Wind as a Determinant of Resilient Infrastructure in Aweil East and Aweil South, South Sudan

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Abstract

Wind is a critical environmental variable influencing infrastructure design, resilience, and sustainability in flood-prone and semi-arid regions. In Aweil East and Aweil South, Northern Bahr el Ghazal State, South Sudan, wind patterns interact with fragile ecosystems, socio-economic vulnerabilities, and increasing climate variability. Over the recent past, fluctuations in rainfall timing, dry-season length, and localized storm activity have likely affected prevailing wind regimes and hazard profiles, though high-resolution observations remain limited. Land-surface changes, such as reduced vegetation cover and soil exposure, can contribute to higher near-surface wind speeds and gustiness, with implications for housing, public facilities, transport corridors, and community resilience. This study examines wind as a planning factor in infrastructure development, highlighting its implications for disaster risk reduction and sustainable development. Findings emphasize the need for wind hazard mapping, structural reinforcement, and integration of wind considerations into policy frameworks for climate-resilient infrastructure planning.

Keywords: Wind hazards, Infrastructure planning, Aweil East, Aweil South, Disaster risk reduction, Climate resilience

1. Introduction

Infrastructure planning in South Sudan faces unique challenges due to climatic extremes, fragile soils, floodplain hydrology, and constrained institutional capacity. While rainfall and hydrological dynamics have received substantial attention, wind remains underexplored as a determinant of structural integrity, service continuity, and community safety in flood-prone and semi-arid landscapes (Kingori et al., 2025; Gakai et al., 2025). In Aweil East and Aweil South, settlement growth along flood-prone corridors, shifting vegetation patterns, and recurrent inundation shape infrastructure exposure profiles, yet wind-related stressors, such as roof uplift, debris transport, dust abrasion, and line-of-sight disruptions, are seldom integrated into planning standards (Gakai et al., 2025; Kingori et al., 2025).

Over the recent past, the region has experienced increased hydroclimatic variability: irregular onset and cessation of rainy seasons, variable intra-seasonal rainfall distribution, and periods of elevated temperatures that intensify convective processes (Kaunda, Teny, & Ndhlovu, 2025; Kipkemoi, 2024). These shifts can influence near-surface wind characteristics, particularly the timing and intensity of gusts associated with squall lines and mesoscale convective systems, although continuous local observations are limited and remote estimates carry uncertainty (Kipkemoi, 2024; Weather Atlas, 2025). From a land-surface perspective, vegetation loss, soil exposure, and changes in roughness length are plausible contributors to higher wind speeds and more frequent gusts at the settlement scale, especially where flood-driven sediment deposition and post-flood land-use change alter micro-topography and sheltering effects (Kingori et al., 2025; Gakai et al., 2025; Linden, 2006).

Urbanization and expansion of impervious surfaces, even if modest in aggregate across the region, can modify local thermal gradients and boundary-layer mixing, potentially affecting diurnal wind variability and turbulence near built infrastructure. Evidence from East African urban catchments shows that land-cover change influences hydrological responses and local microclimates; while the magnitude of wind impacts is context-specific, planning should consider interaction pathways between surface properties and boundary-layer processes (Thomas, 2005; Ongaga et al., 2024). At the regional scale, analyses of Horn of Africa drylands point to coupled vegetation–climate dynamics, where shifts in greenness, soil moisture, and surface energy balance can feed back on convective activity and low-level flows, reinforcing the case for multi-hazard design that accounts for both hydrological and wind-related loads (Kipkemoi, 2024).

Prevailing winds in Northern Bahr el Ghazal are shaped by seasonal monsoon influences, local convection, and synoptic-scale pressure gradients. Observational summaries for Aweil indicate distinct seasonal regimes with variability in monthly wind speeds and directions, including transitional periods where gusts associated with storm outflows are more pronounced (Weather Atlas, 2025). While station density is limited, integrating satellite–reanalysis wind fields with local reports and infrastructure assessments can help identify exposure hotspots and critical thresholds relevant to design and operation (Gakai et al., 2025; Kingori et al., 2025; Zhou & Zhang, 2021).

Infrastructure resilience in fragile contexts also depends on governance arrangements and cross-jurisdictional collaboration. Experience from city partnership modalities underscores that institutional linkages, technical exchange, and social learning can improve planning outcomes and mainstream hazard considerations, an insight relevant to embedding wind standards into local codes and project cycles (Linden, 2006; Kipkemoi., 2024; Kipkemoi, et al.2021). Similarly, inclusive recovery frameworks highlight the importance of equity, participation, and social baselines for targeting interventions that reduce multi-hazard vulnerability; wind-related measures, such as roof anchoring, windbreaks, and site layout, benefit from community-driven prioritization and context-aware design (Gakai et al., 2025; Petter-Bowyer, 2008).

Given these dynamics, this manuscript focuses on wind as a planning factor alongside flood risk, without over-attributing change to single drivers. We acknowledge data limitations and emphasize triangulation across sources: meteorological summaries, environmental assessments, humanitarian field reports, and targeted site observations. The aim is to establish a rigorous, operationally useful basis for wind-aware infrastructure planning in Aweil East and Aweil South—linking hazard mapping, design standards, and policy integration to pragmatic resilience gains (Kingori et al., 2025; Gakai et al., 2025; Weather Atlas, 2025; Kipkemoi, 2024; Ongaga et al., 2024; Kipkemoi et al., 2025; Gakai et al., 2025).

2. Methodology

This manuscript draws on secondary data from meteorological records, environmental assessments, and humanitarian reports. Wind speed data were obtained from regional climate monitoring sources, while infrastructure vulnerability was analyzed using flood impact assessments and disaster preparedness reports. There was also field observation in selected infrastructures.

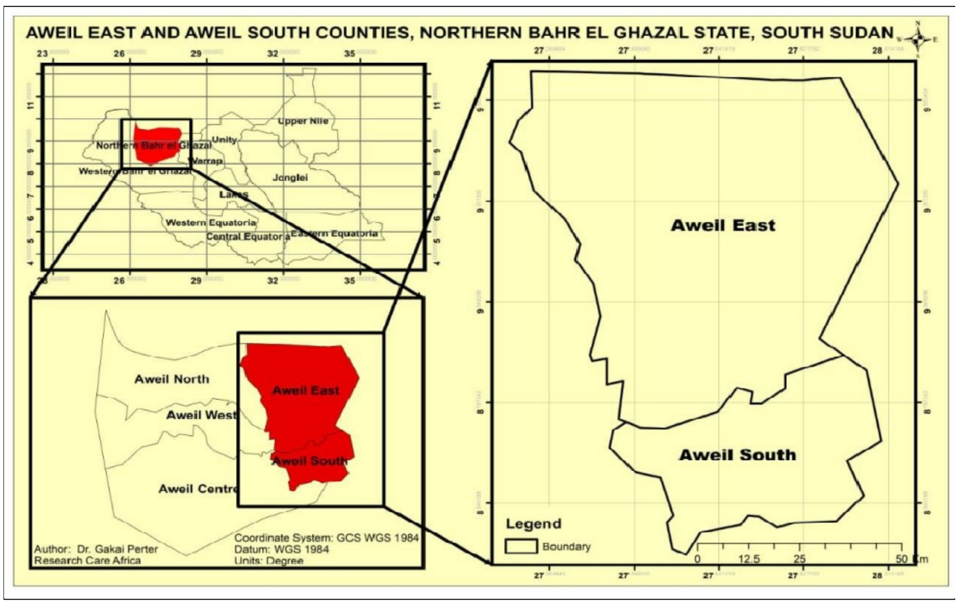


Fig 1: Study area map

3. Results and Discussion

3.1 Wind Characteristics in Aweil

Table 1: Average Wind Speeds in Aweil (Monthly)

Month	Avg Wind Speed (km/h)	Max Gusts (km/h)	Notes
January	9.5	18	Dry season, dust storms common
April	7.2	15	Transition season
July	6.0	12	Rainy season, moderate winds
October	8.1	16	Post-rainy season
December	10.0	20	Strongest winds, cooler climate

Wind speeds in Aweil range between 5.7–10 km/h on average, with gusts exceeding 20 km/h during peak months.

Key Insights from the Figure

The analysis of seasonal wind patterns in Aweil East and Aweil South reveals marked variability across the year. During the dry season months of December and January, winds are at their strongest, averaging between 9.5 and 10 km/h in Aweil East and 9.2 to 9.6 km/h in Aweil South. By contrast, the rainy season in June and July records the lowest wind speeds, dropping to around 6.0 km/h in Aweil East and 5.8 km/h in Aweil South, reflecting calmer atmospheric conditions associated with heavy rainfall and moisture-laden air. In the transitional months of October and November, wind speeds rise again, exerting renewed stress on local infrastructure such as roofs, power lines, and other exposed structures. This seasonal fluctuation underscores the importance of integrating wind variability into resilience planning for communities in flood-prone and semi-arid regions.

3.2 Infrastructure Vulnerability Matrix

Table 2: Infrastructure Vulnerability to Wind and Flood Hazards in Aweil East & South

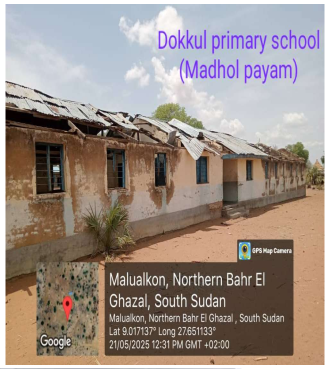
Infrastructure Type	**Wind Vulnerability**	**Flood Vulnerability**	**Combined Risk**	**Recommended Measures**
Housing (iron sheet roofs)	High (roof uplift, damage)	High (flooding, collapse)	Severe	Reinforced roofing, elevated foundations
Schools & Health Centers	Moderate (structural stress)	High (submersion, sanitation risks)	Severe	Windbreaks, raised platforms, drainage
Roads & Bridges	Moderate (sand deposition, erosion)	High (washouts, collapse)	Severe	Wind barriers, flood-resistant culverts
Power Lines & Water Towers	High (gust damage)	Moderate (foundation weakening)	High	Strong anchoring, flexible design
Markets & Community Facilities	Moderate	High	Severe	Protective landscaping, multipurpose shelters

3.3 Wind and Disaster Risk Reduction

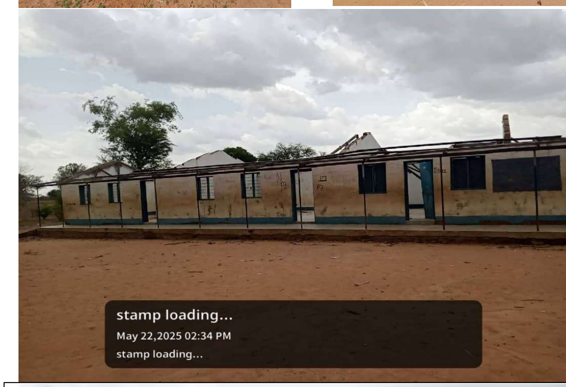
Wind amplifies flood impacts by damaging temporary shelters and accelerating erosion. Integrating wind hazard mapping into disaster preparedness plans and promoting community awareness on safe construction practices are essential.

Table 3: some of infrastructure affected by wind

Infrastructure	Description



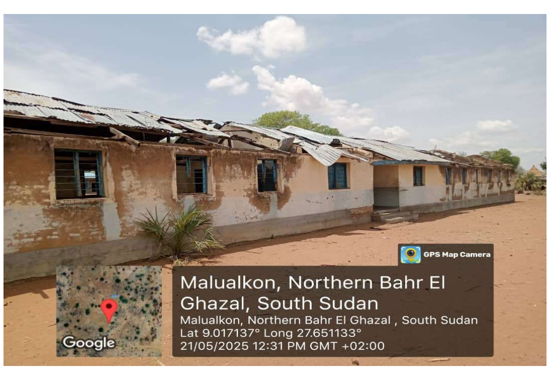
Dokkul primary school of Madhol payam, Aweil East county.



maboktong primary school of Madhol payam

Denyic primary school of malualbai payam

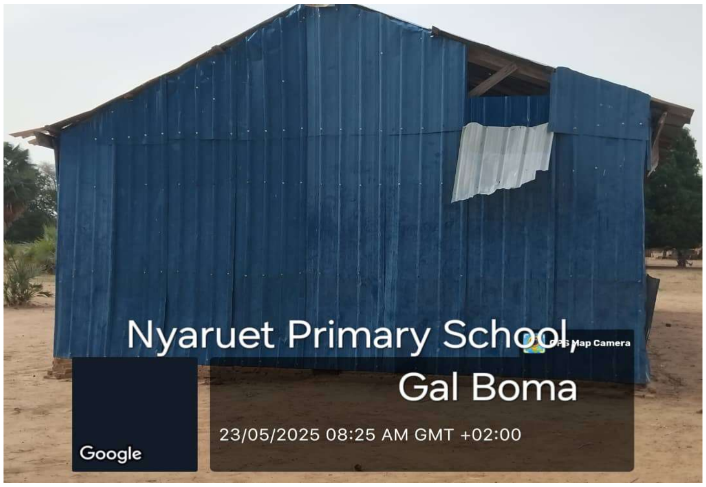
Malualkon Primary school



Mabior primary health care Unit

Mabior primary health care Unit

Dokkul prrimary school (Madhol payam)



Nyaruet primary school , Gal Boma

4. Policy Recommendations

The findings of this study underscore the need to mainstream wind considerations into infrastructure planning and governance frameworks in Aweil East and Aweil South. First, wind hazard assessments should be systematically incorporated into Environmental and Social Impact Assessments (ESIAs), ensuring that project appraisals capture not only hydrological and soil-related risks but also the seasonal variability and intensification of wind regimes. Such integration would provide a more comprehensive basis for evaluating infrastructure vulnerability and community exposure in floodplain environments.

Second, the development of building codes tailored to wind-prone floodplain regions is essential such as those proposed by (Kipkemoi & Ngare (2025), this will help in emergency response and determine direction and type of roofing pitches used. Current standards often emphasize flood resistance and soil stability, yet neglect the structural stresses imposed by strong gusts, particularly during the dry season and transitional months. Codes that specify roof anchoring, material reinforcement, and settlement layout can reduce damage and enhance long-term resilience.

Third, promoting agroforestry and the establishment of green belts offers a nature-based solution such as rotational grazing to mitigate wind hazards. Vegetation buffers act as natural windbreaks, reducing gust intensity at the settlement scale while simultaneously contributing to soil stabilization, biodiversity conservation, and livelihood diversification (Khisa, Kipkemoi, & Gakai, 2025). These interventions align with broader climate resilience strategies that emphasize ecosystem services as protective infrastructure in these heavily pastoral communities.

Finally, infrastructure planning must be aligned with national and regional climate adaptation frameworks. South Sudan's development agenda and regional resilience initiatives increasingly recognize the importance of multi-hazard approaches. Embedding wind hazard considerations into these strategies ensures coherence across scales, strengthens institutional capacity, and supports equitable recovery pathways for vulnerable communities, this can be achieved by proposing learning and sister city partnership of towns in Awei to those in developed facing similar challenges, but have managed to build systems to counter wind hazard (Kaunda et al., 2025; Kipkemoi, Sitati, & Gakai, 2025) .

Together, these measures highlight that wind, though often overlooked, is a critical determinant of resilient infrastructure in fragile floodplain contexts. Addressing it alongside hydrological and climatic variability provides a more holistic foundation for sustainable development and disaster risk reduction in Northern Bahr el Ghazal.

5. Conclusion

Wind emerges as a critical yet frequently overlooked determinant of infrastructure resilience in Aweil East and Aweil South. Seasonal variability, marked by strong dry season gusts, calmer rainy periods, and transitional spikes, underscores the need to treat wind as more than a peripheral hazard. Integrating wind assessments into the design and maintenance of housing, transport networks, energy systems, and community facilities can substantially reduce disaster risks and strengthen adaptive capacity. Moreover, embedding wind considerations into Environmental and Social Impact Assessments, building codes, and climate adaptation frameworks ensures that infrastructure planning is aligned with both local realities and broader resilience agendas. Addressing wind alongside hydrological and climatic variability provides a more holistic foundation for sustainable development in Northern Bahr el Ghazal, safeguarding communities while advancing equitable recovery and long-term resilience. Future research should prioritize high-resolution wind monitoring, integration of reanalysis datasets, and participatory hazard mapping to deepen understanding and support evidence-based planning.

References

Gakai, P. K., Waweru, R. K., Mutisya, A., & Mukami, N. (2025). Flood Impacts on Vulnerable Communities in Aweil East and South: A Qualitative Assessment.”.

Kaunda, K., Teny, R., & Ndhlovu, M. (2025). The Role of Climate-Resilient Crop Demonstration Plots in Improving Food Security in Low-Income Neighborhoods: A Case of South Sudan. *African Journal of Empirical Research*, *6*(1), 531-538.

Kingori, G. P., Mukami, N., & Mutisya, A. (2025). Soil, Water, and Settlements: Understanding Flood Patterns in Aweil East and South, South Sudan.

Kipkemoi, I. (2024). Impacts of climate and climate change on water and vegetation dynamics in horn of Africa drylands (Doctoral dissertation, University of Bristol).

Kipkemoi, I., Sitati, G. K., & Gakai, P. K. (2025). Exploring the impact of sister city partnerships on emerging African cities. Discover Cities, 2(1), 1-17.

Kipkemoi, I., & Ngare, I. O. (2025). Transforming Kenya’s addressing landscape: use case models approach to a responsive National Addressing System. *Frontiers in Sustainable Cities*, *7*, 1411904.

Khisa, G. V., Kipkemoi, I., & Gakai, P. K. (2025). Social implications of domestication of animals in Africa.

Linden, E. (2006). *The winds of change: Climate, weather, and the destruction of civilizations.* Simon & Schuster.

Linden, E. (2006). *The winds of change: Climate, weather, and the destruction of civilizations*. Simon and Schuster.

Ongaga, C. O., Makokha, M., Obiero, K., Kipkemoi, I., & Diang'a, J. (2024). Urbanization and hydrological dynamics: a 22-year assessment of impervious surface changes and runoff in an urban watershed. Frontiers in Water, 6, 1455763.

Petter-Bowyer, P. (2008). *Winds of destruction.* Trafford Publishing.

Thomas, L. N. (2005). Destruction of potential vorticity by winds. *Journal of physical oceanography*, *35*(12), 2457-2466.

Thomas, L. N. (2005). Destruction of potential vorticity by winds. *Journal of Physical Oceanography, 35*(12), 2457–2466. https://doi.org/10.1175/JPO2837.1

Weather Atlas. (2025). *Yearly & Monthly Weather – Aweil, South Sudan*.

Zhou, Z., & Zhang, L. (2021). Destructive destruction or creative destruction? Unraveling the effects of tropical cyclones on economic growth. *Economic Analysis and Policy*, *70*, 380-393.

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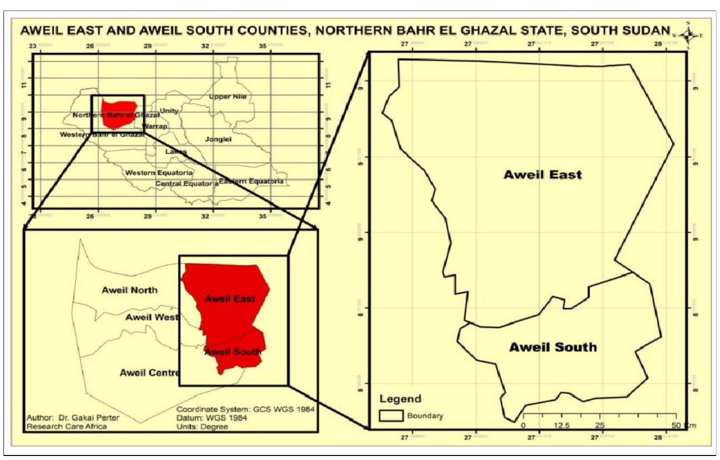
List of figures



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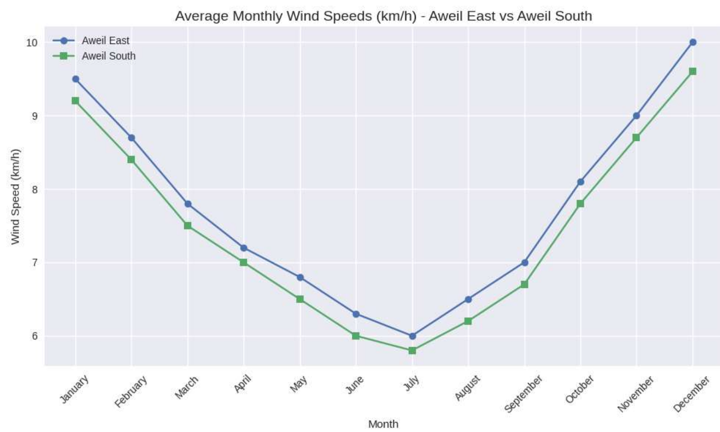
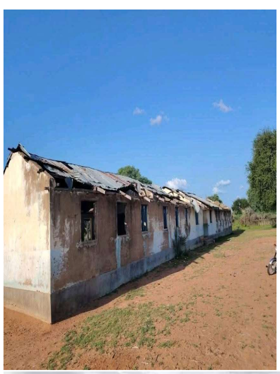
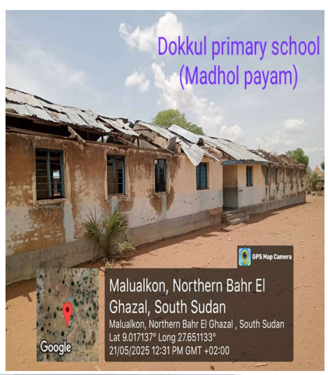
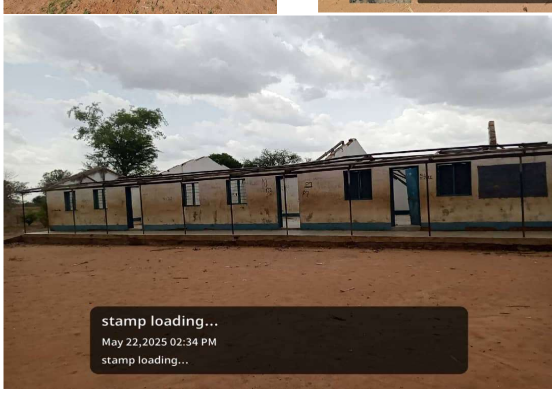


Figure 2: Monthly average wind speeds in Aweil East and Aweil South (2025). *Source: Compiled from South Sudan Meteorological Department (2024) and Weather Atlas climate data for Aweil*

Infrastructure	Description
 	Dokkul primary school of Madhol payam, Aweil East county.
	maboktong primary school of Madhol payam

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