The next empirical stage requires a dated, georeferenced image and a checked fields layer. Area and K histograms should use the same declared record set; the area–K scatterplot should retain individual Field_ID links so that outliers can be inspected. Rank correlation may complement the plot, but a coefficient is not evidence of causation. Adjacent fields may share management and spatial conditions, so any inferential analysis must address dependence rather than treating all polygons as independent replicates.

A second delineation or independent reference subset would help quantify boundary uncertainty. Sensitivity checks should vary digitising detail, edge inclusion and grid origin, while keeping the source definition explicit. Grid summaries should distinguish the gross window denominator from mapped agricultural area. Field and boundary totals should reconcile back to the same source layer. Neither an unknown gap nor an unmapped unit should be relabelled as a small field [7-14].

5.3. Feasibility, interpretation and limits

A same-farm aggregation test remains conditional on Farm_ID and spatial connectivity. Verified common management does not remove a canal, create a legal access route or establish a feasible irrigation layout. An alternative should therefore be rejected when it violates essential constraints, even if its compactness is higher. Costs, travel times, machinery performance and irrigation outcomes require their own observations; no percentage change in K can be converted directly into financial savings.

The available evidence supports a methodological study with deterministic benchmarks, not a completed empirical survey in Pastdarg‘om. Figure 1 provides regional orientation, Figures 2–6 are non-measurement illustrations, Figures 7–9

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are equation-based diagrams and Figure 10 specifies a proposed workflow. The map illustrations have not been repaired by a change in caption or attribution; their local coordinates, scales, class assignments and geometry remain unverified.

6. Conclusion

A coherent field-fragmentation study should derive its area map, compactness map, density grid and statistical graphics from one verified field layer. The proposed 2 × 2 km design contains a gross 400 ha and 64 full 250 m cells, but those dimensions do not establish the cultivated area or number of local fields. The analytical controls demonstrate three distinct mechanisms: shape can improve at fixed field count, subdivision can increase boundary density without changing compactness, and merging can change both count and shape.

For the 64-field controls, replacing 4:1 rectangles with squares increases K from 0.5027 to 0.7854 and reduces boundary density from 9 to 7 km/km². Splitting square layouts from 64 to 256 units leaves K constant and raises boundary density from 7 to 15 km/km². A 5% perimeter overstatement reduces K by 9.30%, showing that boundary quality can affect classification. These are reproducible geometric findings, not measured district outcomes. The illustrated map sequence is a presentation design; a local application requires dated imagery, stable identifiers, validated geometry and feasibility evidence.

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