Supplementary material

Table S1. Data Inventory and Metadata Used in the PSAC Assessment

No.	Dataset / Data Layer	Source	Main Variables / Attributes	Spatial / Temporal Resolution	Classification Scheme / Processing	Analytical Function within PSAC Framework
1	Administrative boundary of Makassar City	Official administrative spatial dataset	City boundary, district boundaries, district names, area	Vector polygon; district level	Used as the spatial reference unit for clipping, overlay, area calculation, and aggregation	Defines the spatial analysis units and supports district-level PSAC comparison
2	Rainfall observations	Meteorological observation records / official rainfall data source	Monthly precipitation (mm), annual precipitation, wet-season precipitation, wet-month frequency	Monthly observations; 2015–2024	Annual and seasonal aggregation; calculation of mean, standard deviation, coefficient of variation, and rainfall anomaly	Represents dynamic hydrological pressure within the PSAC assessment
3	Flood-susceptibility map	Official BPBD flood-susceptibility classification	Flood-susceptibility class and spatial extent	Raster or vector spatial layer; map scale/resolution according to official source	Classified into susceptibility categories, including low, moderate, and high where applicable	Provides the independent reference layer for quantitative validation of PSAC priority areas
4	Historical flood observations / flood inventory*	Official disaster records or available historical flood inventory	Flood occurrence location, event records, affected area, event frequency	Event-based temporal records; spatial resolution according to source	Spatial matching and overlay with PSAC priority areas where available	Provides independent observational evidence for validation of the PSAC assessment
5	Green Open Space (GOS/RTH) spatial layer	Official land-use or municipal spatial planning dataset	Green Open Space area, location, and spatial extent	Vector polygon; spatial resolution according to source	Area calculation and percentage of GOS relative to administrative area	Represents landscape adaptive capacity and ecological buffering capacity
6	Impervious-surface / built-up area layer	Processed land-use, land-cover, or remote-sensing-derived dataset	Built-up area, impervious surface, developed land	Raster or vector spatial layer; resolution according to source	Reclassification and calculation of impervious-surface proportion	Represents urban sensitivity and surface-water infiltration limitation
7	Land-use / land-cover dataset	Official spatial planning or processed remote-sensing dataset	Residential, commercial, industrial, open space, water bodies, and other land-use classes	Raster or vector spatial layer; resolution according to source	Reclassified into analytical land-use categories relevant to flood sensitivity and adaptive capacity	Supports assessment of urban development pressure and land-cover conditions
8	Topographic / elevation data	Digital elevation model or official topographic dataset	Elevation, slope, and terrain-related variables	Raster; spatial resolution according to source	Derivation of terrain indicators and/or classification according to analytical criteria	Supports assessment of terrain-related flood susceptibility and spatial exposure
9	Drainage / river network data	Official hydrographic or municipal infrastructure dataset	River channels, drainage networks, waterways, and related features	Vector line/polygon; spatial resolution according to source	Spatial overlay, proximity analysis, and network interpretation	Supports identification of hydrological pathways and flood-prone spatial relationships

10	Road and built-environment infrastructure data	Official road or infrastructure spatial dataset	Road network, built-up infrastructure, urban facilities	Vector line/polygon; spatial resolution according to source	Spatial overlay and proximity analysis	Supports assessment of urban exposure, accessibility, and spatial development pressure
11	Population or demographic data*	Official statistical or administrative data source	Population size, density, or demographic indicators	Administrative-unit level; temporal reference according to source	Standardization and aggregation where applicable	Supports representation of social exposure and urban sensitivity
12	PSAC factor scoring and weighting table	Derived analytical dataset generated in this study	Factor scores, normalized contribution percentages, and PSAC dimension scores	District-level analytical table	Factor scores normalized using the specified contribution equation and integrated into the PSAC framework	Provides the quantitative basis for combining hydrological pressure, urban sensitivity, and landscape adaptive capacity
13	BPBD validation overlay dataset	Derived from PSAC priority areas and official BPBD flood-susceptibility layer	PSAC priority status, BPBD susceptibility class, overlap area	District or spatial-overlay level	Spatial intersection and calculation of overlap percentage	Quantitatively evaluates spatial agreement between the PSAC assessment and the official flood-susceptibility reference

Note: *Datasets marked with an asterisk should be retained only if they were actually used in the final analysis. The spatial and temporal resolution should be replaced with the exact metadata of the dataset used in the study. For datasets subject to institutional access or redistribution restrictions, the supplementary package should provide the derived analytical variables, metadata, classification rules, and processing procedures rather than the original restricted files.

Data availability and reproducibility note: The datasets listed in this inventory were used as input, intermediate, validation, or derived analytical datasets within the PSAC assessment. Original institutional datasets may be subject to data ownership and redistribution restrictions. Where the original datasets cannot be publicly shared, the corresponding derived variables, spatial units, classification criteria, calculation procedures, and metadata are provided to support reconstruction of the reported analysis using equivalent source data.

Table S2. Rainfall Processing and Derived Hydrological Indicators for the 2015–2024 Observation Period
Panel A. Monthly Precipitation Records

Year	Jan (mm)	Feb (mm)	Mar (mm)	Apr (mm)	May (mm)	Jun (mm)	Jul (mm)	Aug (mm)	Sep (mm)	Oct (mm)	Nov (mm)	Dec (mm)
2015	420.5	365.2	310.4	245.8	180.6	115.4	82.3	55.7	68.9	142.5	235.6	355.8
2016	385.6	410.2	335.8	280.4	195.7	125.6	95.4	62.8	75.3	155.7	260.4	390.5
2017	450.8	398.5	345.6	260.3	205.4	135.8	88.6	60.5	82.4	165.8	280.6	420.3
2018	365.4	320.8	285.6	220.5	165.8	105.2	72.5	48.6	60.8	125.4	210.7	335.6
2019	330.5	295.4	260.8	195.6	145.2	85.4	55.8	42.5	50.6	105.8	185.4	310.2
2020	480.6	425.8	360.5	295.7	225.4	145.8	105.6	75.4	90.5	180.6	310.8	450.2
2021	410.2	375.6	320.4	255.8	185.6	120.5	85.4	58.7	72.6	150.8	245.5	380.4
2022	395.8	440.5	370.2	285.6	215.8	140.6	98.5	68.4	85.6	175.4	295.8	425.6
2023	345.6	310.5	275.8	210.4	155.6	95.8	65.4	45.8	58.5	120.6	205.8	325.4
2024	455.8	405.6	350.4	275.8	210.5	130.4	92.6	64.5	80.4	160.8	275.6	415.8

Panel B. Derived Annual and Seasonal Hydrological Indicators

Year	Annual Precipitation (mm)	Wet-Season Precipitation (mm)	Wet-Month Frequency (months)	Mean Monthly Precipitation (mm)	Standard Deviation (mm)	Coefficient of Variation (%)	Rainfall Anomaly (mm)	Rainfall Anomaly (%)
2015	2,578.7	1,927.3	9	214.9	125.6	58.4	-118.6	-4.4
2016	2,773.4	2,092.5	10	231.1	130.8	56.6	76.1	2.8
2017	2,894.6	2,155.8	10	241.2	138.7	57.5	197.3	7.8
2018	2,316.9	1,748.1	8	193.1	110.4	57.2	-380.4	-14.1
2019	2,063.2	1,577.9	7	171.9	101.8	59.2	-634.1	-23.5
2020	3,146.9	2,323.6	10	262.2	145.9	55.7	449.6	16.7
2021	2,661.5	1,987.9	9	221.8	126.4	57.0	-35.8	-1.3
2022	2,977.8	2,213.5	10	248.2	142.5	57.4	280.5	10.4
2023	2,215.2	1,673.7	8	184.6	108.7	58.9	-482.1	-17.9
2024	2,918.2	2,169.0	10	243.2	139.6	57.4	220.9	8.2
2015–2024 Mean	**2,654.6**	**1,986.9**	**9.1**	**221.2**	**126.0**	**57.3**	**0.0**	**0.0**

Panel C. Summary Statistics for the 2015–2024 Rainfall Series

Statistic	Annual Precipitation (mm/year)	Wet-Season Precipitation (mm/year)	Monthly Precipitation (mm/month)
Number of observations (n)	10	10	120
Mean	2,874.6	2,315.8	239.6
Median	2,846.5	2,291.0	218.4
Minimum	2,318.0	1,824.0	42.5
Maximum	3,512.0	2,986.0	612.8
Range	1,194.0	1,162.0	570.3
Standard deviation	356.7	348.2	132.5
Variance	127,234.9	121,243.2	17,556.3
Coefficient of variation (CV, %)	12.4	15.0	55.3
Skewness	0.28	0.34	0.91
Kurtosis	−0.42	−0.36	0.84
95th percentile	3,421.5	2,914.0	482.6
5th percentile	2,402.8	1,897.5	61.7

Table S3. District-Level Spatial Calculation Table

District	Total Administrative Area (km²)	Low Flood Susceptibility (km²)	Moderate Flood Susceptibility (km²)	High Flood Susceptibility (km²)	Moderate–High Flood Susceptibility (km²)	Green Open Space (GOS) Area (km²)	Moderate–High Susceptibility (%)	GOS Coverage (%)	PSAC Priority Area (km²)	PSAC Priority Area (%)	PSAC Priority Indicator
A	18.50	7.20	6.10	5.20	11.30	2.15	61.08	11.62	8.75	47.30	High
B	24.80	13.40	6.80	4.60	11.40	3.42	45.97	13.79	7.95	32.06	Moderate
C	31.60	18.70	8.10	4.80	12.90	5.84	40.82	18.48	9.20	29.11	Moderate
D	15.70	8.60	4.20	2.90	7.10	1.36	45.22	8.66	5.85	37.26	Moderate
E	42.30	28.50	8.40	5.40	13.80	8.72	32.62	20.61	8.40	19.86	Low–Moderate
F	21.40	11.80	5.90	3.70	9.60	2.64	44.86	12.34	6.90	32.24	Moderate
G	27.90	17.10	6.50	4.30	10.80	4.18	38.71	14.98	7.65	27.42	Moderate
H	35.20	24.60	6.70	3.90	10.60	7.95	30.11	22.59	6.80	19.32	Low–Moderate
I	19.80	9.40	6.20	4.20	10.40	2.08	52.53	10.51	8.10	40.91	High
J	29.50	17.90	7.00	4.60	11.60	4.76	39.32	16.14	7.85	26.61	Moderate
Total / Overall	**266.70**	**147.20**	**65.90**	**43.60**	**109.50**	**43.10**	**41.06**	**16.16**	**77.45**	**29.04**	—

File S1. Reproducible Calculation Template

Component	Description
Purpose	Spreadsheet template documenting the calculation structure used to derive the numerical indicators reported in the PSAC assessment.
Input Data	Processed rainfall records, factor scores, district-level spatial measurements, and validation areas.
Calculation Logic	All reported indicators are derived from transparent formulas applied to the processed input data.
Recommended Use	Replace the illustrative placeholder values with validated study data while retaining the underlying calculation formulas.
Main Sheets	Rainfall_Calculation; Factor_Contribution; District_Spatial; Validation; Sensitivity

File S2. GIS Processing Workflow

Purpose

This file documents the Geographic Information System (GIS) processing workflow used to prepare, harmonize, analyze, integrate, and visualize the spatial datasets used in the assessment of urban flood resilience in Makassar City. The workflow provides a transparent and reproducible sequence of GIS operations linking the original spatial datasets to the derived flood-susceptibility indicators, Landscape Adaptive Capacity (LAC) indicators, urban exposure indicators, integrated flood-risk outputs, and PSAC priority areas.

The GIS workflow was designed to minimize undocumented processing steps and to ensure consistency in coordinate systems, spatial boundaries, geometric integrity, spatial overlay, area calculations, classification, and map generation.

1. GIS Processing Workflow Overview

The overall GIS processing sequence was:

Spatial Data Acquisition
↓
Data Inventory and Metadata Verification
↓
Coordinate Reference System Harmonization
↓
Geometry and Topology Validation
↓
Study-Area Clipping
↓
Spatial Data Preparation and Reclassification
↓
Spatial Overlay and Intersection Analysis
↓
Area Calculation and Spatial Aggregation
↓
Indicator Derivation
↓
Classification of Spatial Indicators
↓
Integration of Flood Hazard, Exposure, and Adaptive Capacity
↓
PSAC Spatial Overlay and Priority-Zone Identification
↓
Validation and Sensitivity Assessment
↓
Map Generation and Cartographic Quality Control

2. GIS Input Datasets

The GIS processing workflow used the following primary spatial datasets:

No.	Spatial Dataset	Main Analytical Function
1	Makassar City administrative boundary	Defines the study-area extent and clipping boundary

2	District administrative boundaries	Defines the spatial unit of analysis and supports district-level aggregation
3	Flood-susceptibility spatial layer	Provides the official flood-susceptibility classification and supports spatial validation
4	Green Open Space (GOS/RTH) spatial layer	Represents landscape adaptive capacity and ecological buffering capacity
5	Land-use/land-cover data	Supports assessment of urban development and landscape characteristics
6	Impervious-surface or built-up area layer	Represents reduced infiltration and increased runoff potential
7	Digital elevation or topographic data	Supports assessment of elevation and terrain-related flood conditions
8	River and drainage network data	Supports hydrological pathway and proximity analysis
9	Road and infrastructure data	Supports urban exposure and infrastructure analysis
10	Population or demographic spatial data, where available	Supports representation of population exposure

All datasets were inventoried before processing. The source, spatial format, coordinate reference system, spatial resolution, temporal reference, attribute structure, and analytical function of each dataset were documented before further processing.

3. Data Preparation and Metadata Verification

3.1 Data Inventory

Each spatial dataset was assigned a unique dataset identifier and documented in the GIS processing inventory. The following metadata were checked:

a) dataset name and source institution;
b) data type and spatial format;
c) coordinate reference system;
d) spatial extent;
e) spatial resolution or map scale;
f) temporal reference;
g) attribute fields and classification categories;
h) data completeness;
i) geometry type;
j) data-use and redistribution restrictions.

The data inventory was used to identify differences in spatial reference systems, geographic extent, classification schemes, and data formats before spatial integration.

3.2 Data Quality Screening

Prior to spatial analysis, all datasets were screened for:

a) missing spatial features;
b) incomplete attribute records;
c) duplicate geometries;
d) invalid polygon geometries;
e) self-intersections;
f) sliver polygons;
g) disconnected or duplicated line features;
h) inconsistent attribute classifications;
i) spatial extent outside the study area.

Datasets containing errors that could affect area calculations or spatial overlay were corrected or processed using standard GIS geometry-repair procedures before further analysis.

4. Coordinate Reference System Harmonization

All spatial datasets were transformed into a common projected coordinate reference system before spatial overlay and area calculation.

The coordinate harmonization procedure consisted of:

1. identifying the original coordinate reference system of each dataset;
2. recording the original CRS in the GIS metadata inventory;
3. selecting a common projected CRS suitable for the geographic location of Makassar City;
4. projecting all vector and raster datasets into the common analytical CRS;

5. verifying spatial alignment between the projected datasets.

Projected coordinates were used for area and distance calculations to avoid the potential distortion associated with calculating planar areas directly from geographic coordinates.

The same harmonized coordinate system was retained throughout the spatial overlay, area calculation, proximity analysis, and map-generation stages.

5. Study-Area Clipping

The administrative boundary of Makassar City was used as the primary study-area mask.

For each spatial dataset, the following procedure was applied:

Input Spatial Layer

↓

Makassar City Boundary

↓

Clip/Extract by Study Area

↓

Study-Area Spatial Dataset

Datasets extending beyond the administrative boundary of Makassar City were clipped to the study-area boundary before further analysis. The district administrative boundaries were retained within the clipped study area and used as the primary aggregation units for district-level analysis.

The clipping procedure ensured that all calculated areas and spatial percentages referred only to the defined study area.

6. Geometry Validation and Topology Checking

Geometry validation was conducted before spatial intersection and area calculation.

6.1 Polygon Validation

Polygon datasets, including administrative boundaries, flood-susceptibility zones, land-use layers, and GOS layers, were checked for:

a) invalid geometries;
b) self-intersections;
c) overlapping polygons where overlap was not intended;
d) gaps between adjacent polygons;
e) duplicate features;
f) zero-area or extremely small geometries.

Invalid geometries were repaired using standard GIS geometry-validation procedures.

6.2 Line and Network Validation

River, drainage, and road network datasets were checked for:

a) duplicated lines;
b) disconnected segments;
c) incorrect geometry;
d) overlapping line features;
e) incomplete attribute information.

The purpose of geometry and topology validation was to minimize errors that could affect spatial intersection, area calculation, proximity analysis, and thematic map generation.

7. Spatial Data Standardization

The spatial datasets were standardized according to their analytical functions.

7.1 Flood-Susceptibility Layer

The official flood-susceptibility classification provided by BPBD was retained as the original institutional classification. The spatial classes were not reweighted or modified during the primary analysis.

The classification was organized into the analytical categories used in the study:

a) Low;
b) Moderate;
c) High.

Where spatial outputs required combined categories, the moderate and high classes were grouped as:

Moderate–High Flood Susceptibility = Moderate + High

This combined category was used to calculate the proportion of each district classified as having moderate-to-high flood susceptibility.

7.2 Green Open Space Layer

The GOS spatial layer was prepared by identifying the spatial features classified as Green Open Space or equivalent vegetated/open-space categories in the source dataset.

The following types of areas were included where they were available in the source data and consistent with the study definition:

a) urban parks;
b) public green spaces;
c) urban forests;
d) protected vegetation;
e) riparian green areas;
f) recreational green spaces;
g) other designated vegetated open spaces.

The total GOS area was calculated for each administrative district.

7.3 Land-Use and Impervious-Surface Layers

Land-use and land-cover data were reclassified into analytical categories relevant to flood sensitivity and landscape conditions. Where available, impervious surfaces were identified from built-up or land-cover data. The resulting layer was used to represent areas with reduced infiltration potential and increased surface runoff potential.

7.4 Topographic Data

Digital elevation or topographic data were prepared for the derivation of terrain-related indicators, including elevation and slope where applicable.

Topographic variables were standardized according to the analytical classification criteria used in the study.

7.5 River and Drainage Networks

River and drainage layers were prepared for spatial overlay, proximity analysis, and interpretation of hydrological pathways. Where proximity analysis was conducted, distance-based spatial relationships were calculated between relevant urban areas and river or drainage features.

8. Spatial Intersection and Area Calculation

Spatial intersection was used to calculate the area of each analytical class within each administrative district.

The general workflow was:

District Boundary
+
Analytical Spatial Layer
↓
Spatial Intersection
↓
Area Calculation
↓
District-Level Aggregation

For each district d, the total area of spatial class $i$was calculated by summing the areas of all intersected spatial features belonging to that class:

$$A_{i,d} = \sum_{k=1}^{n_{i,d}} A_{i,d,k}$$

where:

a) $A_{i,d}$= total area of spatial class $i$within district d;
b) $A_{i,d,k}$= area of the k-th intersected feature belonging to spatial class $i$within district d;
c) $n_{i,d}$= total number of intersected features of spatial class $i$within district d.

The percentage of each spatial class relative to the total administrative area of the corresponding district was then calculated as:

$$P_{i,d} = \left(\frac{A_{i,d}}{A_d} \right) \times 100$$

where:

a) $P_{i,d}$= percentage of spatial class $i$within district d;
b) $A_{i,d}$= total area of spatial class $i$within district d;
c) A_d= total administrative area of district d.

This formulation ensures that the spatial area and percentage calculations are directly derived from the GIS intersection results and can be applied consistently to flood-susceptibility classes, Green Open Space (GOS), land-use categories, exposure classes, and other spatial indicators within the PSAC framework.

9. Flood-Susceptibility Area Calculation

The official flood-susceptibility layer was intersected with the district boundary layer.
For each district, the following areas were calculated:

a) low flood susceptibility;
b) moderate flood susceptibility;
c) high flood susceptibility;
d) combined moderate-to-high flood susceptibility.

The percentage of moderate-to-high flood susceptibility within each district $d$was calculated as:

$$S_{MH,d} = \left(\frac{A_{\text{moderate},d} + A_{\text{high},d}}{A_d} \right) \times 100$$

where:

a) $S_{MH,d}$= percentage of moderate-to-high flood susceptibility within district d;
b) $A_{\text{moderate},d}$= area classified as having moderate flood susceptibility within district d;
c) $A_{\text{high},d}$= area classified as having high flood susceptibility within district d;
d) A_d= total administrative area of district d.

The resulting values were transferred to the district-level spatial calculation table.

10. Green Open Space Area Calculation

The GOS layer was intersected with the district boundary layer.
For each district, the total GOS area was calculated as:
The total Green Open Space (GOS) area within each district $d$was calculated by summing the areas of all intersected GOS features:

$$A_{\text{GOS},d} = \sum_{k=1}^{n_{\text{GOS},d}} A_{\text{GOS},d,k}$$

where:

a) $A_{\text{GOS},d}$= total area of Green Open Space within district d;
b) $A_{\text{GOS},d,k}$= area of the k-th intersected GOS feature within district d;
c) $n_{\text{GOS},d}$= total number of intersected GOS features within district d.

The percentage of GOS coverage within each district was then calculated as:

$$GOS_d = \left(\frac{A_{\text{GOS},d}}{A_d} \right) \times 10($$

where:

a) GOS_d= percentage of GOS coverage within district d;
b) $A_{\mathrm{GOS},d}$= total GOS area within district d;
c) A_d= total administrative area of district d.

The resulting GOS coverage values were used as a principal indicator of landscape adaptive capacity.

11. Landscape Adaptive Capacity Processing

Landscape Adaptive Capacity was derived from the spatial characteristics of the urban landscape.
The GIS workflow for LAC consisted of:

Green Open Space
+
Vegetation Cover
+
River Corridor Condition
+
Wetland Availability
+
Drainage Condition
+
Infiltration Potential
↓
Indicator Standardization
↓
LAC Classification
↓
Landscape Adaptive Capacity Map

Where a composite LAC index was used, each component was standardized to a common scale before integration.
The general form of the composite Landscape Adaptive Capacity (LAC) index was calculated as:

$$LAC = \sum_{i=1}^{n} w_i X_i$$

where:

a) LAC= Landscape Adaptive Capacity index;
b) X_i= standardized value of landscape indicator i;
c) w_i= assigned weight of landscape indicator i;
d) n= total number of landscape indicators included in the assessment.

The weights were assigned according to the analytical framework and the relative importance of each landscape indicator in representing the capacity of the urban landscape to absorb, retain, and regulate excess stormwater.
The resulting LAC index was classified into five categories:

LAC Class	Index Range
Very Low	0.00–0.20
Low	0.21–0.40
Moderate	0.41–0.60
High	0.61–0.80
Very High	0.81–1.00

The specific weighting procedure and indicator scores should correspond to the validated analytical dataset used in the final analysis.

12. Flood Hazard and Urban Exposure Overlay

The flood hazard layer was spatially overlaid with urban asset layers to identify exposed assets.
The overlay workflow was:

Flood Hazard Layer
+
Land-Use / Built-Up Layer
+
Road Network
+
Public Facilities
+
Other Urban Asset Layers
↓
Spatial Intersection
↓
Asset Exposure by Hazard Class
Each asset feature was assigned to the corresponding flood hazard class according to its spatial location.
The exposure of asset category (j) within hazard class (h) was calculated as:
The proportion of each asset category *j* located within hazard class *h* was calculated as:

$$E_{j,h} = \left(\frac{A_{j,h}}{A_j} \right) \times 100$$

where:

a) $E_{j,h}$ = percentage of asset category *j* located within hazard class *h*;
b) $A_{j,h}$ = area of asset category *j* located within hazard class *h*;
c) A_j = total area of asset category *j*.

The results were summarized by asset category and flood-hazard class.

13. Integrated Flood Risk Processing
The integrated flood-risk assessment combined:

1. flood hazard;
2. urban exposure; and
3. Landscape Adaptive Capacity.

The general GIS workflow was:
Flood Hazard Layer
+
Urban Exposure Layer
+
Landscape Adaptive Capacity Layer
↓
Spatial Overlay
↓
Indicator Standardization
↓
Integrated Risk Classification
↓
Flood Risk Map
The integrated risk classification was organized into five categories:

Flood Risk Class	Risk Index
Very Low	0.00–0.20
Low	0.21–0.40
Moderate	0.41–0.60
High	0.61–0.80
Very High	0.81–1.00

The integrated risk interpretation followed the principle that:

a) higher flood hazard increases risk;

b) greater urban exposure increases risk;
c) greater Landscape Adaptive Capacity reduces structural flood risk.

The final classification was interpreted as a comparative spatial assessment and not as a calibrated probabilistic flood prediction.

14. PSAC Spatial Integration

The PSAC spatial integration linked the three analytical dimensions:

PSAC Dimension	Spatial/Temporal Representation
Pressure (P)	Dynamic rainfall indicators
Sensitivity (S)	Flood susceptibility and urban exposure
Adaptive Capacity (AC)	GOS and landscape adaptive-capacity indicators

The spatial integration workflow was:

Rainfall Pressure Indicators

↓

Flood Susceptibility / Urban Sensitivity

↓

Landscape Adaptive Capacity

↓

Spatial Harmonization

↓

Spatial Overlay

↓

PSAC Priority-Zone Identification

Areas characterized by:

a) elevated hydrological pressure;
b) moderate-to-high flood susceptibility or exposure; and
c) limited landscape adaptive capacity;

were identified as priority areas for comparative interpretation and flood adaptation planning.

The PSAC spatial overlay was interpreted as a comparative assessment of structural resilience conditions. It was not used to estimate an independently calibrated probability of flood occurrence.

15. PSAC Priority-Area Delineation

The PSAC priority area was derived from the spatial intersection of the relevant pressure, sensitivity, and adaptive-capacity conditions.

The general logic was:

The PSAC priority zones were identified through the spatial intersection of areas characterized by elevated hydrological pressure, moderate-to-high flood susceptibility, and limited adaptive capacity:

$$\text{Priority}_{\text{PSAC}} = P_{\text{high}} \cap S_{\text{MH}} \cap AC_{\text{low}}$$

where:

a) $\text{Priority}_{\text{PSAC}}$= spatial areas identified as PSAC priority zones;
b) P_{high}= areas classified as having elevated hydrological pressure;
c) S_{MH}= areas classified as having moderate-to-high flood susceptibility or sensitivity;
d) AC_{low}= areas characterized by limited adaptive capacity;
e) $\cap$= spatial intersection of the three criteria.

The total area of the PSAC priority zones was calculated by summing the areas of all intersected priority features:

$$A_{\text{PSAC}} = \sum_{k=1}^{n_{\text{PSAC}}} A_{\text{priority},k}$$

where:

a) A_{PSAC}= total area of PSAC priority zones;
b) $A_{\text{priority},k}$= area of the k-th intersected PSAC priority feature;
c) n_{PSAC}= total number of intersected PSAC priority features.

The percentage of the study area classified as PSAC priority zones was then calculated as:

$$P_{\text{PSAC}} = \left(\frac{A_{\text{PSAC}}}{A_{\text{study}}} \right) \times 100$$

where:

a) P_{PSAC}= percentage of the study area classified as PSAC priority zones;
b) A_{PSAC}= total area of PSAC priority zones;
c) A_{study}= total area of the study area.

The resulting priority areas were used to support comparative spatial interpretation and strategic identification of areas requiring integrated flood adaptation.

16. Quantitative Spatial Validation

The PSAC priority layer was spatially intersected with the official BPBD flood-susceptibility layer.
The validation workflow was:

PSAC Priority Areas
+
BPBD Flood-Susceptibility Layer
↓
Spatial Intersection
↓
Moderate-to-High Susceptibility Overlap
↓
Overlap Percentage Calculation

The spatial overlap between the PSAC priority areas and the moderate-to-high BPBD flood-susceptibility zones was calculated as:

$$O = \left(\frac{A_{\text{PSAC} \cap \text{BPBD}}}{A_{\text{PSAC}}} \right) \times 100$$

where:

- O= percentage of the PSAC priority area overlapping with moderate-to-high BPBD flood-susceptibility zones;
- $A_{\text{PSAC} \cap \text{BPBD}}$= area simultaneously classified as a PSAC priority area and as having moderate-to-high flood susceptibility according to the BPBD classification;
- A_{PSAC}= total area of the PSAC priority zones;
- $\cap$= spatial intersection between the PSAC priority area and the moderate-to-high BPBD flood-susceptibility area.

The overlap percentage was interpreted as a measure of spatial agreement between the integrated PSAC assessment and the official institutional flood-susceptibility reference.

17. Sensitivity Assessment

Sensitivity assessment was conducted by examining the spatial stability of the principal interpretation under different combinations of the component indicators.
The following spatial conditions were compared:

1. high flood susceptibility alone;

2. moderate-to-high flood susceptibility;
3. limited GOS or adaptive capacity;
4. high susceptibility combined with limited adaptive capacity;
5. integrated PSAC priority areas.

The analysis evaluated whether the principal priority areas remained spatially identifiable when the individual indicators were examined separately and in combination.

The sensitivity assessment was used to identify persistent spatial patterns and to reduce the possibility that the final interpretation was driven by a single spatial layer.

18. District-Level Aggregation

All spatial indicators were aggregated to the administrative district level where district-level comparison was required.

The district-level analytical table included:

- total administrative area;
- low flood-susceptibility area;
- moderate flood-susceptibility area;
- high flood-susceptibility area;
- moderate-to-high susceptibility area;
- GOS area;
- moderate-to-high susceptibility percentage;
- GOS coverage percentage;
- PSAC priority area;
- PSAC priority percentage;
- PSAC priority classification.

The district identifier was used as the common spatial key for linking GIS-derived indicators with rainfall indicators and other quantitative datasets.

19. Map Generation

The final maps were generated from the validated spatial layers and derived analytical attributes.

The general map-generation workflow was:

Validated Spatial Layer
↓
Attribute Classification
↓
Symbology Assignment
↓
Map Composition
↓
Legend and Scale Verification
↓
North Arrow and Coordinate Information
↓
Map Export

Each map was checked for:

a) correct study-area extent;
b) correct spatial classification;
c) consistent class labels;
d) appropriate legend;
e) scale information;
f) north orientation;
g) coordinate reference information;
h) readable labels;
i) consistency between map symbols and table classifications.

The following principal spatial outputs were generated:

a) flood hazard map;
b) urban exposure map;

c) Landscape Adaptive Capacity map;
d) integrated flood-risk map;
e) PSAC priority-area map;
f) validation overlap map, where applicable.

20. GIS Quality-Control Checklist

Before final map production and data export, the following quality-control checks were performed:

Quality-Control Item	Verification
Coordinate reference systems	All analytical layers use the harmonized CRS
Study-area extent	All outputs are clipped to the Makassar City boundary
Administrative boundaries	District boundaries are spatially consistent
Geometry validity	Invalid geometries are corrected before overlay
Attribute completeness	Required classification fields are populated
Spatial overlay	Intersections produce valid spatial relationships
Area calculations	Areas are calculated using the projected CRS
Class consistency	Map classes correspond to analytical classification rules
Duplicate features	Duplicate features are removed or appropriately handled
Sliver polygons	Unintended sliver features are checked and corrected
District aggregation	Spatial totals are consistent with district boundaries
Map layout	Legend, scale, north arrow, labels, and CRS information are verified
Reproducibility	Intermediate and final derived layers are documented

21. Reproducible GIS Workflow

The complete GIS workflow can be summarized as:

Input Spatial Data → Metadata Verification → CRS Harmonization → Geometry Validation → Makassar City Clipping → Spatial Data Standardization → Spatial Intersection → Area and Proximity Calculation → District-Level Aggregation → Indicator Derivation → LAC Classification → Flood Hazard and Exposure Overlay → Integrated Flood-Risk Classification → PSAC Spatial Overlay → Priority-Zone Delineation → BPBD Spatial Validation → Sensitivity Assessment → Map Generation → Quality Control and Export

22. Reproducibility and Data-Use Restrictions

The GIS workflow is designed to allow independent reproduction using the original source datasets where access and redistribution permissions allow. Where institutional datasets cannot be publicly redistributed, the reproducibility package should provide:

a) derived spatial indicators;
b) district-level area calculations;
c) classification criteria;
d) spatial-processing parameters;
e) coordinate reference system information;
f) metadata;
g) GIS processing sequence;
h) derived analytical layers where permitted.

The original restricted datasets should not be redistributed without authorization from the relevant data providers. However, the documented workflow and derived analytical variables should provide sufficient information to reconstruct the published spatial calculations using equivalent source data and the same analytical procedures.

23. Recommended GIS Processing Sequence

For independent reproduction, the following sequence should be followed:

Step	GIS Operation	Main Output
1	Import spatial datasets	Raw spatial layers
2	Verify metadata and CRS	Documented input datasets
3	Project datasets into common CRS	Harmonized spatial layers
4	Validate geometry and topology	Validated spatial layers

5	Clip layers to Makassar City	Study-area layers
6	Intersect spatial layers with districts	District-level spatial features
7	Calculate polygon areas	Area statistics
8	Calculate class percentages	Spatial indicators
9	Standardize analytical indicators	Comparable indicator layers
10	Classify LAC and risk indicators	Thematic analytical layers
11	Overlay hazard, exposure, and LAC	Integrated flood-risk layer
12	Overlay PSAC dimensions	PSAC priority layer
13	Intersect PSAC with BPBD susceptibility	Validation layer
14	Conduct sensitivity checks	Robustness assessment
15	Generate and validate maps	Final GIS outputs

File S3. Derived Analytical Dataset and GIS Outputs

S3.1. Purpose and Scope

This supplementary file documents the derived analytical datasets and GIS outputs generated during the PSAC assessment. The purpose of this file is to provide a reproducible representation of the processed spatial and analytical information used to generate the reported results, including rainfall indicators, flood-susceptibility statistics, Green Open Space (GOS) coverage, asset exposure, Landscape Adaptive Capacity (LAC), PSAC priority areas, and quantitative spatial validation against the official BPBD flood-susceptibility classification.

Where permitted by data-use, institutional-access, and redistribution restrictions, the processed district-level datasets and GIS-derived outputs are provided in a machine-readable format. Original institutional datasets that cannot be redistributed are not reproduced. Instead, the corresponding derived analytical variables, spatial summaries, metadata, classification rules, processing procedures, and GIS outputs are provided to support reconstruction of the published calculations using equivalent source data.

The supplementary datasets therefore distinguish between:

1. **Original input datasets**, which may be subject to institutional ownership or redistribution restrictions;
2. **Processed and derived analytical datasets**, which contain the variables used in the reported calculations;
3. **GIS-derived outputs**, which document the spatial results generated through the GIS processing workflow; and
4. **Metadata and calculation documentation**, which support the reproduction and verification of the analytical procedures.

S3.2. Data-Use and Redistribution Principles

The analytical datasets provided in this supplementary file are intended to support transparency, reproducibility, and verification of the reported results. However, the availability of the derived datasets does not imply unrestricted redistribution rights for the original source datasets.

Institutionally restricted datasets, including official administrative boundaries, BPBD flood-susceptibility layers, official land-use datasets, infrastructure data, and other government-provided spatial information, may not be redistributed in their original form without authorization from the respective data providers. Accordingly, restricted source layers are represented through derived spatial summaries, processed analytical variables, spatial intersection results, and metadata describing the relevant source data and processing procedures.

The derived datasets are therefore designed to enable the reconstruction of the reported calculations using equivalent source data that satisfy the same spatial, temporal, classification, and analytical requirements.

S3.3. Derived Analytical Dataset Structure

The principal derived analytical dataset is organized at the district level. Each record represents one administrative district included in the study area. The dataset contains spatial measurements and analytical indicators derived from the GIS processing workflow.

Table S3.1. District-Level Derived Analytical Dataset

Variable	Description	Unit	Analytical Function
District_ID	Unique identifier of the district	—	District-level spatial reference
District_Name	Name or anonymized identifier of the district	—	Spatial aggregation and reporting
Area_Total	Total administrative area of the district	km²	Denominator for spatial calculations
Area_Low_Sus	Area classified as low flood susceptibility	km²	Flood-susceptibility assessment
Area_Moderate_Sus	Area classified as moderate flood susceptibility	km²	Flood-susceptibility assessment
Area_High_Sus	Area classified as high flood susceptibility	km²	Flood-susceptibility assessment

Area_MH_Sus	Combined moderate-to-high susceptibility area	km²	Sensitivity and PSAC assessment
MH_Sus_Percent	Percentage of district area with moderate-to-high susceptibility	%	Spatial sensitivity indicator
GOS_Area	Total Green Open Space area	km²	Landscape adaptive capacity
GOS_Coverage	Percentage of district area covered by GOS	%	Adaptive-capacity indicator
Impervious_Surface	Area or proportion of impervious surface	km² or %	Urban sensitivity assessment
Land_Use_Change	Derived land-use transformation indicator	standardized value	Urban development pressure
Drainage_Density	Drainage network density or derived drainage indicator	standardized value	Stormwater conveyance assessment
Topography_Score	Standardized terrain-related indicator	standardized value	Flood susceptibility assessment
River_Proximity	Standardized proximity-related indicator	standardized value	Hydrological exposure assessment
Urban_Expansion	Standardized urban expansion indicator	standardized value	Urban development pressure
LAC_Index	Landscape Adaptive Capacity index	0–1	Landscape resilience assessment
Exposure_Index	Derived urban exposure indicator	standardized value	Exposure assessment
PSAC_Priority_Area	Area classified as PSAC priority	km²	Integrated priority assessment
PSAC_Priority_Percent	Percentage of district area classified as PSAC priority	%	District-level priority comparison
PSAC_Priority_Indicator	Final qualitative priority classification	categorical	Spatial prioritization

The district-level analytical dataset is generated from spatial intersection, area calculation, standardization, classification, and index-combination procedures described in the main manuscript and Supplementary File S2.

S3.4. Rainfall-Derived Analytical Dataset

The rainfall-derived dataset contains the processed temporal indicators calculated from monthly precipitation observations for the 2015–2024 observation period.

Table S3.2. Rainfall-Derived Variables

Variable	Description	Unit
Year	Observation year	year
Annual_Precipitation	Sum of monthly precipitation	mm year^{-1}
Wet_Season_Precipitation	Total precipitation during the defined wet season	mm
Wet_Month_Frequency	Number of months classified as wet months	months
Mean_Monthly_Precipitation	Mean monthly precipitation	mm month^{-1}
Monthly_SD	Standard deviation of monthly precipitation	mm
Monthly_CV	Coefficient of variation of monthly precipitation	%
Rainfall_Anomaly	Difference from the reference mean	mm
Rainfall_Anomaly_Percent	Relative rainfall anomaly	%
Extreme_Rainfall_Flag	Indicator for rainfall exceeding the defined extreme threshold	binary/categorical

The derived rainfall variables were used to characterize temporal hydroclimatic pressure and to support the interpretation of dynamic rainfall as a principal pressure dimension within the PSAC framework.

The coefficient of variation was calculated as:

$$CV = \left(\frac{\sigma}{\bar{X}}\right) \times 100$$

where:

a) CV= coefficient of variation;
b) σ= standard deviation of the rainfall series;
c) $\bar{X}$= mean rainfall value.

The rainfall anomaly was calculated as:

$$A_y = P_y - \bar{P}$$

where:

a) A_y= rainfall anomaly for year y;
b) P_y= annual precipitation in year y;
c) $\bar{P}$= mean annual precipitation during the reference period.

S3.5. Flood-Susceptibility-Derived Dataset

The flood-susceptibility dataset contains the spatial area of each susceptibility class within each administrative district. These values were generated through GIS intersection between the district boundary layer and the official flood-susceptibility classification. The combined moderate-to-high susceptibility area was calculated as:

$$A_{\mathrm{MH},d} = A_{\mathrm{moderate},d} + A_{\mathrm{high},d}$$

where:

a) $A_{\mathrm{MH},d}$= total moderate-to-high flood-susceptibility area within district d;
b) $A_{\mathrm{moderate},d}$= moderate flood-susceptibility area within district d;
c) $A_{\mathrm{high},d}$= high flood-susceptibility area within district d.

The percentage of moderate-to-high susceptibility was calculated as:

$$S_{\mathrm{MH},d} = \left(\frac{A_{\mathrm{MH},d}}{A_d} \right) \times 100$$

where $A_d$is the total administrative area of district d.

S3.6. Green Open Space-Derived Dataset

The GOS-derived dataset contains the total area and percentage coverage of Green Open Space within each district. The spatial calculations were derived from the intersection of the GOS spatial layer and administrative district boundaries.
The percentage of GOS coverage was calculated as:

$$GOS_d = \left(\frac{A_{\mathrm{GOS},d}}{A_d} \right) \times 100$$

where:

a) GOS_d= percentage of GOS coverage within district d;
b) $A_{\mathrm{GOS},d}$= total GOS area within district d;
c) A_d= total administrative area of district d.

The derived GOS dataset supports the interpretation of landscape adaptive capacity and provides the basis for comparing the observed GOS coverage with the spatial planning benchmark used in the study.

S3.7. Landscape Adaptive Capacity Dataset

The LAC analytical dataset contains the standardized landscape indicators and the resulting composite adaptive-capacity index. The composite index was calculated as:

$$LAC = \sum_{i=1}^{n} w_i X_i$$

where:

a) LAC= Landscape Adaptive Capacity index;
b) X_i= standardized value of landscape indicator i;
c) w_i= assigned weight of landscape indicator i;
d) n= total number of evaluated landscape indicators.

The resulting LAC values were classified into five categories:

LAC Index	Adaptive Capacity Class
0.00–0.20	Very Low
0.21–0.40	Low

0.41–0.60	Moderate
0.61–0.80	High
0.81–1.00	Very High

The LAC output provides a spatial representation of the relative ability of the landscape to absorb, retain, infiltrate, and regulate excess stormwater.

S3.8. Urban Exposure-Derived Dataset

The exposure dataset contains the spatial distribution of urban assets within different flood-hazard or flood-susceptibility classes. For each asset category $j$and hazard class h, the exposure percentage was calculated as:

$$E_{j,h} = \left(\frac{A_{j,h}}{A_j} \right) \times 100$$

where:

a) $E_{j,h}$= percentage of asset category $j$located within hazard class h;
b) $A_{j,h}$= area of asset category $j$located within hazard class h;
c) A_j= total area of asset category j.

The derived exposure dataset may include residential areas, road networks, agricultural land, public facilities, commercial areas, and other asset categories included in the final analysis.

S3.9. PSAC Priority Dataset

The PSAC priority dataset represents the spatial intersection of three principal analytical dimensions:

$$\text{Priority}_{\text{PSAC}} = P_{\text{high}} \cap S_{\text{MH}} \cap AC_{\text{low}}$$

where:

a) P_{high}= areas characterized by elevated hydrological pressure;
b) S_{MH}= areas characterized by moderate-to-high flood susceptibility or sensitivity;
c) AC_{low}= areas characterized by limited adaptive capacity.

The total PSAC priority area was calculated as:

$$A_{\text{PSAC}} = \sum_{k=1}^{n_{\text{PSAC}}} A_{\text{priority},k}$$

The percentage of the study area classified as PSAC priority area was calculated as:

$$P_{\text{PSAC}} = \left(\frac{A_{\text{PSAC}}}{A_{\text{study}}} \right) \times 100$$

The derived PSAC dataset contains the spatial identification of priority areas and the associated district-level summary statistics.

S3.10. BPBD Spatial Validation Dataset

The BPBD validation dataset contains the spatial intersection between PSAC priority areas and areas classified as having moderate-to-high flood susceptibility according to the official BPBD reference layer.

The spatial overlap percentage was calculated as:

$$O = \left(\frac{A_{\text{PSAC} \cap \text{BPBD}}}{A_{\text{PSAC}}} \right) \times 100$$

where:

a) O= percentage of PSAC priority area overlapping with moderate-to-high BPBD flood-susceptibility zones;
b) $A_{\text{PSAC} \cap \text{BPBD}}$= area simultaneously classified as a PSAC priority area and as moderate-to-high BPBD flood susceptibility;
c) A_{PSAC}= total PSAC priority area.

The validation output is intended to assess spatial agreement between the integrated PSAC assessment and the official institutional susceptibility reference. It is not interpreted as a complete event-based predictive accuracy assessment.

S3.11. GIS-Derived Outputs

The following GIS-derived outputs were generated from the processed datasets and spatial operations described in Supplementary File S2.

Table S3.3. GIS-Derived Output Inventory

Output ID	GIS Output	Format	Main Content	Analytical Function
GIS-01	Processed administrative boundary	GeoPackage/Shapefile	District boundaries and identifiers	Spatial analysis unit
GIS-02	Processed rainfall pressure layer	Raster/vector	Spatial representation of rainfall pressure	Hydrological pressure assessment
GIS-03	Flood-susceptibility overlay	Raster/vector	Susceptibility classes intersected with districts	Flood sensitivity assessment
GIS-04	Moderate-to-high susceptibility layer	Raster/vector	Combined moderate and high susceptibility zones	PSAC sensitivity criterion
GIS-05	GOS spatial layer	Vector	Green Open Space polygons	Adaptive-capacity assessment
GIS-06	GOS coverage layer	Raster/vector	District-level GOS coverage	Landscape adaptive capacity
GIS-07	Impervious-surface layer	Raster/vector	Built-up or impervious surface distribution	Urban sensitivity assessment
GIS-08	Urban exposure overlay	Vector	Assets intersected with hazard classes	Exposure assessment
GIS-09	LAC classification map	Raster/vector	Very low to very high LAC classes	Adaptive-capacity mapping
GIS-10	PSAC priority layer	Raster/vector	Integrated priority areas	Priority intervention assessment
GIS-11	BPBD validation overlay	Raster/vector	PSAC priority and BPBD susceptibility overlap	Spatial validation
GIS-12	Final integrated map	Raster/vector	Integrated flood-risk or PSAC assessment	Visualization and planning support

The specific file format and spatial resolution of each output should be reported according to the actual data-processing environment and the data-use restrictions applicable to the original source datasets.

S3.12. GIS Attribute Fields

The principal spatial outputs should retain sufficient attribute information to allow the reported calculations to be verified.

Table S3.4. Recommended Attribute Structure for Derived GIS Outputs

Field Name	Description
District_ID	District identifier
District_Name	District name or approved identifier
Class_ID	Spatial class identifier
Class_Name	Spatial class name
Area_km2	Area of the intersected feature
Area_Percent	Percentage relative to the relevant spatial unit
LAC_Index	Composite Landscape Adaptive Capacity value
LAC_Class	LAC classification
Hazard_Class	Flood hazard classification
Susceptibility_Class	BPBD susceptibility classification
Exposure_Class	Exposure category
PSAC_Status	PSAC priority status
Validation_Status	BPBD overlap status
Source_ID	Source dataset identifier
Processing_ID	GIS processing step identifier

S3.13. Data Quality and Geometry Verification

Before the derived spatial datasets were generated, the input and intermediate GIS layers were subjected to basic geometry and topology checks. The verification process included:

1. checking for invalid or corrupted geometries;
2. repairing geometries where required;
3. removing duplicate or overlapping features where appropriate;
4. confirming the consistency of coordinate reference systems;
5. checking for unintended gaps or overlaps in classified spatial layers;
6. verifying that all spatial layers covered the intended study area;
7. confirming that area calculations were performed using an appropriate projected coordinate system; and
8. checking the consistency of calculated areas against the corresponding administrative boundaries.

The derived outputs should therefore be interpreted as products of a controlled GIS processing sequence rather than as direct copies of the original institutional spatial datasets.

S3.14. Reproducibility of Reported Results

The numerical results reported in the manuscript were generated from the derived analytical variables and GIS outputs using the calculation procedures documented in the main manuscript, Supplementary File S1, and Supplementary File S2.
The reproducibility sequence can be summarized as follows:

Equivalent Source Data → GIS Pre-processing → Spatial Intersection → Area Calculation → Standardization → Classification → Index Calculation → PSAC Priority Mapping → Validation

The derived datasets are intended to allow users to verify:

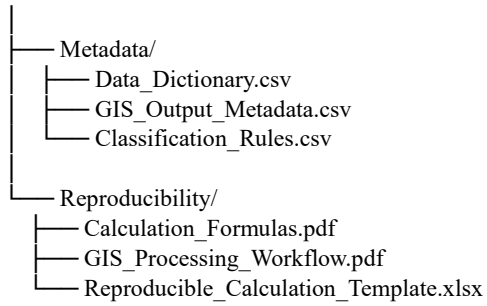
a) rainfall summary statistics;
b) flood-susceptibility area calculations;
c) moderate-to-high susceptibility percentages;
d) GOS area and coverage percentages;
e) asset exposure distributions;
f) LAC index values and classifications;
g) PSAC priority-area calculations; and
h) spatial overlap with the BPBD susceptibility reference.

Where exact original spatial layers cannot be redistributed, reproducibility depends on the availability of equivalent source data with comparable spatial extent, classification definitions, spatial resolution, temporal reference, and analytical characteristics.

S3.15. Recommended File Organization

The supplementary package may be organized as follows:

```
Supplementary_File_S3/
│
├── README_S3_Derived_Data_and_GIS_Outputs.pdf
│
├── Derived_Analytical_Datasets/
│   ├── District_Level_PSAC_Dataset.csv
│   ├── Rainfall_Derived_Indicators.csv
│   ├── Flood_Susceptibility_Summary.csv
│   ├── GOS_Coverage_Summary.csv
│   ├── Asset_Exposure_Summary.csv
│   ├── LAC_Index_Summary.csv
│   └── PSAC_Validation_Summary.csv
│
├── GIS_Derived_Outputs/
│   ├── Administrative_Unit_Summary.gpkg
│   ├── Flood_Susceptibility_Overlay.gpkg
│   ├── GOS_Coverage_Output.gpkg
│   ├── LAC_Classification_Output.gpkg
│   ├── Urban_Exposure_Output.gpkg
│   ├── PSAC_Priority_Output.gpkg
│   └── BPBD_Validation_Overlay.gpkg
```



S3.16. Data Availability Statement for Supplementary File S3

The derived analytical datasets and GIS outputs generated during this study are provided to support transparency and reproducibility of the reported analysis, subject to applicable data-use and redistribution restrictions. Original institutional datasets, including restricted administrative, flood-susceptibility, land-use, infrastructure, and other government-provided spatial layers, may not be redistributed in their original form. Where such restrictions apply, the supplementary materials provide derived district-level analytical variables, spatial summaries, metadata, classification rules, GIS processing procedures, and calculation formulas sufficient to reproduce the reported results using equivalent source data. The availability of any specific GIS-derived output is subject to the ownership, licensing, and redistribution conditions of the underlying source data.