

## Supplementary Materials

*An integrated GIS and remote sensing framework for district-level dengue risk assessment in northern India: development of a spatial Dengue Risk Index and assessment of its spatial concordance with reported incidence*

### Supplementary Note S1. Summary of data-processing corrections made during revision

1. Redundant predictors and rainfall source. In the supplied rasters, the ERA5-Land relative humidity layer was an exact linear function of the rainfall layer initially prepared from the same source (pixel-level  $r = 1.000$ ), so the two layers did not carry independent information. Rainfall was therefore re-derived from the India Meteorological Department (IMD) 0.25° daily gridded rainfall dataset as the 2025 annual total (277–1,033 mm within the district), and relative humidity was excluded. NDBI was the exact negative of NDMI ( $r = -1.000$ ; both computed from Landsat bands 5 and 6), and NDMI was excluded. ESI weights were re-derived from the  $6 \times 6$  sub-matrix of the original expert matrix (Tables S2–S3).
2. LULC scoring. The LULC raster stores class codes (1 water, 2 built-up, 3 agriculture, 4 vegetation, 5 open space, as defined in the Google Earth Engine classification). These codes had been used directly as suitability scores; they were recoded to the suitability scores stated in Table S1a (water 5, built-up 4, vegetation 3, agriculture 2, open space 1).
3. Direction of distance to river. The distance-to-river raster stores 1.6 km buffer bands (1 = nearest). It is now scored so that the nearest band receives score 5, consistent with the negative relationship stated in Table S11.
4. Aspect. Aspect is now classified into five circular sectors (Table S1a), replacing a linear 0–360° cut in which 1° and 359° fell in opposite classes.
5. Elevation and slope were scored negatively, as stated in Table S11.
6. Grid alignment. Input layers were on three different grids (a geographic 0.00027° grid and two UTM grids offset by non-integer pixels). All layers were resampled to one UTM Zone 44N 30 m reference grid (bilinear for continuous, nearest-neighbour for categorical layers) before overlay.
7. DRI construction and scale. The block DRI values in the previous Table 6 could not be reproduced from the reported ESI, HI, and VI values and weights. The DRI was therefore recomputed pixel-wise as  $0.540 \cdot \text{ESI} + 0.163 \cdot \text{HI} + 0.297 \cdot \text{VI}$  on the continuous 1–5 scale; block values are zonal means (Tables S21, S24).
8. Population denominators. Population density and incidence denominators now use WorldPop 2025 constrained estimates summed to block boundaries (Table S22). The Census 2011 figure for Chargaan excludes Gorakhpur city, and the Census population of Bharohiya was missing in the block attribute table.
9. Case data. Block-level laboratory-confirmed dengue cases were updated to the final 2025 line list (225 cases; Table S20).
10. AHP statistics. All weights and consistency statistics are now computed with the principal-eigenvector method (Table S12).
11. Elevation source. Elevation, slope, aspect, and TWI are derived from the Copernicus Global DEM GLO-30 (30 m), distributed by OpenTopography; earlier text that referred to the SRTM DEM has been corrected.
12. Bharohiya. No dengue cases were recorded for Bharohiya in the 2025 line list; the block was assigned zero cases, and a sensitivity analysis excluding it is reported in Table S23.

**Supplementary Table S1.** Reclassification criteria, suitability direction, and scientific basis used for standardizing the 14 retained predictor variables and the thematic indices.

| Domain | Predictor variable                        | Native resolution           | Scale               | Direction                            | Scientific basis of classification                                                                                                            |
|--------|-------------------------------------------|-----------------------------|---------------------|--------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------|
| ESI    | Land Surface Temperature (LST)            | 30 m                        | 1–5                 | Positive                             | Temperature regulates Aedes development, survival, biting activity, and dengue virus replication (Brady et al., 2014; Mordecai et al., 2017). |
| ESI    | Rainfall (IMD gridded, 2025 annual total) | 0.25° (~25 km)              | 1–5                 | Positive                             | Rainfall creates and replenishes breeding habitats (Lowe et al., 2018; Morin et al., 2013).                                                   |
| ESI    | NDVI                                      | 30 m                        | 1–5                 | Positive                             | Vegetation density influences habitat suitability and local microclimate.                                                                     |
| ESI    | MNDWI                                     | 30 m                        | 1–5                 | Positive                             | Surface-water distribution indicates potential breeding habitats.                                                                             |
| ESI    | NDBI                                      | 30 m                        | 1–5                 | Positive                             | Built-up environments are associated with Aedes aegypti breeding and human exposure.                                                          |
| ESI    | Land Use/Land Cover (LULC)                | 30 m                        | 1–5                 | Categorical                          | Land-cover classes differ in habitat suitability and human–vector contact.                                                                    |
| HI     | Elevation (DEM)                           | 30 m                        | 1–5                 | Negative                             | Low-lying areas accumulate water and drainage.                                                                                                |
| HI     | Slope                                     | 30 m                        | 1–5                 | Negative                             | Flat terrain retains surface water.                                                                                                           |
| HI     | Aspect                                    | 30 m                        | 1–5                 | Circular sectors                     | South-facing slopes receive more solar radiation (warmer); scored by direction, not degree.                                                   |
| HI     | Topographic Wetness Index (TWI)           | 30 m                        | 1–5                 | Positive                             | Indicates potential water accumulation.                                                                                                       |
| HI     | Distance to river                         | Vector (30 m grid)          | 1–5                 | Negative                             | Proximity to rivers increases moisture and breeding habitats.                                                                                 |
| VI     | Population density (WorldPop 2025)        | ~100 m, aggregated to block | 1–5                 | Positive                             | Population concentration increases human exposure.                                                                                            |
| VI     | Household density (Census 2011)           | Block level                 | 1–5                 | Positive                             | Residential clustering enhances human–vector contact.                                                                                         |
| VI     | Distance to health facilities             | Vector (30 m grid)          | 1–5                 | Positive (farther = more vulnerable) | Poorer access delays diagnosis and case management.                                                                                           |
| DRI    | ESI, HI, VI                               | 30 m                        | 1–5<br>(continuous) | Positive                             | Weighted linear combination of thematic indices (AHP weights).                                                                                |

*Note:* Relative humidity, NDMI, and Percent Vegetation were screened out as redundant (Supplementary Table S14). All thematic indices and the DRI are weighted means of 1–5 scores and therefore remain on the 1–5 scale without further rescaling.

**Supplementary Table S1a.** Numeric and categorical thresholds used to convert each retained predictor to the 1–5 suitability score (1 = Very Low, 5 = Very High).

| Variable                         | Method, direction        | Score 1       | Score 2       | Score 3       | Score 4       | Score 5       |
|----------------------------------|--------------------------|---------------|---------------|---------------|---------------|---------------|
| LST (°C)                         | Equal interval, positive | 22.97 – 27.47 | 27.47 – 31.97 | 31.97 – 36.48 | 36.48 – 40.98 | 40.98 – 45.48 |
| Rainfall, 2025 annual total (mm) | Equal interval, positive | 277 – 428     | 428 – 580     | 580 – 731     | 731 – 882     | 882 – 1033    |
| NDVI                             | Equal interval, positive | –0.26 – –0.04 | –0.04 – 0.19  | 0.19 – 0.41   | 0.41 – 0.64   | 0.64 – 0.86   |
| MNDWI                            | Equal interval, positive | –0.56 – –0.31 | –0.31 – –0.06 | –0.06 – 0.19  | 0.19 – 0.44   | 0.44 – 0.69   |
| NDBI                             | Equal interval, positive | –0.73 – –0.53 | –0.53 – –0.33 | –0.33 – –0.13 | –0.13 – 0.07  | 0.07 – 0.27   |

| Variable                                              | Method, direction           | Score 1         | Score 2                          | Score 3                         | Score 4                             | Score 5           |
|-------------------------------------------------------|-----------------------------|-----------------|----------------------------------|---------------------------------|-------------------------------------|-------------------|
| Elevation (m)                                         | Equal interval, negative    | 106.17 – 117.18 | 95.16 – 106.17                   | 84.14 – 95.16                   | 73.13 – 84.14                       | 62.12 – 73.13     |
| Slope (°)                                             | Equal interval, negative    | 21.98 – 27.47   | 16.48 – 21.98                    | 10.99 – 16.48                   | 5.49 – 10.99                        | 0.00 – 5.49       |
| TWI                                                   | Equal interval, positive    | 0.28 – 0.36     | 0.36 – 0.44                      | 0.44 – 0.53                     | 0.53 – 0.61                         | 0.61 – 0.69       |
| Aspect (°)                                            | Circular sectors            | N: 337.5–22.5   | NE/NW: 22.5–67.5,<br>292.5–337.5 | E/W: 67.5–112.5,<br>247.5–292.5 | SE/SW: 112.5–<br>157.5, 202.5–247.5 | S: 157.5–202.5    |
| LULC                                                  | Categorical                 | Open space      | Agriculture                      | Vegetation                      | Built-up                            | Water             |
| Distance to river (km)                                | Buffer bands, negative      | 6.4–8.0         | 4.8–6.4                          | 3.2–4.8                         | 1.6–3.2                             | 0–1.6             |
| Distance to health facility (km)                      | Buffer bands, positive      | 0–1.2           | 1.2–2.4                          | 2.4–3.6                         | 3.6–4.8                             | 4.8–6.0           |
| Population density 2025<br>(persons/km <sup>2</sup> ) | Jenks (20 blocks), positive | 1,058 – 1,346   | 1,347 – 1,651                    | 1,652 – 2,122                   | 2,123 – 2,468                       | 8,135 (Chargawan) |
| Household density (households/km <sup>2</sup> )       | Equal interval, positive    | 99.40 – 125.24  | 125.24 – 151.08                  | 151.08 – 176.92                 | 176.92 – 202.76                     | 202.76 – 228.60   |

*Note:* Equal-interval classes span the observed district minimum to maximum. For negatively scored variables the lowest values receive score 5. Aspect sectors: the north sector is continuous across 0°/360°. Population density classes were derived by Jenks Natural Breaks across the 20 block values; household density by equal intervals. The earlier version of this table labelled all thresholds as Jenks breaks; the thresholds were in fact equal intervals, which is now stated correctly.

**Supplementary Table S2.** Pairwise comparison matrix for the Environmental Suitability Index (ESI; six retained criteria).

| Criteria | LST | Rainfall | NDVI | MNDWI | NDBI | LULC |
|----------|-----|----------|------|-------|------|------|
| LST      | 1   | 3        | 8    | 6     | 9    | 4    |
| Rainfall | 1/3 | 1        | 6    | 4     | 7    | 2    |
| NDVI     | 1/8 | 1/6      | 1    | 1/3   | 2    | 1/4  |
| MNDWI    | 1/6 | 1/4      | 3    | 1     | 4    | 1    |
| NDBI     | 1/9 | 1/7      | 1/2  | 1/4   | 1    | 1/5  |
| LULC     | 1/4 | 1/2      | 4    | 1     | 5    | 1    |

*Note:* The matrix is the 6 × 6 sub-matrix of the original expert consensus matrix after removal of relative humidity and NDMI (redundant criteria); expert judgements are unchanged.  $\lambda_{\max} = 6.224$ ; CI = 0.045; RI = 1.24; CR = 0.036.

**Supplementary Table S3.** Final AHP weights for the ESI (principal-eigenvector method).

| Rank | Predictor variable | AHP weight |
|------|--------------------|------------|
| 1    | LST                | 0.463      |
| 2    | Rainfall           | 0.241      |
| 3    | LULC               | 0.125      |
| 4    | MNDWI              | 0.098      |
| 5    | NDVI               | 0.042      |

| Rank | Predictor variable | AHP weight |
|------|--------------------|------------|
| 6    | NDBI               | 0.030      |

Note: CR = 0.036. For comparison, the original eight-criterion weights were LST 0.341, RH 0.241, rainfall 0.169, LULC 0.087, MNDWI 0.068, NDMI 0.044, NDVI 0.029, NDBI 0.021.

**Supplementary Table S4.** Pairwise comparison matrix for the Hazard Index (HI).

| Criteria          | Elevation | Slope | Aspect | TWI | Distance to river |
|-------------------|-----------|-------|--------|-----|-------------------|
| Elevation         | 1         | 3     | 5      | 1/2 | 1/3               |
| Slope             | 1/3       | 1     | 3      | 1/4 | 1/5               |
| Aspect            | 1/5       | 1/3   | 1      | 1/6 | 1/7               |
| TWI               | 2         | 4     | 6      | 1   | 2                 |
| Distance to river | 3         | 5     | 7      | 1/2 | 1                 |

Note:  $\lambda_{\max} = 5.225$ ; CI = 0.056; RI = 1.12; CR = 0.050 (principal-eigenvector method).

**Supplementary Table S5.** Final AHP weights for the HI.

| Rank | Predictor variable | AHP weight |
|------|--------------------|------------|
| 1    | TWI                | 0.373      |
| 2    | Distance to river  | 0.331      |
| 3    | Elevation          | 0.175      |
| 4    | Slope              | 0.080      |
| 5    | Aspect             | 0.041      |

Note: Weights recomputed with the principal-eigenvector method (earlier approximate weights: TWI 0.367, distance to river 0.326, elevation 0.181, slope 0.079, aspect 0.047).

**Supplementary Table S6.** Pairwise comparison matrix for the Vulnerability Index (VI).

| Criteria                      | Population density | Household density | Distance to health facilities |
|-------------------------------|--------------------|-------------------|-------------------------------|
| Population density            | 1                  | 3                 | 2                             |
| Household density             | 1/3                | 1                 | 1/2                           |
| Distance to health facilities | 1/2                | 2                 | 1                             |

Note:  $\lambda_{\max} = 3.009$ ; CI = 0.0046; RI = 0.58; CR = 0.0079.

**Supplementary Table S7.** Final AHP weights for the VI.

| Rank | Predictor variable | AHP weight |
|------|--------------------|------------|
| 1    | Population density | 0.540      |

| Rank | Predictor variable            | AHP weight |
|------|-------------------------------|------------|
| 2    | Distance to health facilities | 0.297      |
| 3    | Household density             | 0.163      |

**Supplementary Table S8.** Pairwise comparison matrix for integrating the thematic indices into the DRI.

| Criteria | ESI | HI | VI  |
|----------|-----|----|-----|
| ESI      | 1   | 3  | 2   |
| HI       | 1/3 | 1  | 1/2 |
| VI       | 1/2 | 2  | 1   |

Note:  $\lambda_{\max} = 3.009$ ; CI = 0.0046; RI = 0.58; CR = 0.0079 (principal-eigenvector method).

**Supplementary Table S9.** Final AHP weights for constructing the DRI.

| Rank | Thematic index                        | AHP weight |
|------|---------------------------------------|------------|
| 1    | Environmental Suitability Index (ESI) | 0.540      |
| 2    | Vulnerability Index (VI)              | 0.297      |
| 3    | Hazard Index (HI)                     | 0.163      |

Note:  $DRI = 0.540 \cdot ESI + 0.163 \cdot HI + 0.297 \cdot VI$  (1–5 relative scale).

**Supplementary Table S10.** Summary of the GIS–AHP–WLC framework used to construct the DRI.

| Thematic index | Predictor variables                                                  | No. | Weighting | Integration                   | Output scale |
|----------------|----------------------------------------------------------------------|-----|-----------|-------------------------------|--------------|
| ESI            | LST, rainfall, NDVI, MNDWI, NDBI, LULC                               | 6   | AHP       | WLC                           | 1–5          |
| HI             | Elevation, slope, aspect, TWI, distance to river                     | 5   | AHP       | WLC                           | 1–5          |
| VI             | Population density, household density, distance to health facilities | 3   | AHP       | WLC                           | 1–5          |
| DRI            | ESI, HI, VI                                                          | 3   | AHP       | WLC; Jenks 5 relative classes | 1–5          |

**Supplementary Table S11.** Characteristics and expected relationship of predictor variables with dengue suitability.

| Domain | Predictor                     | Unit                       | Data source                            | Pre-processing                                               | Expected relationship                |
|--------|-------------------------------|----------------------------|----------------------------------------|--------------------------------------------------------------|--------------------------------------|
| ESI    | LST                           | °C                         | Landsat-8/9 TIRS                       | 2025 annual mean composite                                   | Positive                             |
| ESI    | Rainfall                      | mm                         | IMD 0.25° daily gridded rainfall       | 2025 annual total (sum of daily values); bilinear resampling | Positive                             |
| ESI    | NDVI                          | Index                      | Landsat-8/9                            | 2025 annual mean                                             | Positive                             |
| ESI    | MNDWI                         | Index                      | Landsat-8/9                            | 2025 annual mean                                             | Positive                             |
| ESI    | NDBI                          | Index                      | Landsat-8/9                            | 2025 annual mean                                             | Positive                             |
| ESI    | LULC                          | Categorical                | Landsat-8/9 (Random Forest)            | Post-monsoon composite                                       | Class-specific                       |
| HI     | Elevation                     | m                          | Copernicus DEM GLO-30 (OpenTopography) | —                                                            | Negative                             |
| HI     | Slope                         | Degrees                    | Derived from DEM                       | Terrain analysis                                             | Negative                             |
| HI     | Aspect                        | Degrees                    | Derived from DEM                       | Circular sectors                                             | Direction-specific (south = highest) |
| HI     | TWI                           | Index                      | Derived from DEM                       | Hydrological modelling                                       | Positive                             |
| HI     | Distance to river             | km                         | OpenStreetMap                          | Euclidean distance bands                                     | Negative                             |
| VI     | Population density            | Persons/km <sup>2</sup>    | WorldPop R2025A                        | Block total / block area                                     | Positive                             |
| VI     | Household density             | Households/km <sup>2</sup> | Census of India 2011                   | Block level                                                  | Positive                             |
| VI     | Distance to health facilities | km                         | OpenStreetMap / Health Department      | Euclidean distance bands                                     | Positive (poorer access)             |

*Note:* The earlier version listed distance to health facilities as "negative"; the scoring actually applied (and described in the main text) assigns higher vulnerability to greater distance.

**Supplementary Table S12.** Consistency statistics for the AHP pairwise comparison matrices (principal-eigenvector method).

| Matrix                    | No. of criteria | $\lambda_{max}$ | CI     | RI   | CR     |
|---------------------------|-----------------|-----------------|--------|------|--------|
| Environmental Suitability | 6               | 6.224           | 0.045  | 1.24 | 0.036  |
| Hazard                    | 5               | 5.225           | 0.056  | 1.12 | 0.050  |
| Vulnerability             | 3               | 3.009           | 0.0046 | 0.58 | 0.0079 |
| DRI thematic              | 3               | 3.009           | 0.0046 | 0.58 | 0.0079 |

*Note:* All CR < 0.10. This table supersedes the previous Tables S12 and S17 (approximate vs eigenvector audit).

**Supplementary Table S13.** Composition of the multidisciplinary expert panel used for AHP weight derivation.

| Discipline                        | No. of experts | Professional experience (years) |
|-----------------------------------|----------------|---------------------------------|
| Public Health                     | 2              | 4–6                             |
| Epidemiology                      | 1              | 5                               |
| Climatology                       | 1              | 6                               |
| Environmental Science             | 1              | 4                               |
| GIS and Remote Sensing            | 1              | 3                               |
| Medical Geography                 | 1              | 8                               |
| Vector-borne Disease (Entomology) | 1              | 4                               |
| Total                             | 8              | 3–8 (mean 5)                    |

**Supplementary Table S14.** Predictor redundancy screening across the ESI, HI, and VI domains.

| Domain | Pair                                             | Pearson r | Spearman $\rho$ | Decision                                                                                            |
|--------|--------------------------------------------------|-----------|-----------------|-----------------------------------------------------------------------------------------------------|
| ESI    | Relative humidity – Rainfall, initial ERA5 layer | 1.000     | 1.000           | Removed (RH): identical to the initial ERA5-Land rainfall layer, which was replaced by IMD rainfall |
| ESI    | Relative humidity – Rainfall (IMD)               | 0.468     | 0.443           | RH not retained (provenance; see Methods)                                                           |
| ESI    | NDMI – NDBI                                      | –1.000    | –1.000          | Removed (NDMI): NDBI = –NDMI algebraically (same bands)                                             |
| ESI    | MNDWI – NDBI                                     | –0.515    | –0.364          | Retained                                                                                            |
| ESI    | NDVI – NDBI                                      | –0.467    | –0.716          | Retained                                                                                            |
| ESI    | NDVI – MNDWI                                     | –0.459    | –0.140          | Retained                                                                                            |
| ESI    | LST – NDBI                                       | 0.415     | 0.359           | Retained                                                                                            |
| ESI    | LST – NDVI                                       | –0.209    | –0.279          | Retained                                                                                            |
| ESI    | LST – Rainfall (IMD)                             | 0.067     | 0.080           | Retained                                                                                            |
| ESI    | Rainfall (IMD) – NDVI                            | –0.005    | –0.005          | Retained                                                                                            |
| ESI    | Percent Vegetation – NDVI                        | 0.800     | 0.950           | Removed (PV) in the previous revision                                                               |
| HI     | Elevation – Slope (scores)                       | 0.125     | 0.092           | Retained                                                                                            |
| HI     | Elevation – Aspect (scores)                      | –0.042    | –0.044          | Retained                                                                                            |
| HI     | Elevation – TWI (scores)                         | 0.226     | 0.212           | Retained                                                                                            |

| Domain | Pair                                                                     | Pearson r | Spearman $\rho$ | Decision |
|--------|--------------------------------------------------------------------------|-----------|-----------------|----------|
| HI     | Elevation – Distance to river (scores)                                   | 0.118     | 0.143           | Retained |
| HI     | Slope – Aspect (scores)                                                  | 0.005     | 0.003           | Retained |
| HI     | Slope – TWI (scores)                                                     | 0.213     | 0.229           | Retained |
| HI     | Slope – Distance to river (scores)                                       | 0.012     | 0.007           | Retained |
| HI     | Aspect – TWI (scores)                                                    | –0.059    | –0.040          | Retained |
| HI     | Aspect – Distance to river (scores)                                      | 0.016     | 0.011           | Retained |
| HI     | TWI – Distance to river (scores)                                         | –0.004    | 0.005           | Retained |
| VI     | Population density – Household density (block level, n = 20)             | 0.535     | 0.334           | Retained |
| VI     | Population density – Distance to health facilities (block level, n = 20) | 0.169     | –0.444          | Retained |
| VI     | Household density – Distance to health facilities (block level, n = 20)  | 0.024     | 0.039           | Retained |

*Note:* ESI and HI correlations are pixel-level (random sample of 200,000 district pixels); ESI values use raw variables, HI values use 1–5 scores. Exact collinearity ( $|r| = 1.000$ ) led to removal of one variable of each pair.

**Supplementary Table S14a.** Association of LULC class with continuous ESI predictors (eta-squared, correlation ratio).

| Continuous variable | Eta-squared | Eta   |
|---------------------|-------------|-------|
| MNDWI               | 0.454       | 0.674 |
| NDVI                | 0.283       | 0.532 |
| NDBI                | 0.125       | 0.353 |
| LST                 | 0.041       | 0.202 |
| Rainfall            | 0.003       | 0.052 |

*Note:* LULC class codes follow the Google Earth Engine classification: 1 = water, 2 = built-up, 3 = agriculture, 4 = vegetation, 5 = open space; suitability scores were then assigned as in Table S1a.

**Supplementary Table S15.** Confusion matrix and accuracy assessment of the Land Use/Land Cover classification (independent 30% hold-out sample, n = 1,498 pixels; rows = reference, columns = classified).

| Reference \ Classified | Water | Built-up | Agriculture | Vegetation | Open space | Row total | Producer's accuracy |
|------------------------|-------|----------|-------------|------------|------------|-----------|---------------------|
| Water                  | 224   | 2        | 15          | 17         | 28         | 286       | 78.32%              |

| Reference \ Classified | Water  | Built-up | Agriculture | Vegetation | Open space | Row total | Producer's accuracy |
|------------------------|--------|----------|-------------|------------|------------|-----------|---------------------|
| Built-up               | 0      | 246      | 60          | 2          | 0          | 308       | 79.87%              |
| Agriculture            | 6      | 61       | 210         | 18         | 2          | 297       | 70.71%              |
| Vegetation             | 12     | 7        | 15          | 238        | 26         | 298       | 79.87%              |
| Open space             | 27     | 1        | 2           | 15         | 264        | 309       | 85.44%              |
| Column total           | 269    | 317      | 302         | 290        | 320        | 1,498     | –                   |
| User's accuracy        | 83.27% | 77.60%   | 69.54%      | 82.07%     | 82.50%     | –         | –                   |

*Note:* Overall accuracy = 78.91% (1,182 of 1,498 pixels correctly classified); kappa coefficient = 0.736 (substantial agreement). Matrix exported directly from the Random Forest classification output (Google Earth Engine errorMatrix); the previous version of this table contained transcription errors in the cell counts, but the reported accuracy statistics were correct and are unchanged.

**Supplementary Table S16.** Sensitivity of block rankings and spatial concordance to the thematic (ESI/HI/VI) weights.

| Scenario                                        | W(ESI) | W(HI) | W(VI) | Spearman $\rho$ vs baseline ranking | Top-5 blocks retained | Pearson r with incidence | Spearman $\rho$ with incidence |
|-------------------------------------------------|--------|-------|-------|-------------------------------------|-----------------------|--------------------------|--------------------------------|
| Baseline AHP                                    | 0.540  | 0.163 | 0.297 | 1.000                               | 5/5                   | 0.164                    | -0.003                         |
| Equal weights                                   | 0.333  | 0.333 | 0.333 | 0.926                               | 5/5                   | 0.187                    | 0.070                          |
| ESI +20%                                        | 0.585  | 0.147 | 0.268 | 0.973                               | 4/5                   | 0.156                    | -0.014                         |
| ESI –20%                                        | 0.484  | 0.183 | 0.333 | 0.973                               | 5/5                   | 0.169                    | 0.044                          |
| VI +20%                                         | 0.510  | 0.154 | 0.336 | 0.976                               | 5/5                   | 0.166                    | 0.049                          |
| VI –20%                                         | 0.574  | 0.173 | 0.253 | 0.965                               | 4/5                   | 0.156                    | -0.003                         |
| HI +20%                                         | 0.523  | 0.189 | 0.288 | 0.998                               | 4/5                   | 0.166                    | 0.016                          |
| HI –20%                                         | 0.558  | 0.135 | 0.307 | 1.000                               | 5/5                   | 0.161                    | -0.003                         |
| 8-criterion ESI (RH, NDMI retained)             | 0.540  | 0.163 | 0.297 | 0.770                               | 3/5                   | 0.241                    | 0.145                          |
| Rainfall as Jun–Oct total (transmission season) | 0.540  | 0.163 | 0.297 | 0.992                               | 5/5                   | 0.164                    | -0.001                         |

*Note:*  $\pm 20\%$  scenarios change one thematic weight by 20% and renormalize the three weights to sum to one. The 8-criterion scenario retains relative humidity and NDMI with the original eight-criterion AHP weights. The transmission-season scenario replaces annual rainfall with the June–October 2025 IMD total (220–904 mm). Incidence uses WorldPop 2025 denominators ( $n = 20$ ).

**Supplementary Table S17.** Criterion-level sensitivity: effect of  $\pm 10\%$  perturbation of each criterion weight (renormalized within its index) on block-level DRI.

| Index | Criterion | Weight | Mean DRI change –10% (%) | $\rho$ vs baseline (–10%) | Top-5 retained (–10%) | Mean DRI change +10% (%) | $\rho$ vs baseline (+10%) | Top-5 retained (+10%) |
|-------|-----------|--------|--------------------------|---------------------------|-----------------------|--------------------------|---------------------------|-----------------------|
| ESI   | LST       | 0.463  | 0.085                    | 0.998                     | 4/5                   | –0.073                   | 0.998                     | 5/5                   |
| ESI   | Rainfall  | 0.241  | –0.220                   | 0.997                     | 5/5                   | 0.214                    | 0.997                     | 4/5                   |
| ESI   | NDVI      | 0.042  | –0.070                   | 0.998                     | 4/5                   | 0.073                    | 1.000                     | 5/5                   |
| ESI   | MNDWI     | 0.098  | 0.308                    | 0.998                     | 4/5                   | –0.297                   | 1.000                     | 5/5                   |

| Index | Criterion                     | Weight | Mean DRI change −10% (%) | ρ vs baseline (−10%) | Top-5 retained (−10%) | Mean DRI change +10% (%) | ρ vs baseline (+10%) | Top-5 retained (+10%) |
|-------|-------------------------------|--------|--------------------------|----------------------|-----------------------|--------------------------|----------------------|-----------------------|
| ESI   | NDBI                          | 0.030  | −0.054                   | 0.998                | 4/5                   | 0.058                    | 1.000                | 5/5                   |
| ESI   | LULC                          | 0.125  | −0.035                   | 0.998                | 4/5                   | 0.039                    | 1.000                | 5/5                   |
| HI    | Elevation                     | 0.175  | −0.074                   | 1.000                | 5/5                   | 0.076                    | 1.000                | 5/5                   |
| HI    | Slope                         | 0.080  | −0.072                   | 1.000                | 5/5                   | 0.075                    | 1.000                | 5/5                   |
| HI    | Aspect                        | 0.041  | 0.012                    | 1.000                | 5/5                   | −0.008                   | 1.000                | 5/5                   |
| HI    | TWI                           | 0.373  | 0.217                    | 1.000                | 5/5                   | −0.197                   | 1.000                | 5/5                   |
| HI    | Distance to river             | 0.331  | −0.068                   | 1.000                | 5/5                   | 0.068                    | 0.998                | 4/5                   |
| VI    | Population density            | 0.540  | 0.069                    | 0.997                | 4/5                   | −0.057                   | 0.994                | 5/5                   |
| VI    | Household density             | 0.163  | −0.112                   | 0.997                | 4/5                   | 0.113                    | 1.000                | 5/5                   |
| VI    | Distance to health facilities | 0.297  | 0.053                    | 0.995                | 5/5                   | −0.046                   | 0.998                | 4/5                   |

Note: Supersedes the previous Table S23, whose weights did not correspond to the reported AHP weights.

**Supplementary Table S18.** Spatial data sources, resolution, and acquisition details.

| Variable                      | Type          | Data source                                                                                     | Spatial / temporal resolution                               | Period          |
|-------------------------------|---------------|-------------------------------------------------------------------------------------------------|-------------------------------------------------------------|-----------------|
| LST                           | Environmental | Landsat-8/9 TIRS (Collection 2 Level-2)                                                         | 30 m / annual mean composite                                | 2025            |
| Rainfall                      | Climatic      | India Meteorological Department (IMD) high-resolution daily gridded rainfall (Pai et al., 2014) | 0.25° × 0.25° (~25 km) / daily, summed to annual total (mm) | 2025            |
| NDVI                          | Environmental | Landsat-8/9 OLI (bands 4, 5)                                                                    | 30 m / annual mean                                          | 2025            |
| MNDWI                         | Environmental | Landsat-8/9 OLI (bands 3, 6)                                                                    | 30 m / annual mean                                          | 2025            |
| NDBI                          | Environmental | Landsat-8/9 OLI (bands 5, 6)                                                                    | 30 m / annual mean                                          | 2025            |
| LULC                          | Environmental | Landsat-8/9; Random Forest; GLC-FCS30D reference                                                | 30 m / post-monsoon composite                               | 2025            |
| Elevation, slope, aspect, TWI | Topographic   | Copernicus Global DEM GLO-30, distributed by OpenTopography (doi:10.5069/G9028PQB)              | 30 m / static                                               | 2021 release    |
| Distance to river             | Hydrological  | OpenStreetMap                                                                                   | Vector → 30 m grid                                          | 2025 extraction |

| Variable                               | Type              | Data source                                                                                                                                                                                                                                     | Spatial / temporal resolution                          | Period          |
|----------------------------------------|-------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------|-----------------|
| Distance to health facilities          | Accessibility     | OpenStreetMap / District Health Department                                                                                                                                                                                                      | Vector → 30 m grid                                     | 2025 extraction |
| Population                             | Socio-demographic | WorldPop Global2 constrained estimates of total number of people per grid square, R2025A version v1 (Bondarenko et al., 2025; doi:10.5258/SOTON/WP00839). Random Forest-based dasymetric redistribution; WGS84; people per pixel; alpha release | 3 arc-seconds (~100 m at the equator), summed to block | 2025            |
| Household density                      | Socio-demographic | Census of India                                                                                                                                                                                                                                 | Block level                                            | 2011            |
| Dengue cases                           | Epidemiological   | District Health Surveillance System (IDSP), Gorakhpur                                                                                                                                                                                           | Block level, laboratory-confirmed                      | Jan–Dec 2025    |
| Relative humidity, NDMI (screened out) | —                 | ERA5-Land; Landsat-8/9                                                                                                                                                                                                                          | —                                                      | 2025            |
| Rainfall, initial layer (replaced)     | —                 | ERA5-Land (identical to relative humidity layer, $r = 1.000$ )                                                                                                                                                                                  | —                                                      | 2025            |

**Supplementary Table S19.** Summary statistics of predictor variables within Gorakhpur district (30 m pixels unless stated).

| Variable                          | Unit                       | Min   | Max    | Mean   | SD    |
|-----------------------------------|----------------------------|-------|--------|--------|-------|
| LST                               | °C                         | 22.96 | 45.60  | 32.69  | 2.30  |
| Rainfall (2025 annual total, IMD) | mm                         | 277.1 | 1033.4 | 688.9  | 203.0 |
| NDVI                              | —                          | −0.26 | 0.86   | 0.43   | 0.11  |
| MNDWI                             | —                          | −0.56 | 0.69   | −0.36  | 0.11  |
| NDBI                              | —                          | −0.78 | 0.29   | −0.09  | 0.09  |
| Elevation                         | m                          | 61.44 | 121.63 | 76.89  | 4.69  |
| Slope                             | °                          | 0.00  | 29.46  | 1.35   | 1.60  |
| Aspect                            | °                          | 0.00  | 360.00 | —      | —     |
| TWI                               | —                          | 0.28  | 0.69   | 0.44   | 0.09  |
| Population density 2025 (blocks)  | persons/km <sup>2</sup>    | 1,058 | 8,135  | 1,889  | 1,520 |
| Household density (blocks)        | households/km <sup>2</sup> | 99.48 | 228.60 | 163.20 | 32.58 |
| Relative humidity (screened out)  | %                          | 46.78 | 51.90  | 48.30  | 1.42  |
| NDMI (screened out)               | —                          | −0.29 | 0.78   | 0.09   | 0.09  |

*Note:* Aspect is circular; its arithmetic mean is not meaningful and is not reported.

**Supplementary Table S20.** Block-level dengue cases, 2025 population, observed and regression-estimated incidence (per 100,000).

| S. No | Block         | Mean DRI | Cases 2025 | Population 2025 (WorldPop) | Observed incidence | Estimated incidence | Residual |
|-------|---------------|----------|------------|----------------------------|--------------------|---------------------|----------|
| 1     | Campierganj   | 2.757    | 8          | 244,720                    | 3.27               | 2.63                | 0.64     |
| 2     | Jungle Kaudia | 2.992    | 13         | 181,219                    | 7.17               | 2.97                | 4.20     |
| 3     | Chargawan     | 3.351    | 110        | 1,935,207                  | 5.68               | 3.48                | 2.20     |
| 4     | Pali          | 2.820    | 2          | 156,151                    | 1.28               | 2.72                | -1.44    |
| 5     | Pipraich      | 2.815    | 11         | 300,961                    | 3.65               | 2.72                | 0.94     |
| 6     | Sahjanwa      | 3.085    | 3          | 313,729                    | 0.96               | 3.10                | -2.15    |
| 7     | Piprauli      | 2.987    | 4          | 291,605                    | 1.37               | 2.96                | -1.59    |
| 8     | Khorabar      | 2.778    | 9          | 388,454                    | 2.32               | 2.66                | -0.35    |
| 9     | Sardarnagar   | 2.877    | 0          | 295,218                    | 0.00               | 2.80                | -2.80    |
| 10    | Khajni        | 2.876    | 9          | 257,505                    | 3.50               | 2.80                | 0.69     |
| 11    | Bansgaon      | 2.687    | 17         | 247,608                    | 6.87               | 2.53                | 4.33     |
| 12    | Brahmpur      | 2.174    | 3          | 235,169                    | 1.28               | 1.80                | -0.53    |
| 13    | Kauriram      | 2.516    | 2          | 229,561                    | 0.87               | 2.29                | -1.42    |
| 14    | Uruwa         | 2.837    | 1          | 333,837                    | 0.30               | 2.75                | -2.45    |
| 15    | Gola          | 2.721    | 4          | 235,818                    | 1.70               | 2.58                | -0.89    |
| 16    | Barhalganj    | 2.450    | 10         | 264,041                    | 3.79               | 2.20                | 1.59     |
| 17    | Bhathat       | 2.530    | 12         | 226,833                    | 5.29               | 2.31                | 2.98     |
| 18    | Bharohiya     | 2.751    | 0          | 175,725                    | 0.00               | 2.62                | -2.62    |
| 19    | Belghat       | 2.783    | 3          | 184,168                    | 1.63               | 2.67                | -1.04    |
| 20    | Gagaha        | 2.556    | 4          | 196,336                    | 2.04               | 2.35                | -0.31    |
|       | Total         |          | 225        | 6,693,865                  | 3.36               |                     |          |

*Note:* OLS: incidence =  $-1.301 + 1.427 \times \text{mean DRI}$  ( $n = 20$ ). Case counts from the 2025 block-wise line list (225 cases); the single case reported under "Gorakhpur Urban" was assigned to Chargawan, which contains the city; Derwa, Karauta and Ragar Ganj reported no cases; Bharohiya had no cases recorded in the line list and is recorded as 0 (sensitivity analysis excluding Bharohiya in Table S23).

**Supplementary Table S21.** Zonal statistics of the DRI raster by block (30 m pixels).

| Block         | Pixels  | Min   | Max   | Mean  | Median | SD    |
|---------------|---------|-------|-------|-------|--------|-------|
| Campierganj   | 250,633 | 1.875 | 3.606 | 2.757 | 2.771  | 0.224 |
| Jungle Kaudia | 149,430 | 2.276 | 3.613 | 2.992 | 2.992  | 0.161 |
| Chargawan     | 264,305 | 2.531 | 4.280 | 3.351 | 3.346  | 0.252 |
| Pali          | 154,689 | 1.951 | 3.557 | 2.820 | 2.821  | 0.178 |
| Pipraich      | 156,523 | 2.224 | 3.482 | 2.815 | 2.816  | 0.177 |

| Block       | Pixels  | Min   | Max   | Mean  | Median | SD    |
|-------------|---------|-------|-------|-------|--------|-------|
| Sahjanwa    | 179,373 | 2.233 | 3.974 | 3.085 | 3.093  | 0.183 |
| Piprauli    | 179,117 | 2.128 | 3.895 | 2.987 | 2.972  | 0.256 |
| Khorabar    | 174,890 | 2.006 | 3.655 | 2.778 | 2.774  | 0.195 |
| Sardarnagar | 140,726 | 2.264 | 3.522 | 2.877 | 2.870  | 0.160 |
| Khajni      | 186,272 | 1.939 | 3.537 | 2.876 | 2.885  | 0.222 |
| Bansgaon    | 183,102 | 1.986 | 3.455 | 2.687 | 2.678  | 0.180 |
| Brahmpur    | 202,841 | 1.425 | 3.119 | 2.174 | 2.162  | 0.201 |
| Kauriram    | 175,702 | 1.686 | 3.526 | 2.516 | 2.511  | 0.186 |
| Uruwa       | 265,739 | 2.041 | 3.611 | 2.837 | 2.846  | 0.189 |
| Gola        | 157,260 | 2.089 | 3.586 | 2.721 | 2.714  | 0.190 |
| Barhalganj  | 226,975 | 1.699 | 3.353 | 2.450 | 2.441  | 0.188 |
| Bhathat     | 172,769 | 1.945 | 3.250 | 2.530 | 2.506  | 0.205 |
| Bharohiya   | 132,320 | 2.109 | 3.464 | 2.751 | 2.761  | 0.184 |
| Belghat     | 176,463 | 1.934 | 3.796 | 2.783 | 2.769  | 0.201 |
| Gagaha      | 155,780 | 1.963 | 3.276 | 2.556 | 2.552  | 0.156 |

**Supplementary Table S22.** Comparison of Census 2011 and WorldPop 2025 denominators and resulting incidence (per 100,000).

| Block         | Cases 2025 | Population,<br>Census 2011<br>(shapefile) | Population,<br>WorldPop 2025 | Incidence<br>(Census) | Incidence<br>(WorldPop) | Area (km <sup>2</sup> ) | Population<br>density 2025 |
|---------------|------------|-------------------------------------------|------------------------------|-----------------------|-------------------------|-------------------------|----------------------------|
| Campierganj   | 8          | 274,914                                   | 244,720                      | 2.91                  | 3.27                    | 231.3                   | 1,058                      |
| Jungle Kaudia | 13         | 235,235                                   | 181,219                      | 5.53                  | 7.17                    | 134.5                   | 1,347                      |
| Chargawan     | 110        | 208,230                                   | 1,935,207                    | 52.83                 | 5.68                    | 237.9                   | 8,135                      |
| Pali          | 2          | 144,080                                   | 156,151                      | 1.39                  | 1.28                    | 140.9                   | 1,108                      |
| Pipraich      | 11         | 188,645                                   | 300,961                      | 5.83                  | 3.65                    | 141.8                   | 2,123                      |
| Sahjanwa      | 3          | 151,488                                   | 313,729                      | 1.98                  | 0.96                    | 163.1                   | 1,923                      |
| Piprauli      | 4          | 190,262                                   | 291,605                      | 2.10                  | 1.37                    | 161.2                   | 1,809                      |
| Khorabar      | 9          | 203,081                                   | 388,454                      | 4.43                  | 2.32                    | 157.4                   | 2,468                      |
| Sardarnagar   | 0          | 178,005                                   | 295,218                      | 0.00                  | 0.00                    | 128.0                   | 2,307                      |
| Khajni        | 9          | 196,763                                   | 257,505                      | 4.57                  | 3.50                    | 168.4                   | 1,529                      |
| Bansgaon      | 17         | 176,523                                   | 247,608                      | 9.63                  | 6.87                    | 164.8                   | 1,503                      |
| Brahmpur      | 3          | 193,681                                   | 235,169                      | 1.55                  | 1.28                    | 184.3                   | 1,276                      |
| Kauriram      | 2          | 176,345                                   | 229,561                      | 1.13                  | 0.87                    | 158.5                   | 1,448                      |

| Block      | Cases 2025 | Population, Census 2011 (shapefile) | Population, WorldPop 2025 | Incidence (Census) | Incidence (WorldPop) | Area (km <sup>2</sup> ) | Population density 2025 |
|------------|------------|-------------------------------------|---------------------------|--------------------|----------------------|-------------------------|-------------------------|
| Uruwa      | 1          | 202,021                             | 333,837                   | 0.49               | 0.30                 | 239.7                   | 1,393                   |
| Gola       | 4          | 167,583                             | 235,818                   | 2.39               | 1.70                 | 142.7                   | 1,652                   |
| Barhalganj | 10         | 182,977                             | 264,041                   | 5.47               | 3.79                 | 208.2                   | 1,268                   |
| Bhathat    | 12         | 193,535                             | 226,833                   | 6.20               | 5.29                 | 157.2                   | 1,443                   |
| Bharohiya  | 0          | missing                             | 175,725                   | —                  | 0.00                 | 121.0                   | 1,452                   |
| Belghat    | 3          | 195,776                             | 184,168                   | 1.53               | 1.63                 | 161.1                   | 1,143                   |
| Gagaha     | 4          | 185,525                             | 196,336                   | 2.16               | 2.04                 | 141.2                   | 1,390                   |

*Note:* The Census figure for Chargawan (208,230) refers to the rural block only, whereas the block polygon (237.9 km<sup>2</sup>) contains Gorakhpur city (WorldPop 1,935,207). The Census population for Bharohiya was missing (0) in the shapefile attribute table, whose area and density fields had been copied from Jungle Kaudia.

**Supplementary Table S23.** Spatial concordance statistics under the primary analysis and sensitivity analyses.

| Analysis set                                      | n  | Pearson r | p     | Bootstrap 95% CI | Spearman $\rho$ | p     | Kendall $\tau$ | R <sup>2</sup> | RMSE  | MAE   | Shapiro–Wilk residuals W (p) | Breusch–Pagan $\chi^2$ (p) | Max Cook's D         | NB IRR per 0.1 DRI (95% CI) |
|---------------------------------------------------|----|-----------|-------|------------------|-----------------|-------|----------------|----------------|-------|-------|------------------------------|----------------------------|----------------------|-----------------------------|
| Primary: WorldPop 2025 denominators, all blocks   | 20 | 0.164     | 0.491 | −0.41 to 0.53    | −0.003          | 0.990 | −0.026         | 0.027          | 2.107 | 1.758 | 0.929 (0.149)                | 0.76 (0.382)               | Chargawan (0.37)     | 1.05 (0.91–1.21); p = 0.498 |
| WorldPop, excluding Chargawan                     | 19 | −0.019    | 0.940 | −0.52 to 0.38    | −0.142          | 0.562 | −0.117         | 0.000          | 2.071 | 1.696 | 0.891 (0.034)                | 0.52 (0.470)               | Jungle Kaudia (0.40) | 0.98 (0.81–1.20); p = 0.878 |
| WorldPop, excluding Bharohiya (no reported cases) | 19 | 0.166     | 0.497 | −0.41 to 0.55    | −0.030          | 0.904 | −0.053         | 0.028          | 2.072 | 1.735 | 0.934 (0.208)                | 0.86 (0.353)               | Chargawan (0.35)     | 1.05 (0.92–1.20); p = 0.485 |
| Census 2011 denominators, excluding Bharohiya     | 19 | 0.524     | 0.021 | −0.39 to 0.80    | −0.005          | 0.983 | −0.006         | 0.274          | 9.637 | 6.720 | 0.800 (0.001)                | 5.92 (0.015)               | Chargawan (4.04)     | 1.25 (1.09–1.42); p = 0.001 |
| Census 2011, excluding Bharohiya and Chargawan    | 18 | −0.065    | 0.799 | −0.51 to 0.32    | −0.183          | 0.468 | −0.124         | 0.004          | 2.424 | 2.065 | 0.911 (0.091)                | 0.15 (0.702)               | Brahmpur (0.47)      | 0.98 (0.82–1.16); p = 0.804 |

Note: Poisson dispersion ratio (primary analysis) = 4.59. The apparently strong Census-based correlation is driven entirely by Chargawan (Cook's D = 6.08), whose Census denominator excludes Gorakhpur city.

**Supplementary Table S24.** Zonal statistics of the ESI, HI, and VI rasters by block (1–5 scale).

| Block         | ESI mean | HI mean | VI mean | ESI range   | HI range    | VI range    |
|---------------|----------|---------|---------|-------------|-------------|-------------|
| Campierganj   | 3.017    | 3.335   | 1.963   | 1.911–4.061 | 1.371–4.825 | 1.000–2.678 |
| Jungle Kaudia | 3.154    | 3.702   | 2.306   | 2.034–4.129 | 2.308–5.000 | 1.540–3.381 |
| Chargawan     | 2.921    | 3.075   | 4.284   | 1.683–4.338 | 1.296–5.000 | 3.158–5.000 |
| Pali          | 3.236    | 3.468   | 1.709   | 2.140–4.129 | 1.828–5.000 | 1.000–2.515 |
| Pipraich      | 2.342    | 3.277   | 3.418   | 1.637–3.405 | 1.591–4.825 | 3.109–4.000 |
| Sahjanwa      | 3.186    | 3.404   | 2.725   | 2.140–4.647 | 1.552–5.000 | 2.243–3.594 |
| Piprauli      | 2.845    | 3.625   | 2.894   | 1.416–4.159 | 2.098–5.000 | 2.243–3.460 |
| Khorabar      | 2.208    | 3.432   | 3.452   | 1.175–3.604 | 1.572–5.000 | 2.782–4.297 |
| Sardarnagar   | 2.322    | 3.313   | 3.643   | 1.187–3.405 | 1.842–4.959 | 2.782–4.460 |
| Khajni        | 3.050    | 3.502   | 2.216   | 1.881–4.129 | 1.591–5.000 | 1.703–2.891 |
| Bansgaon      | 2.697    | 3.486   | 2.229   | 1.880–3.887 | 1.882–5.000 | 1.866–3.054 |
| Brahmpur      | 2.060    | 3.661   | 1.564   | 1.175–3.405 | 2.213–5.000 | 1.163–2.515 |
| Kauriram      | 2.426    | 3.372   | 2.208   | 1.175–3.898 | 1.767–5.000 | 1.703–3.054 |
| Uruwa         | 2.970    | 3.423   | 2.273   | 1.795–4.139 | 1.882–5.000 | 1.703–3.054 |
| Gola          | 2.667    | 3.229   | 2.539   | 1.848–3.761 | 1.552–5.000 | 2.243–3.430 |
| Barhalganj    | 2.597    | 3.454   | 1.632   | 1.564–3.856 | 1.767–5.000 | 1.163–2.351 |
| Bhathat       | 2.377    | 3.358   | 2.351   | 1.511–3.341 | 1.452–4.825 | 1.540–3.218 |
| Bharohiya     | 3.059    | 3.261   | 1.911   | 2.089–3.948 | 1.591–4.838 | 1.540–2.787 |
| Belghat       | 3.118    | 3.455   | 1.803   | 2.121–4.381 | 1.591–4.838 | 1.327–2.515 |
| Gagaha        | 2.553    | 3.494   | 2.045   | 1.638–3.645 | 1.767–5.000 | 1.703–2.891 |

**Supplementary Table S25.** Pearson (lower triangle) and Spearman (upper triangle) correlation matrix of candidate ESI predictors (pixel level).

| Variable                     | LST    | Rainfall (IMD) | Rainfall, initial ERA5 layer | Relative humidity | NDVI   | NDMI   | MNDWI  | NDBI   |
|------------------------------|--------|----------------|------------------------------|-------------------|--------|--------|--------|--------|
| LST                          | 1      | 0.080          | −0.287                       | −0.287            | −0.279 | −0.359 | −0.017 | 0.359  |
| Rainfall (IMD)               | 0.067  | 1              | 0.443                        | 0.443             | −0.005 | −0.052 | 0.012  | 0.052  |
| Rainfall, initial ERA5 layer | −0.225 | 0.468          | 1                            | 1.000             | 0.177  | 0.086  | −0.051 | −0.086 |
| Relative humidity            | −0.225 | 0.468          | 1.000                        | 1                 | 0.177  | 0.086  | −0.051 | −0.086 |

| Variable | LST    | Rainfall (IMD) | Rainfall, initial ERA5 layer | Relative humidity | NDVI   | NDMI   | MNDWI  | NDBI   |
|----------|--------|----------------|------------------------------|-------------------|--------|--------|--------|--------|
| NDVI     | −0.209 | −0.005         | 0.182                        | 0.182             | 1      | 0.716  | −0.140 | −0.716 |
| NDMI     | −0.415 | −0.042         | 0.111                        | 0.111             | 0.467  | 1      | 0.364  | −1.000 |
| MNDWI    | −0.198 | 0.002          | −0.021                       | −0.021            | −0.459 | 0.515  | 1      | −0.364 |
| NDBI     | 0.415  | 0.042          | −0.111                       | −0.111            | −0.467 | −1.000 | −0.515 | 1      |

*Note:* Random sample of 200,000 district pixels. Relative humidity, NDMI, and the initial ERA5-Land rainfall layer are shown to document their exclusion or replacement.

**Supplementary Table S26.** Pearson (lower) and Spearman (upper) correlations among vulnerability predictors (block level, n = 20).

| Variable                      | Population density | Household density | Distance to health facilities |
|-------------------------------|--------------------|-------------------|-------------------------------|
| Population density            | 1                  | 0.334             | −0.444                        |
| Household density             | 0.535              | 1                 | 0.039                         |
| Distance to health facilities | 0.169              | 0.024             | 1                             |

*Note:* Distance to health facilities is summarized as the block mean of the 1–5 distance-band score.

**Supplementary Table S27.** Pearson (lower) and Spearman (upper) correlations among hazard scores (pixel level).

| Variable          | Elevation | Slope | Aspect | TWI    | Distance to river |
|-------------------|-----------|-------|--------|--------|-------------------|
| Elevation         | 1         | 0.092 | −0.044 | 0.212  | 0.143             |
| Slope             | 0.125     | 1     | 0.003  | 0.229  | 0.007             |
| Aspect            | −0.042    | 0.005 | 1      | −0.040 | 0.011             |
| TWI               | 0.226     | 0.213 | −0.059 | 1      | 0.005             |
| Distance to river | 0.118     | 0.012 | 0.016  | −0.004 | 1                 |

*Note:* Raw-variable Pearson correlations: elevation–slope 0.29, elevation–TWI −0.30, slope–TWI −0.73.

**Supplementary Table S28.** Global Moran’s I and Lagrange multiplier (LM) tests for spatial dependence.

| Variable                     | Weights | Moran’s I | E[I]   | Permutation p (9,999) | LM-error (p) | LM-lag (p) |
|------------------------------|---------|-----------|--------|-----------------------|--------------|------------|
| Block mean DRI (n = 20)      | queen   | 0.217     | −0.053 | 0.048                 |              |            |
| Incidence, WorldPop (n = 20) | queen   | −0.125    | −0.053 | 0.626                 |              |            |
| Incidence, Census (n = 19)   | queen   | 0.009     | −0.056 | 0.260                 |              |            |
| Block mean ESI               | queen   | 0.602     | −0.053 | 0.000                 |              |            |
| Block mean VI                | queen   | 0.258     | −0.053 | 0.029                 |              |            |

| Variable                        | Weights | Moran's I | E[I]   | Permutation p<br>(9,999) | LM-error (p) | LM-lag (p)   |
|---------------------------------|---------|-----------|--------|--------------------------|--------------|--------------|
| Block mean HI                   | queen   | 0.027     | −0.053 | 0.586                    |              |              |
| OLS residuals, primary (n = 20) | queen   | −0.166    |        | 0.444                    | 1.03 (0.310) | 0.81 (0.368) |
| OLS residuals, excl. Chargawan  | queen   | −0.267    |        | 0.166                    | 2.28 (0.131) | 2.31 (0.129) |
| OLS residuals, Census (n = 19)  | queen   | 0.059     |        | 0.359                    | 0.12 (0.732) | 0.01 (0.911) |
| Block mean DRI (n = 20)         | knn4    | 0.319     | −0.053 | 0.003                    |              |              |
| Incidence, WorldPop (n = 20)    | knn4    | −0.040    | −0.053 | 0.925                    |              |              |
| Incidence, Census (n = 19)      | knn4    | −0.034    | −0.056 | 0.671                    |              |              |
| Block mean ESI                  | knn4    | 0.639     | −0.053 | 0.000                    |              |              |
| Block mean VI                   | knn4    | 0.260     | −0.053 | 0.014                    |              |              |
| Block mean HI                   | knn4    | −0.073    | −0.053 | 0.889                    |              |              |
| OLS residuals, primary (n = 20) | knn4    | −0.084    |        | 0.799                    | 0.33 (0.567) | 0.18 (0.670) |
| OLS residuals, excl. Chargawan  | knn4    | −0.157    |        | 0.414                    | 1.08 (0.299) | 1.11 (0.293) |
| OLS residuals, Census (n = 19)  | knn4    | −0.042    |        | 0.901                    | 0.08 (0.779) | 0.38 (0.540) |

*Note:* queen = queen contiguity with 60 m snapping tolerance, row-standardized; knn4 = four nearest block centroids, row-standardized. Because residual spatial dependence was not significant, spatial lag or error models were not required.

**Supplementary Table S29.** Dengue cases and pooled incidence by DRI risk class of the block mean (2025).

| DRI class | Blocks | Block names                                                                                                          | Cases | Population 2025 | Pooled incidence<br>/100,000 | Share of cases |
|-----------|--------|----------------------------------------------------------------------------------------------------------------------|-------|-----------------|------------------------------|----------------|
| Very Low  | 1      | Brahmpur                                                                                                             | 3     | 235,169         | 1.28                         | 1.3%           |
| Low       | 4      | Kauriram,<br>Barhalganj, Bhathat,<br>Gagaha                                                                          | 28    | 916,772         | 3.05                         | 12.4%          |
| Moderate  | 11     | Campierganj, Pali,<br>Pipraich, Khorabar,<br>Sardarnagar, Khajni,<br>Bansgaon, Uruwa,<br>Gola, Bharohiya,<br>Belghat | 64    | 2,820,165       | 2.27                         | 28.4%          |
| High      | 3      | Jungle Kaudia,<br>Sahjanwa, Piprauli                                                                                 | 20    | 786,553         | 2.54                         | 8.9%           |
| Very High | 1      | Chargawan                                                                                                            | 110   | 1,935,207       | 5.68                         | 48.9%          |

*Note:* Kruskal–Wallis test of block incidence across classes:  $H = 2.75$ ,  $p = 0.600$  (descriptive; very small groups).

**Supplementary Figure S1.** Relationship between block mean DRI and observed dengue incidence in 2025 (per 100,000, WorldPop 2025 denominators; n = 20 blocks), with fitted least-squares line.

