

RiskBased Zoning Directions for Flash-Flood Mitigation in Wasior District, Teluk Wondama Regency, Indonesia

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ABSTRACT: Wasior District, West Papua, has a history of destructive flash floods and continuing development pressure along river corridors and low-lying urban areas. This study formulates risk-informed zoning directions by translating flash-flood susceptibility into spatial-planning controls. An applied descriptive-quantitative design was combined with Geographic Information System (GIS) analysis. Ten physical-spatial parameters: rainfall, slope, elevation, flow accumulation, distance to rivers, drainage density, land use/land cover, soil or geological conditions, upstream landslide potential, and landform/topographic position: were reclassified, scored, weighted, and integrated using weighted overlay. The susceptibility map was overlaid with existing land use and the planned spatial pattern and compared with the documented 2010 affected area. Of 20,854.56 ha, 51.71% is classified as low susceptibility, 34.57% as moderate, and 13.71% as high. In the planned urban-settlement area, 779.00 ha (82.78%) lies in moderate and high classes, while 166.39 ha (87.29%) of the mapped 2010 affected area also falls within those classes. The study proposes controlled development in low-susceptibility areas, limited and conditional development in moderate areas, and strict protection and development restriction in high-susceptibility areas. Its main contribution is a planning workflow that links GIS susceptibility evidence directly to differentiated zoning and development control.

KEY WORDS: Flash flood, Susceptibility mapping, risk-based zoning, spatial planning, disaster mitigation

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I. INTRODUCTION

Hydrometeorological hazards are a major challenge for spatial development in Indonesia, particularly in steep tropical catchments where intense rainfall, short river systems, unstable slopes, and rapidly expanding settlements interact. Flash floods differ from ordinary inundation because peak discharge develops quickly, flow velocity is high, warning time may be short, and the flow can transport sediment, boulders, woody debris, and other material. For spatial planning, these characteristics mean that exposure is created not only by the physical hazard but also by decisions that place housing, infrastructure, public facilities, and economic activities in river corridors, fan surfaces, valley mouths, and low-lying receiving zones [1,2].

Wasior District, TelukWondama Regency, experienced a major flash-flood disaster on 4 October 2010. The event damaged settlements, public facilities, roads, and basic infrastructure and became an important reference for post-disaster rehabilitation and reconstruction [2]. The district is situated between mountainous terrain and the coastal lowlands. This physiographic transition produces a connected upstream-to-downstream system in which steep source areas, confined river corridors, and relatively flat depositional zones coexist within a narrow spatial setting. Recent district-level disaster documentation continues to identify flooding as a significant local hazard [3].

The spatial-planning problem is not solved by producing a hazard map alone. A susceptibility map becomes useful for land-use governance only when it is translated into differentiated controls on where development may occur, under what conditions, at what intensity, and with which mitigation requirements. Disaster-risk guidance in Indonesia places hazard assessment within a broader process of risk reduction, while contemporary flood-risk management emphasizes the role of spatial planning in preventing the creation of new

exposure [1,12]. This shift is especially important in post-disaster areas, where reconstruction and subsequent urban growth can gradually reoccupy hazardous corridors if risk information is not institutionalized in zoning and permitting.

In Wasior, the existing spatial plan recognizes areas affected by flooding and landslides and includes general measures such as river setbacks, infrastructure improvement, revegetation, early warning, and evacuation. However, the thesis evidence indicates that these provisions remain relatively general and have not been fully operationalized into susceptibility-specific zoning rules, treatment of existing buildings, source–path–impact delineation, or location-specific development controls. This creates a practical gap between disaster knowledge and day-to-day spatial management.

This study therefore aims to formulate zoning directions for Wasior District by integrating GIS-based flash-flood susceptibility analysis with existing land use and the planned spatial pattern. The contribution lies in the conversion of physical-spatial evidence into a planning instrument: low-susceptibility areas are assessed for controlled development, moderate-susceptibility areas for conditional and limited use, and high-susceptibility areas for strict protection, development restriction, and phased exposure reduction. The approach is intended as an input to more detailed spatial plans, zoning regulations, development control, and disaster-risk reduction rather than as a complete statutory zoning code.

II. LITERATURE REVIEW

2.1. Flash-Flood Susceptibility and Spatial Drivers

Flash-flood susceptibility expresses the relative tendency of a location to experience rapid flooding under a combination of physical and environmental conditions. In steep catchments, susceptibility is controlled by multiple interacting variables rather than a single determinant. Rainfall provides the immediate hydrological trigger, while slope, elevation, drainage configuration, land cover, soil and geological properties, geomorphology, and proximity to river channels influence runoff generation, concentration, conveyance, and deposition [5,6,7,8].

The upstream–downstream connection is critical for debris-rich flash floods. Steep upper catchments can generate rapid runoff and mobilize soil, rock, sediment, and woody material. River corridors and narrow valleys act as conveyance pathways, while valley mouths, confluences, breaks in slope, and low-lying downstream areas function as receiving and depositional zones. This process means that susceptibility should be interpreted as a spatial system that links source areas, transport pathways, and affected zones rather than as isolated pixels on a map.

GIS provides a practical environment for organizing these multi-criteria relationships. Weighted overlay converts individual thematic layers into comparable classes, assigns scores that represent relative contribution to susceptibility, applies parameter weights, and integrates the layers into a composite index [4,10]. The method is particularly useful when the purpose is to establish a transparent planning classification rather than to estimate a precise event probability.

2.2. Risk Reduction Through Spatial Planning and Zoning

Spatial planning is a non-structural risk-reduction measure because it influences the location and intensity of future exposure. Development control can complement engineering measures by maintaining river corridors, protecting upstream ecological functions, limiting building density in hazard-prone areas, reserving evacuation space, and directing new growth toward relatively safer land. This aligns with the broader resilience literature, which treats urban resilience as a capacity that emerges from the interaction of ecological, infrastructural, institutional, and social systems [13,14,15].

Risk-based zoning requires differentiated responses. In relatively safe areas, development may proceed under ordinary planning and environmental safeguards. In intermediate areas, development can be conditional on risk assessment, drainage and access requirements, evacuation provision, building-resilience standards, and limits on density or intensity. In the highest-susceptibility areas, new development that increases population or asset exposure should be strongly restricted, and existing uses should be managed through mitigation, monitoring, selective relocation, and ecosystem rehabilitation. Such differentiation turns a susceptibility map into an operational planning tool.

Equity and climate adaptation are also relevant. Risk-reduction measures must consider the needs of children, older persons, persons with disabilities, pregnant women, low-income households, and communities with customary land rights. Climate change may increase uncertainty in rainfall extremes, while poorly planned relocation can transfer rather than reduce vulnerability. Thus, zoning decisions should be linked to accessible warning systems, inclusive evacuation, livelihood continuity, tenure security, and locally legitimate consultation [15,16,17].

2.3. Research Gap and Planning Contribution

The main research gap addressed by the thesis is the incomplete translation of flash-flood information into spatial-development controls. Existing disaster assessments can identify hazardous or susceptible locations, but planning authorities still require explicit guidance on whether a use should be permitted, limited, made conditional, protected, or gradually relocated. This study addresses that gap by combining susceptibility classification, land-use overlay, planned spatial-pattern overlay, historical-event comparison, and zoning formulation within one applied workflow. The novelty is therefore planning-oriented: the map is treated as an intermediate analytical product, while the final output is a differentiated set of spatial-control directions.

III. RESEARCH METHODS

4.1. Research Design and Study Area

The research used an applied descriptive-quantitative design supported by spatial analysis. The applied orientation was selected because the objective was not only to characterize flash-flood susceptibility but also to produce practical recommendations for zoning and development control. Field observation, measurement, interviews, planning documents, disaster records, and GIS data were combined to support interpretation and validation. The fieldwork period reported in the thesis was May–June 2026.

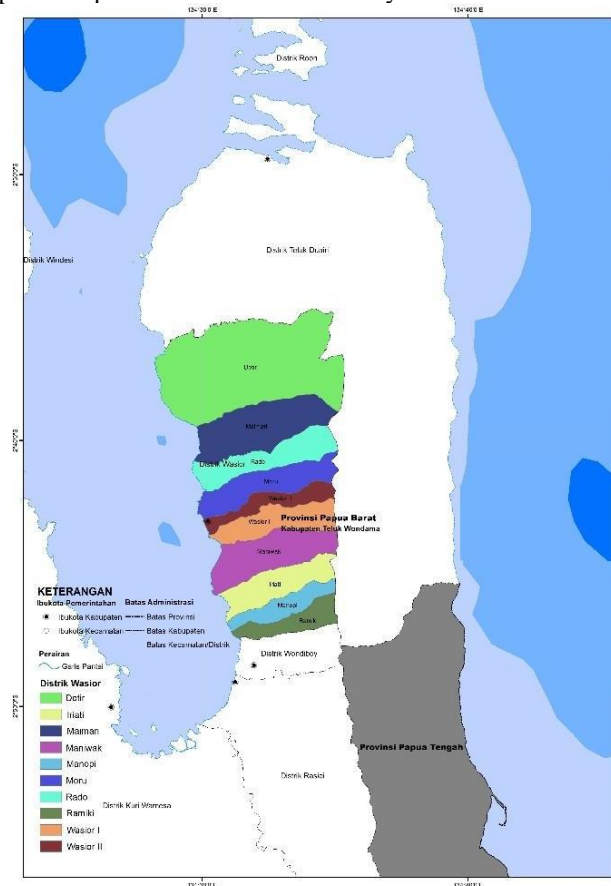


Figure 1. Administrative context of the Wasior District study area.

The study area covers the administrative territory of Wasior District, TelukWondama Regency, West Papua, including one urban village and nine villages. The district occupies a narrow transition from mountainous terrain to the coastal lowlands. Priority attention was given to areas historically affected by flash flooding and to settlements associated with the main river systems, including Rado, Moru, Wasior I/KelurahanWasior, Wasior II, and Maniwak.

4.2. Data and Susceptibility Parameters

Primary data were obtained through field observation, measurement, and interviews, while secondary data were collected from regional agencies, spatial-planning documents, disaster-management records, thematic maps, and previous technical studies. Ten parameters were selected because of their relevance to the local

hydro-geomorphological setting and the availability of spatial data. Each parameter was reclassified into five classes, scored from 1 (very low contribution) to 5 (very high contribution), and multiplied by its relative weight.

Table 1. Parameters used in the flash-flood susceptibility analysis.

No	Parameter	Planning relevance
1	Rainfall	Hydrological trigger for rapid runoff and peak discharge
2	Slope	Controls flow acceleration and runoff concentration
3	Elevation	Represents vertical position in the catchment and receiving zones
4	Flow accumulation	Identifies convergent drainage and concentrated surface flow
5	Distance to river	Represents direct proximity to conveyance corridors
6	Drainage density	Indicates degree of channel-network development
7	Land use / land cover	Influences infiltration, runoff, and surface roughness
8	Soil / geological condition	Affects infiltration, stability, and sediment availability
9	Upstream landslide potential	Represents potential debris and sediment source areas
10	Landform / topographic position	Distinguishes source, pathway, fan, valley, and depositional settings

4.3. GIS Weighted-Overlay Analysis

The flash-flood susceptibility index was calculated as $IKBB = \sum(W_i \times S_i)$, where IKBB is the composite flash-flood susceptibility index, W_i is the weight of parameter i , and S_i is the score assigned to the relevant class of parameter i . The weighted layers were processed in GIS to produce a composite surface and then grouped into three planning classes, low, moderate, and high, so that the final output remained consistent with the risk-assessment logic used in Indonesian disaster management and with the operational needs of zoning [1,2,3,4].

The three-class system has a direct planning interpretation. Low susceptibility represents areas where the combined physical conditions are relatively less supportive of flash-flood formation or impact; moderate susceptibility represents areas where several influential conditions are present and development requires limitations and mitigation; high susceptibility represents areas where the combination of factors strongly supports formation, flow concentration, direct impact, or deposition and therefore requires the strictest development control.

4.4. Spatial-Conformity and Historical-Event Analysis

The susceptibility map was overlaid with two planning layers: existing land use and the planned spatial pattern. The overlays identified where settlement, infrastructure, agriculture, conservation areas, and other functions intersect low, moderate, and high susceptibility. The output was used to classify spatial use as relatively suitable, conditionally suitable, or inappropriate from a mitigation perspective. A further overlay with the mapped 2010 affected area tested whether historically affected locations were concentrated in the moderate and high susceptibility classes.

4.5. Formulation of Zoning Directions

The final stage was prescriptive. Zoning directions were derived from susceptibility class, existing exposure, planned land use, ecological function, evacuation needs, and the feasibility of reducing risk. Activities were grouped into four regulatory responses: permitted, permitted on a limited basis, permitted with specific requirements, and not permitted. Recommendations also addressed river-corridor protection, density limitation, engineering and non-engineering mitigation, early warning, evacuation, phased relocation, and monitoring.

IV. RESULTS AND DISCUSSIONS

4.1. Spatial Pattern of Flash-Flood Susceptibility

The GIS model produced a clear spatial differentiation of flash-flood susceptibility across Wasior District. The overall study area used in the final zoning calculation is 20,854.56 ha. Low-susceptibility areas occupy 10,784.05 ha (51.71%), moderate-susceptibility areas 7,210.56 ha (34.57%), and high-susceptibility areas 2,859.95 ha (13.71%). The high class is concentrated along major and tributary river corridors, near channel junctions, at valley mouths, in areas with high flow accumulation, and in downstream receiving zones connected to steep upstream catchments.

This distribution confirms that proximity to rivers is important but insufficient as a stand-alone explanation. High susceptibility reflects the connection among catchment condition, slope, flow concentration, land cover, geological or soil characteristics, landslide potential, and topographic position. The result supports a

systems interpretation of Wasior: upstream slopes generate water and potentially debris, channels convey the flow, and low-lying urban areas receive and accumulate the impact.

The mapped pattern has a direct planning implication. Even though the largest share of the district is classified as low susceptibility, the more critical issue is the location of moderate and high classes relative to urban settlement, infrastructure, and public facilities. A relatively small high-susceptibility share can still generate disproportionate risk when it overlaps densely occupied or strategically important land uses.

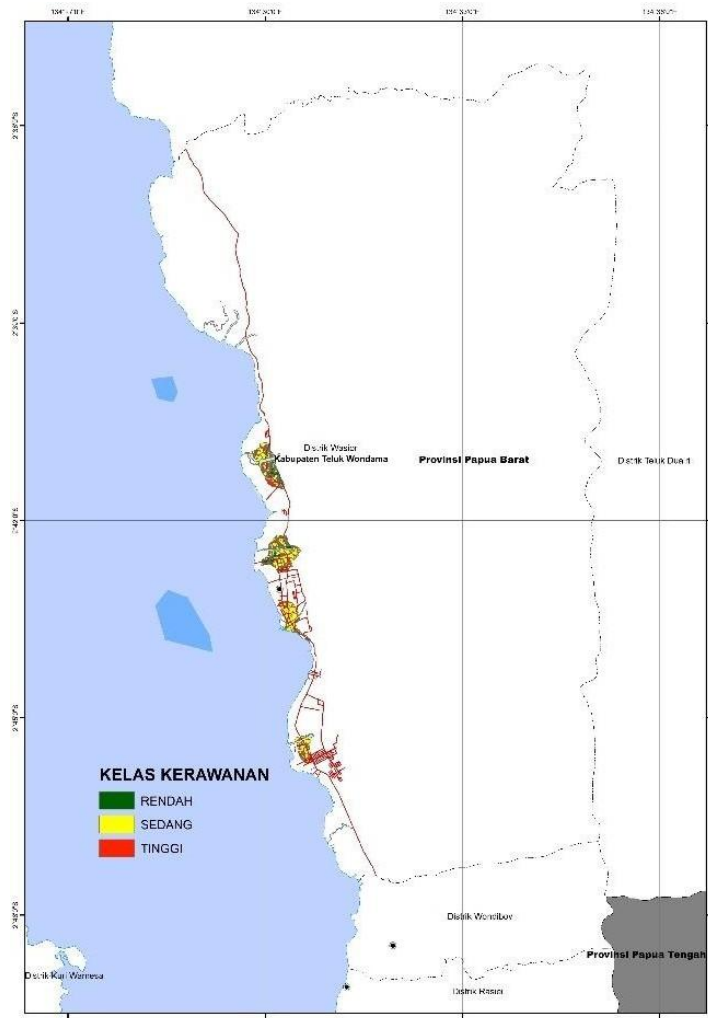


Figure 2. Flash-flood susceptibility classes in Wasior District.

Table 2. Distribution of flash-flood susceptibility and general planning direction.

Class	Area (ha)	Share (%)	General planning direction
Low	10,784.05	51.71	Controlled development; maintain infiltration and ecological functions
Moderate	7,210.56	34.57	Limited/conditional use with risk study, evacuation, drainage, density controls
High	2,859.95	13.71	Protection and strict restriction; no new exposure-intensive development

4.2. Overlap With the Planned Spatial Pattern

The overlay with the planned spatial pattern shows that susceptibility is distributed across both protected and development-oriented land uses. The largest high-susceptibility area occurs within the nature-reserve allocation (2,419.22 ha), followed by limited-production forest (174.83 ha) and planned urban settlement (188.76 ha). The nature-reserve overlap supports maintaining strict ecological protection because upstream forest and slope functions are integral to runoff regulation, erosion control, and sediment management.

The most important development issue is the planned urban-settlement area. Of the total planned urban settlement, 162.08 ha is in the low class, 590.24 ha in the moderate class, and 188.76 ha in the high class. Thus, 779.00 ha—or 82.78% of the planned urban-settlement area—is located in the moderate and high susceptibility classes. This finding indicates that the spatial plan cannot rely on a uniform settlement policy; it requires class-specific rules that distinguish safer growth areas from locations where density, building expansion, and critical facilities should be controlled.

Transportation areas also intersect all three classes, including 27.39 ha in the high class. Because roads, bridges, terminals, and evacuation routes have both every day and emergency functions, infrastructure located in susceptible corridors requires additional attention to bridge openings, drainage capacity, slope stability, sediment accumulation, redundancy, and evacuation continuity.

Table 3. Flash-flood susceptibility within the planned spatial pattern.

Planned spatial function	Low (ha)	Moderate (ha)	High (ha)
Water bodies	3.63	20.06	7.25
Nature reserve	9,681.45	5,775.88	2,419.22
Mangrove ecosystem	60.04	44.02	7.61
Limited-production forest	581.44	533.03	174.83
Power-generation area	0.00	0.86	0.18
Plantation	87.82	60.49	14.90
Local-protection area	33.11	52.94	10.93
Urban settlement	162.08	590.24	188.76
Defense and security	0.00	1.09	0.50
Food-crop area	19.91	19.56	7.48
Transportation	148.81	110.02	27.39
National park	5.77	2.38	0.90

4.3. Existing Land Use and Exposure

The existing-land-use overlay confirms that current exposure is already substantial. Settlement/open land totals 496.97 ha, of which only 0.08 ha lies in the low class, while 345.92 ha is moderate and 150.97 ha is high. This concentration means that many occupied locations cannot simply be treated as future-development questions; they require management of existing exposure through building resilience, warning, evacuation, river-corridor protection, and selective relocation where risk cannot be reduced to an acceptable level.

Field observations recorded several conditions that can amplify risk: buildings close to riverbanks, river narrowing, sedimentation, bridges with limited openings, and land-use conditions in upstream areas that can affect runoff and sediment supply. The thesis also identifies five educational facilities, three health facilities, four government facilities, four houses of worship, and approximately 14 km of roads in the highest susceptibility categories reported in the detailed analysis. Because public facilities often function as emergency service nodes, their location and operational continuity should be assessed as part of spatial risk management.

Table 4. Susceptibility classes within existing land use (ha).

Existing land use	Low	Moderate	High	Total (ha)
Shrubland	27.99	668.28	198.16	894.43
Garden/plantation plot	11.65	19.91	6.44	38.00
Primary forest	10,740.35	6,175.61	2,503.94	19,419.90
Settlement/open land	0.08	345.92	150.97	496.97

4.4. Historical-Event Comparison

The 2010 flash-flood footprint provides an important empirical reference. The thesis maps 190.80 ha of affected area across Rado, Moru, Wasior I/KelurahanWasior, and Maniwak, with inundation or flow-depth classes of 0–1 m and 1–2.5 m. When the affected-area map is overlaid with the susceptibility model, 166.39 ha (87.29%) falls in the moderate and high classes. This substantial agreement supports the interpretation that the susceptibility model captures the major spatial logic of historical impact.

The historical comparison also clarifies planning priority. Rado, Moru, Wasior I/KelurahanWasior, and Maniwak contain elongated settlement patterns that follow roads and rivers. Such morphology can place buildings near channels and within low-relief valley settings. In these locations, development control should not

be limited to setback distances alone; it should also consider micro-flow paths, bridge constrictions, evacuation access, local topography, and upstream sediment sources.

Table 5. Susceptibility classes within the mapped 2010 affected area (ha).

Affected location	Mapped area (ha)	Low	Moderate	High
Rado	60.55	11.36	33.67	15.52
Moru	67.48	12.70	41.62	13.16
Wasior I / Kelurahan Wasior	35.93	0.18	29.55	6.20
Maniwak	26.66	0.00	19.55	7.11
Total	190.63	24.24	124.40	41.99

4.5. Risk-Based Zoning Directions

The zoning strategy is based on a graduated-control principle. Low-susceptibility areas are the primary locations for future growth, provided that development maintains infiltration, river and drainage performance, ecological functions, and other planning requirements. This does not imply zero risk; rather, it indicates a comparatively lower flash-flood constraint within the district-scale analysis.

Moderate-susceptibility areas require conditional use. New projects should be supported by site-specific risk assessment and, where relevant, hydrological or hydraulic review. Requirements should include adequate drainage, open and infiltration space, safe access, evacuation routes and assembly areas, limitations on building density and land-use intensity, protection of minor flow paths, and building measures appropriate to local flood conditions. Critical facilities should be evaluated more strictly because failure during an emergency has wider consequences.

High-susceptibility areas should function primarily as protection and strict-control zones. New settlement or development that substantially increases population or asset exposure should not be permitted. Existing activities require monitoring and strengthened structural and non-structural mitigation. Buildings located on the river channel, principal flow path, or locations where technical protection is not feasible should become priorities for phased and consultative relocation. River corridors, riparian vegetation, upstream forest, and sediment-source areas should be managed as connected components of the mitigation system.

Table 6. Proposed zoning directions derived from the thesis analysis.

Susceptibility class	Regulatory response	Spatial-use direction	Key mitigation requirements
Low	Permitted under control	Settlement, transport, agriculture and other cultivation may develop subject to planning and environmental rules.	Maintain infiltration and ecological functions; avoid degradation of drainage and river systems.
Moderate	Limited / conditional	Development may continue only with specific mitigation and risk-management requirements.	Risk assessment; drainage; evacuation routes/space; density and intensity limits; resilient building and access standards.
High	Strict protection / restriction	Avoid new development that increases population or asset exposure; maintain only compatible existing uses under strong controls.	River-corridor protection; ecosystem rehabilitation; monitoring; structural/non-structural mitigation; selective phased relocation where risk cannot be reduced.

The zoning strategy must also be supported by governance and emergency preparedness. The susceptibility and zoning maps should be incorporated into detailed spatial planning, zoning regulations, development-permit screening, regional development programs, and disaster-management documents. Early-warning systems should link rainfall and water-level monitoring in upstream areas with communication, sirens, radio networks, community procedures, and accessible warnings in visual, audio, written, and direct formats.

4.6. Planning Implications

The results show why susceptibility mapping should be treated as an input to governance rather than as an end product. The central planning task is to prevent the accumulation of new exposure while progressively reducing existing exposure. This requires coordination among spatial-planning, public-works, disaster-

management, environmental, district, and village institutions. A shared geospatial database can support consistent permitting, monitoring, infrastructure investment, and public communication.

Ecosystem management is inseparable from zoning. Upstream forest rehabilitation, protection of critical slopes and springs, riparian restoration, erosion control, sediment monitoring, and waste management can reduce processes that intensify rapid runoff and channel blockage. Customary communities and holders of customary land rights should be involved in the designation and management of protection areas so that implementation is technically credible and socially legitimate.

Relocation should be selective rather than automatic. It is appropriate primarily where buildings occupy very high-risk locations, principal flow paths, or sites where practical mitigation cannot reduce risk. Any relocation program should address tenure, housing quality, access to livelihoods, schools, health care, transport, markets, social networks, and customary land rights. In this sense, spatial-risk management must combine physical safety with social continuity and procedural fairness [15].

The study has limitations. The susceptibility model is designed for district-scale planning and depends on the resolution and quality of the available spatial data. The zoning directions are conceptual and are not a substitute for detailed hydraulic modelling, site investigation, structural design, or a complete statutory RDTR and zoning regulation. Future work should refine micro-zonation, test alternative weighting methods, incorporate dynamic rainfall scenarios, quantify social vulnerability and capacity more explicitly, and evaluate implementation after spatial controls are adopted.

V. CONCLUSIONS

Wasior District exhibits a connected flash-flood susceptibility system from steep upstream source areas to river corridors and low-lying downstream receiving zones. The GIS analysis classifies 20,854.56 ha into 51.71% low, 34.57% moderate, and 13.71% high susceptibility. The high class is concentrated along river networks, confluences, valley mouths, zones of concentrated flow, and historically affected downstream areas.

The spatial-planning significance is substantial because moderate and high susceptibility overlap important development functions. Within the planned urban-settlement allocation, 779.00 ha—82.78% of the planned settlement area—falls in the moderate and high classes. Existing settlement/open land is likewise concentrated in these classes. Comparison with the 2010 affected-area map shows that 87.29% of the mapped historical impact lies in moderate and high susceptibility, providing empirical support for the model's planning interpretation.

The resulting zoning framework differentiates spatial controls by susceptibility. Low-susceptibility areas are the preferred locations for controlled growth; moderate areas require limited and conditional development with mitigation and evacuation requirements; high areas require protection, strict restrictions on new exposure, stronger management of existing uses, ecosystem rehabilitation, and selective relocation where risk cannot be acceptably reduced. The principal contribution is thus the transformation of spatial hazard evidence into an operational logic for zoning and development control.

For implementation, the maps and zoning directions should be integrated into detailed spatial plans, zoning regulations, development-permit review, infrastructure programs, early-warning systems, and community preparedness. Long-term resilience will depend on consistent enforcement, updated geospatial data, upstream and river-corridor protection, inclusive evacuation planning, inter-agency coordination, and meaningful participation of local and customary communities.

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