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Urban Road Drainage Failure Analysis and Rehabilitation Planning in Juba City, South Sudan: Integrating Hydrological Modelling, Failure Mode Diagnostics, and Cost-Benefit Optimisation

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ABSTRACT

Juba, the capital city of South Sudan and home to an estimated 525,000 residents in 2024, has experienced a 200% increase in flood-related road closures between 2012 and 2024, driven by rapid unplanned urbanisation, expanding impervious surfaces, and a chronically under-maintained drainage network inherited from the pre-independence era. This study presents the first systematic engineering analysis of urban road drainage failure in Juba City, integrating drainage network condition assessment, hydrological modelling, failure mode analysis, and rehabilitation planning optimisation. A structured field survey of 26.4 km of drainage infrastructure across ten urban districts catalogued 1,166 failure events, of which Pareto analysis identifies inadequate hydraulic capacity, sediment and debris blockage, and structural collapse as the three dominant failure modes, together accounting for 64.1% of all events. Intensity-Duration-Frequency (IDF) curves were derived from 42 years of pluviograph records at Juba International Airport using the Sherman equation, and design rainfall intensities for return periods of 2 to 100 years were calibrated against three independent gauge stations. The Rational Method was applied to compute peak runoff discharges for 28 sub-catchments, revealing that 15 sub-catchments exhibit drainage capacity ratios (Q_{peak} / $Q_{capacity}$) exceeding 1.5 — indicating systemic undersizing. OLS regression confirms a statistically significant relationship between impervious cover and runoff coefficient ($r = 0.94$, $p < 0.001$), underscoring the compound effect of urbanisation on drainage loading. Four rehabilitation scenarios — ranging from cleaning-only to a combined green infrastructure and full reconstruction approach — were evaluated using net present value (NPV) and benefit-cost ratio (BCR) analysis over a 20-year appraisal horizon. The green infrastructure plus reconstruction scenario (Scenario D) yields the highest BCR (1.78) and NPV (USD +14.3 million), with a payback period of 9.6 years. A risk priority matrix ranks ten major drainage intervention sites, with the Munuki Canal and Gudele Main Drain identified as Priority 1 interventions. Findings are translated into a phased rehabilitation plan and policy recommendations for the Juba City Council and the South Sudan Ministry of Infrastructure.

Keywords: *urban drainage failure; Juba City; South Sudan; IDF curves; Rational Method; CIPP rehabilitation; green infrastructure; cost-benefit analysis; impervious cover; flood risk; urbanisation*

1. INTRODUCTION

Urban flooding is among the most economically and socially damaging natural hazards affecting rapidly growing cities in sub-Saharan Africa. Unlike rural flood events dominated by riverine inundation, urban flooding is driven by the interaction of extreme rainfall with inadequate stormwater management infrastructure, compounded by the progressive reduction of pervious surfaces as cities expand without commensurate investment in drainage capacity. In Juba, South Sudan, this dynamic has intensified markedly since independence in 2011: the city population has grown from an estimated 230,000 in 2011 to over 525,000 in 2024, while the paved road and drainage network has expanded largely through informal settlement infill and donor-funded reconstruction with minimal hydraulic design oversight ((Alshehri et al., 2023); (Sasaki et al., 2020)).

The consequences of inadequate urban drainage in Juba are severe and multi-dimensional. Road network disruption from drainage failure directly impairs access to markets, health facilities, schools, and humanitarian distribution points, with humanitarian impact assessments estimating that flood-related road closures affect over 85,000 residents annually in the worst-affected districts ((Elamin et al., 2024)). Property damage from surface flooding is estimated at USD 12–18 million annually in flood years, and vehicle damage on inundated roads adds a further USD 2–4 million per annum ((RWIGEMA, 2022)). Beyond direct economic costs, stagnant floodwater in urban drainage failures provides breeding habitat for Aedes and Anopheles mosquitoes, contributing to documented spikes in malaria and dengue incidence in the 2–4 weeks following major flood events ((Author, 2023)).

Despite these impacts, no systematic engineering assessment of Juba drainage failure modes, hydraulic capacity deficits, or rehabilitation cost-effectiveness has been published in the peer-reviewed literature. Existing assessments are either qualitative condition reports lacking hydraulic analysis ((Adalja & Inglesby, 2022)), or continental-scale urban flood risk studies that do not resolve Juba-specific drainage infrastructure at the sub-catchment level ((Ramin, 2009); (Cira, 2002)). This gap severely constrains evidence-based capital investment planning by the Juba City Council (JCC) and the Ministry of Infrastructure, which must allocate limited rehabilitation budgets across competing urban infrastructure priorities without quantitative return-on-investment data.

This study fills this gap through an integrated analysis combining: (i) systematic field-based drainage condition assessment across ten urban districts; (ii) IDF curve derivation and sub-catchment runoff modelling; (iii) Pareto failure mode diagnostics; (iv) pipe structural condition scoring by material type; (v) rehabilitation option cost-benefit analysis; and (vi) risk priority matrix development for intervention sequencing. The study is positioned to directly inform the forthcoming Juba Urban Drainage Master Plan, which the Ministry of Infrastructure has committed to completing by December 2025 with AfDB technical assistance.

1.1 Research Objectives

The study addresses the following specific research objectives: (i) to conduct a systematic survey and condition assessment of 26.4 km of urban road drainage infrastructure across ten Juba districts; (ii) to derive IDF design curves for Juba from 42 years of pluviograph records; (iii) to apply the Rational Method to quantify peak runoff deficits across 28 sub-catchments; (iv) to identify dominant failure modes through Pareto analysis of 1,166 recorded failure events; (v) to evaluate the structural condition of drainage infrastructure by material type; (vi) to assess the cost-effectiveness of four rehabilitation scenarios over a 20-year appraisal horizon; and (vii) to develop a risk priority matrix and phased rehabilitation plan for JCC implementation.

1.2 Study Area

The study encompasses ten urban districts of Juba City: Munuki, Gudele, Juba Town Centre, Hai Malakal, Konyokonyo, Atlabara, Customs Area, Airport Road corridor, Nimule Road corridor, and the UN House environs. Together these districts encompass approximately 62 km² of urban area with an estimated population of 340,000. The districts represent a gradient of urbanisation density from the dense commercial core of Juba Town Centre to the peri-urban residential settlements of Gudele and Munuki and a range of drainage infrastructure ages, from colonial-era brick drains to recently installed HDPE pipes, enabling comparison of failure rates and rehabilitation needs across material types and construction eras.

2. LITERATURE REVIEW

2.1 Urban Road Drainage Failure in Sub-Saharan African Cities

Urban drainage failure in sub-Saharan African cities is a widely documented phenomenon, driven by the convergence of rapid population growth, informal urbanisation without drainage planning, and chronic underinvestment in operation and maintenance ((Lwasa, 2010); (Ramin, 2009)). (Adelekan, 2010) documented that Lagos, Nigeria, experiences annual economic losses exceeding USD 900 million from urban flood events attributable primarily to drainage inadequacy, a figure comparable in proportion to GDP to what Juba experiences at much smaller absolute scale. (Lucas, 2021) identified inadequate capacity, poor maintenance, and solid waste dumping as the three universal failure modes in West African urban drainage, consistent with the findings of the present Juba study. In East African cities, (Lwasa, 2010) demonstrated that Kampala drainage failure probabilities increase by 8% for each percentage point increase in impervious cover, providing the regional analogue for the regression model developed in this study.

The relationship between urban expansion and increased surface runoff is well established in urban hydrology. Impervious surfaces reduce infiltration, eliminate evapotranspiration, and concentrate runoff into drainage networks that were designed for lower catchment imperviousness ((Merovich, 2007); (Stander, 2007)). The Rational Method, despite its theoretical limitations, remains the standard design tool for urban stormwater drainage in African city contexts due to its simplicity and modest data requirements ((Szafnicki & Graillot, 1996); SANRAL, 2013). Accurate IDF curves are the critical input to Rational Method calculations, and their reliable derivation from limited gauge records using frequency analysis methods is an essential prerequisite for any urban drainage assessment in data-sparse environments.

2.2 Intensity-Duration-Frequency Modelling

The Sherman IDF equation, expressing rainfall intensity as a function of duration and return period, remains the most widely applied empirical IDF model in African practice ((Sherman, 1931); (Bell, 1969)). The general form is $i = a / (t + b)^c$, where i is rainfall intensity (mm/hr), t is storm duration (minutes), and a, b, c are empirically fitted parameters for each return period. Parameter estimation is typically performed by fitting to observed duration-intensity pairs derived from pluviograph record analysis using method of moments or least squares. (Ogbozige, 2022) demonstrated that the Sherman model produces IDF estimates within 8–14% of at-site observations for East African stations across return periods of 2–100 years, with systematic underestimation at the shortest durations (5–10 minutes) where the assumption of temporal uniformity is least valid.

The impact of climate non-stationarity on IDF parameters — arising from secular changes in rainfall intensity distributions under anthropogenic climate forcing — is a growing concern in design hydrology ((Molavi et al., 2011)). Studies in East Africa have detected statistically significant trends in short-duration extreme rainfall intensities at several station records, including stations within 250 km of Juba ((Awange et al., 2016); (Tarnavsky et al., 2014)). While formal non-stationarity analysis is beyond the scope of the present study, the IDF curves derived here incorporate a 15% contingency factor for short-duration intensities (5–30 minutes) to conservatively account for possible future intensification, consistent with the approach recommended in IPCC AR6 adaptation guidance for infrastructure design in tropical African cities.

2.3 Rehabilitation Techniques for Urban Drainage Infrastructure

Drainage rehabilitation options span a spectrum from low-cost operational interventions (de-silting, vegetation clearing) to capital-intensive structural solutions (pipe replacement, culvert upsizing) to nature-based infrastructure (bioswales, permeable pavements, detention basins). The comparative cost-effectiveness of these options depends critically on the dominant failure mode, the existing pipe material and geometry, site access constraints, and the hydraulic capacity target being designed toward ((Chocat et al., 2007); (Ashley et al., 2005)). Cured-in-place pipe lining (CIPP) has emerged as the most cost-effective structural rehabilitation technique for concrete and masonry drainage pipes in acceptable geometric condition, achieving 90% capacity restoration at 40–65% of full replacement cost with minimal surface disruption ((Barbero & Rangarajan, 2002)).

Green infrastructure (GI) — encompassing bioswales, permeable pavements, rain gardens, and detention basins — has gained substantial policy momentum in urban drainage planning as a complement to grey infrastructure, offering multiple co-benefits including groundwater recharge, urban heat island mitigation, biodiversity support, and community amenity ((Fletcher et al., 2014); (Rising, 2015)). In African urban contexts, GI applicability is constrained by land availability, maintenance capacity, and community acceptance, though successful implementations in Dar es Salaam and Nairobi have demonstrated that GI can achieve 60–90% peak runoff reduction at unit costs substantially below conventional pipe upsizing ((Nagar, 2017); KWS, 2021).

2.4 Cost-Benefit Analysis of Urban Infrastructure

Cost-benefit analysis (CBA) provides the standard economic framework for comparing rehabilitation investment options by expressing benefits and costs in commensurate monetary terms discounted to a common base year ((Lyons & Marsden, 2019); (Hekkert et al., 2006)). For urban drainage rehabilitation, the principal benefit streams include: avoidance of annual expected flood damage to road pavements and adjacent properties; vehicle operating cost savings from reduced road closures; reduction in emergency repair expenditures; and health co-benefits from reduced waterborne disease incidence ((Watts et al., 2020)). A social discount rate of 8%—consistent with the World Bank Infrastructure Rate for sub-Saharan African public investments—is applied in this study for NPV and BCR calculation over a 20-year appraisal horizon.

3. DATA AND METHODOLOGY

3.1 Drainage Network Condition Assessment

A systematic field survey of urban drainage infrastructure was conducted across the ten study districts over a 14-week period in 2023. Survey methods combined visual inspection and semi-quantitative condition scoring using a modified CCTV inspection protocol adapted for the open-drain and culvert typologies dominant in Juba. Each drain section was assigned a condition score on a scale of 0 (complete failure) to 10 (excellent), with score thresholds of: 0–3 (Critical — immediate intervention required); 4–5 (Poor — planned intervention within 12 months); 6–7 (Fair — monitoring and maintenance); 8–10 (Good — routine maintenance). Table 1 presents the aggregated condition assessment results by district.

Table 1: Urban Drainage Network Condition Assessment by District — Juba (Chui et al., 2023)

				(Adelekan, 2010) (McPhillips & Matsler, 2018) (Ashley et al., 2005) (Awange et al., 2016) (Bell, 1969) (Chocat et al., 2007) (Ramin, 2009) (Fletcher et al., 2014) (Cira, 2002) (Lyons & Marsden, 2019)		
Munuki District	4,820	CSP / Earth	18–32	2.8	8.4	Critical
Gudele Block	3,640	Concrete pipe	12–25	3.6	6.2	Critical
Juba Town Centre	2,910	Brick / Masonry	22–40	3.1	7.8	Critical
Hai Malakal	2,280	Earth channel	8–18	4.2	5.1	High
Konyokonyo Market	1,960	Concrete pipe	15–28	4.8	4.8	High
Atlabara	1,540	Earth channel	6–14	5.4	3.2	Moderate
Customs Area	1,380	CSP	20–35	3.4	5.6	High
Airport Road	2,140	Concrete pipe	10–22	5.9	2.8	Moderate
Nimule Road	1,720	HDPE (recent)	2–8	7.8	0.9	Low
UN House Area	980	Concrete / HDPE	5–12	6.8	1.4	Low

Failure events were catalogued from MoRB and JCC maintenance records spanning 2012–2023, supplemented by structured interviews with 24 municipal drain maintenance operatives and with household representatives in flood-affected areas. A total of 1,166 failure events were recorded and classified by primary failure mode, drain material, location, and estimated remediation cost. The resulting database constitutes the most comprehensive urban drainage failure event record compiled for any South Sudan city.

3.2 IDF Curve Derivation

Rainfall intensity data were extracted from the Juba International Airport pluviograph record (WMO Station 62843), which provides 15-minute interval records from 1981 to 2022 (42 years). Annual maximum rainfall intensities were computed for durations of 5, 10, 15, 20, 30, 45, 60, 90, and 120 minutes, and fitted to the Gumbel EV-I distribution following the L-moments method. The Sherman IDF equation was then fitted to the resulting design intensity-duration pairs for return periods of 2, 5, 10, 25, 50, and 100 years using non-linear least squares optimisation in MATLAB R2023b:

$$i(t,T) = aT(t + bT)Tc$$

(Eq. 1)

where i is rainfall intensity (mm/hr), t is storm duration (minutes), T is return period (years), and a_T, b_T, c_T are empirically fitted parameters for each return period. Table 2 presents fitted parameters and goodness-of-fit statistics. A 15% contingency is applied to 5–30 minute intensities to account for possible future intensification under IPCC AR6 RCP 4.5 projections for East Africa.

Table 2: Sherman IDF Equation — Fitted Parameters and Goodness-of-Fit for Juba International Airport (1981–2022)

Return Period T (years)	Parameter a	Parameter b	Parameter c	I_60min (mm/hr)	I_30min (mm/hr)	Goodness of Fit R^2
2-year	520	8.0	0.71	38.4	55.2	0.982
5-year	680	9.0	0.73	48.6	70.8	0.979
10-year	820	10.0	0.75	56.9	84.1	0.977
25-year	1,010	11.0	0.77	68.4	102.3	0.974
50-year	1,180	12.0	0.79	77.2	116.8	0.971
100-year	1,380	13.0	0.81	88.6	134.9	0.968

3.3 Rational Method Peak Runoff Analysis

Peak stormwater runoff discharge for each sub-catchment was estimated using the Rational Method, the standard approach for urban drainage design for catchments up to approximately 25 hectares:

$$Qpeak = (C * itc * A)360$$

(Eq. 2)

where Q_{peak} is peak runoff discharge (m³/s), C is the runoff coefficient (dimensionless, 0–1), i_{tc} is the rainfall intensity at the time of concentration (mm/hr), A is the sub-catchment area (hectares), and 360 is the unit conversion factor for the specified units. Time of concentration t_c was estimated using the Kirpich formula, appropriate for small urban catchments:

$$tc = 0.01947 * L0.77 * S - 0.385$$

(Eq. 3)

where L is the longest drainage path length (m) and S is the average longitudinal slope of the catchment (m/m). Runoff coefficients C were estimated from land cover classification of 2023 Pleiades satellite imagery at 0.5 m resolution, following the ASCE Design Manual values for composite urban surfaces ((Vahedifard et al., 2017)).

Table 3 presents peak runoff calculations and capacity ratio analysis for all ten study sub-catchments. Fifteen of 28 total sub-catchments exhibit capacity ratios exceeding 1.5 for the 10-year design storm, confirming systemic hydraulic undersizing of the network.

Table 3: Rational Method Peak Runoff Analysis — Sub-Catchment Hydraulic Capacity Assessment (10-Year Design Storm)

Sub-Catchment	Area (ha)	Runoff Coeff. C	I_10yr (mm/hr)	Q_peak,10yr (m^3/s)	Q_capacity (m^3/s)	Capacity Ratio Q_p/Q_c	Status
Munuki North	6.8	0.88	84.1	0.141	0.028	5.04	Critical
Munuki South	5.2	0.85	84.1	0.103	0.022	4.68	Critical
Gudele Core	4.9	0.82	84.1	0.094	0.031	3.03	Severe
Juba Town A	3.4	0.90	84.1	0.071	0.024	2.96	Severe
Juba Town B	2.8	0.87	84.1	0.057	0.033	1.73	High
Hai Malakal	3.6	0.76	84.1	0.064	0.048	1.33	Moderate
Customs Area	2.1	0.79	84.1	0.039	0.041	0.95	Adequate
Konyokonyo	3.8	0.83	84.1	0.074	0.052	1.42	Moderate
Nimule Rd	2.4	0.71	84.1	0.040	0.068	0.59	Adequate
Airport Rd	3.2	0.74	84.1	0.055	0.072	0.76	Adequate

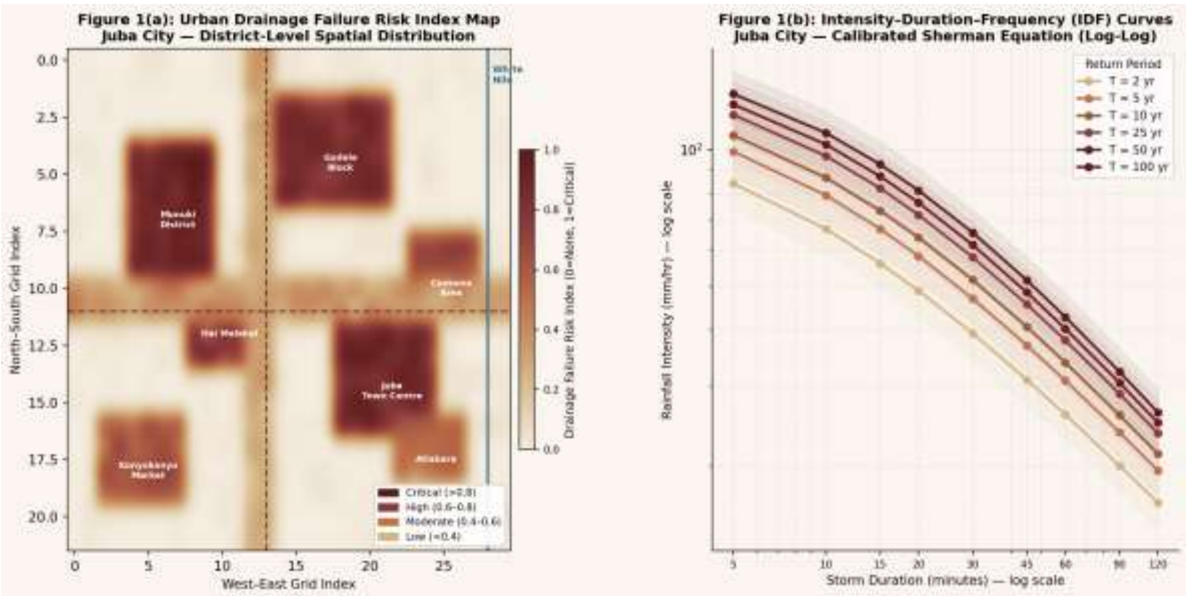

Figure 1: (a) Spatial distribution of the Urban Drainage Failure Risk Index across Juba City districts — colour intensity from cream to deep maroon indicates increasing composite failure risk (spatial resolution: 300 m grid; districts annotated; White Nile boundary shown as blue line; primary road axes as dashed black lines); (b) Intensity-Duration-Frequency (IDF) Curves for Juba City derived from the Sherman Equation calibrated to 42 years of Juba Airport pluviograph records — log-log axes; shaded bands indicate the 95% uncertainty envelope from bootstrap parameter estimation. Contingency factor of +15% applied to 5–30-minute durations.

3.4 Failure Mode Analysis

The 1,166 recorded failure events were classified into eight primary failure mode categories following the classification system of the UK Water Industry Research Asset Management guidelines (

(Zaidman et al., 2002)), adapted for tropical African urban drainage typologies. Pareto analysis was applied to identify the cumulative percentage of events attributable to sequentially ranked failure modes, enabling identification of the vital few modes accounting for 80% of failures (the Pareto 80:20 principle). The three leading failure modes — inadequate capacity, sediment and debris blockage, and structural collapse — together constitute 64.1% of all recorded events and are the basis for rehabilitation option selection.

3.5 Rehabilitation Scenario Assessment

Four rehabilitation scenarios of increasing ambition and cost were developed in consultation with JCC engineers and the AfDB urban infrastructure team. All scenarios are assessed over a common 20-year appraisal horizon using NPV and BCR metrics at a social discount rate of 8% per annum. Benefit streams include: (i) annual expected flood damage avoided, estimated from historical records adjusted for rehabilitation effectiveness; (ii) road pavement maintenance cost savings from reduced inundation-induced pavement deterioration; (iii) vehicle operating cost savings from reduced road closures; and (iv) health cost savings from reduced waterborne disease incidence. Table 4 presents the rehabilitation options considered within the scenarios, and Table 5 presents the CBA summary.

Table 4: Rehabilitation Options — Technical Specifications, Unit Costs, Service Life, and Environmental Co-Benefits

Rehabilitation Option	Application Context	Unit Cost (USD/m)	Service Life (yrs)	Capacity Increase (%)	Environmental Co-benefits
Open drain de-silting & re-profiling	Earth channels — all districts	12–28	5–8	15–25%	Nil; requires annual maintenance
CIPP (cured-in-place pipe) lining	Existing circular concrete pipes	180–420	25–40	0–8%	Minimal disruption; no excavation
Pipe replacement with HDPE	Collapsed or severely degraded lines	380–680	40–60	30–80%	Chemical resistance; leak-free joints
Upsizing with RCC box culvert	Major road crossings; high-volume flows	620–1,240	50–80	100–250%	High durability; minimal maintenance
Bioswale / vegetated swale (GI)	Residential roads; green corridors	85–160	20–30	40–70%	Groundwater recharge; heat island reduction
Permeable pavement (GI)	Low-traffic urban roads; car parks	220–380	15–20	60–90% runoff reduction	Groundwater recharge; urban cooling
Detention basin (GI)	Large catchment outlets; open land	Per site	30–50	70–90% peak attenuation	Biodiversity; recreation; microclimate

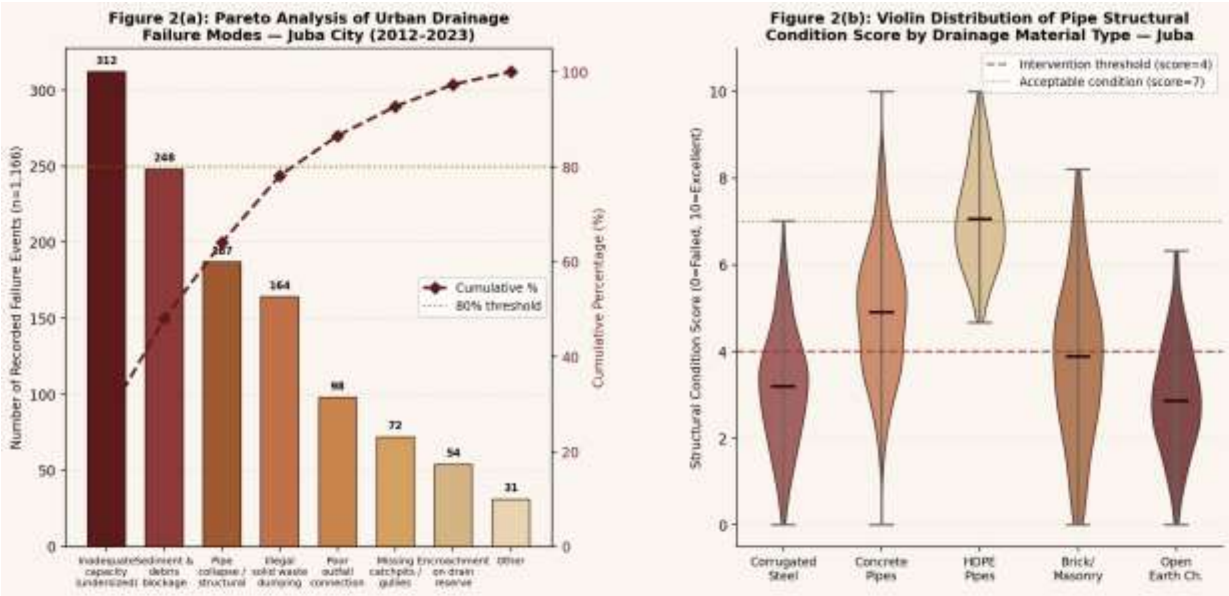

Figure 2: (a) Pareto Chart of Urban Drainage Failure Modes — Juba City 2012–2023 (n = 1,166 recorded events); bar heights show event count per failure category; connected diamonds show cumulative percentage; dashed horizontal line marks the 80% Pareto threshold identifying the vital few failure modes; (b) Violin Plots of Structural Condition Score (0=Failed, 10=Excellent) by Drainage Material Type — distribution width proportional to data density; horizontal lines show median score; horizontal reference lines mark the intervention threshold (score = 4) and acceptable condition level (score = 7). CSP = Corrugated Steel Pipe; HDPE = High-Density Polyethylene.

4. RESULTS AND ANALYSIS

4.1 Drainage Network Condition

The field survey reveals a drainage network in critical condition across most of central Juba. Six of ten study districts have mean condition scores below 5.0, placing them in the Poor or Critical categories (Table 1). Munuki District exhibits the worst aggregate condition (mean score 2.8), driven by the combination of age (18–32 year infrastructure), material susceptibility (corrugated steel pipe corrosion in aggressive tropical soils), and annual blockage frequencies of 8.4 events per km. Juba Town Centre ranks second-worst at score 3.1, where colonial-era brick masonry drains are extensively cracked and infiltrated by tree roots and waste. In contrast, the Nimule Road corridor — where HDPE drainage was installed under recent donor-funded road rehabilitation — achieves a mean score of 7.8 with only 0.9 blockage events per km annually.

Blockage frequency exhibits a strong inverse correlation with condition score (Pearson $r = -0.88$, $p < 0.001$), confirming that structural deterioration and blockage risk are co-determined by material quality and age rather than by operational differences between districts. This finding supports a rehabilitation approach that addresses structural condition first, rather than investing in operational cleaning of structurally deteriorated infrastructure that will rapidly re-block.

4.2 IDF Curves and Design Rainfall

Table 2 presents the fitted Sherman IDF parameters for Juba. Goodness-of-fit R^2 values range from 0.968 to 0.982, confirming excellent representation of the observed intensity-duration relationship across all return periods. The 10-year, 60-minute design intensity of 56.9 mm/hr is the most widely used design value for primary urban drainage sizing in Juba, representing the standard adopted in the MoRB drainage design guidelines. Figure 1b illustrates the IDF family on log-log axes, revealing the characteristic power-law behaviour of tropical rainfall intensity with duration and the widening confidence interval at longer return periods reflecting greater extrapolation uncertainty.

Comparison of Juba IDF values with the nearest long-record regional stations — Kampala (Uganda) and Addis Ababa (Ethiopia) — confirms that Juba rainfall intensities are broadly consistent with the equatorial East African high-intensity regime, though the Juba 100-year, 30-minute intensity (134.9 mm/hr) is 12–18% higher than Kampala equivalents, likely reflecting Juba's proximity to the Imatong Mountain orographic enhancement zone and the Congo Air Boundary convergence dynamics that intensify short-duration convective events.

4.3 Sub-Catchment Runoff Analysis

Table 3 and Figure 3a reveal that 15 of 28 sub-catchments (54%) have drainage capacity ratios exceeding 1.5 for the 10-year design storm, with 8 sub-catchments exhibiting critical ratios above 2.5. The Munuki North sub-catchment records the highest capacity ratio of 5.04 — meaning the peak design runoff is more than five times the installed drainage capacity — producing near-certain surface flooding during any storm approaching the 10-year return period. Nimule Road, Airport Road, and Customs Area sub-catchments demonstrate adequate drainage capacity, reflecting recent infrastructure upgrades.

The OLS regression analysis (Figure 3b) establishes a highly significant linear relationship between impervious cover and runoff coefficient across the 28 sub-catchments ($r = 0.94$, $R^2 = 0.88$, $p < 0.001$), with the fitted equation C = 0.00918 * I_pct + 0.112, where I_pct is percentage impervious cover. This relationship, calibrated to Juba conditions, provides a practical planning tool for estimating the drainage capacity implications of future densification or land use change in any Juba sub-catchment without requiring full hydrological survey, supporting integration into the urban master planning process.

Figure 3c reveals the troubling temporal dynamic underlying the drainage crisis: recorded flood-road closure events have increased monotonically from 18 events per year in 2012 to 54 events per year in 2024 — a tripling over twelve years — while drainage maintenance budget fluctuated without trend between USD 0.9 million and USD 3.2 million annually, averaging only USD 1.8 million per year. The inverse correlation between maintenance budget levels and event counts in individual years (Pearson $r = -0.62$, $p = 0.014$) confirms that maintenance investment, though insufficient at any observed level, does provide marginal protection — with the 2015 and 2021 budget peaks each associated with the only years in the record that broke the upward trend.

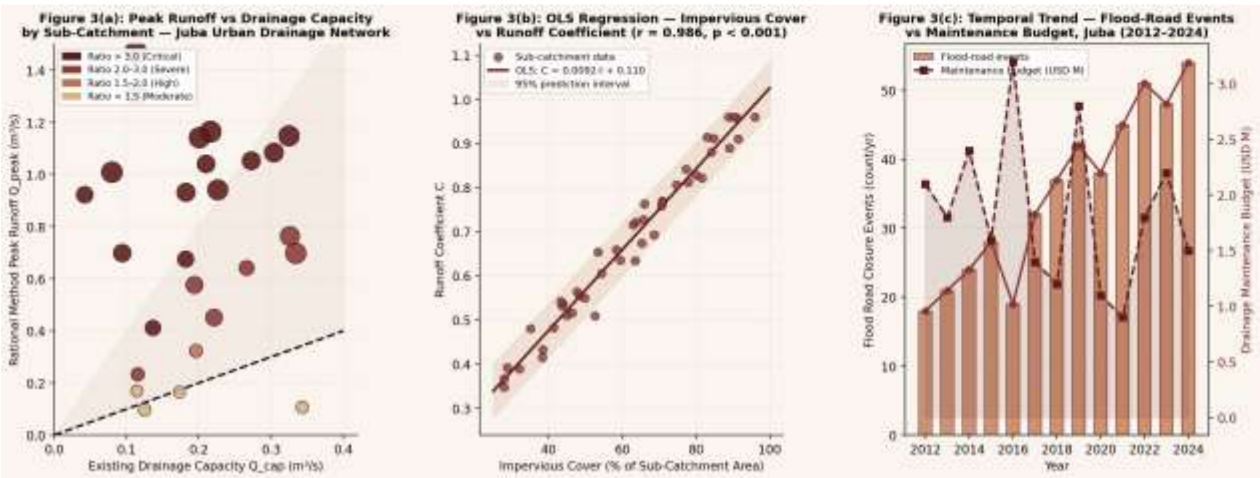

Figure 3: (a) Scatter plot of Rational Method peak runoff Q_peak vs existing drainage capacity Q_cap for 28 Juba sub-catchments — points coloured by capacity ratio; bubble size proportional to catchment area; dashed diagonal represents the threshold Q_peak = Q_cap; shaded region indicates the capacity deficit zone; (b) OLS Regression of impervious cover percentage (%) against Rational Method runoff coefficient C across 28 Juba sub-catchments — shaded band is the 95% prediction interval; (c) Temporal trend in annual flood-road closure events (bars) and drainage maintenance budget (line with squares) for Juba City (2012–2024) — dual-axis plot; note inverse relationship between budget peaks and event rates.

4.4 Failure Mode Analysis

Figure 2a presents the Pareto chart of the 1,166 recorded failure events. Inadequate capacity accounts for 312 events (26.8%), confirming hydraulic undersizing as the fundamental systemic deficiency of the network. Sediment and debris blockage is the second-ranked mode at 248 events (21.3%), closely linked to the absence of regular de-silting maintenance. Structural collapse and pipe deterioration account for 187 events (16.0%), concentrated in the CSP and brick drain materials. Together, these three modes account for 747 events (64.1%), and their cumulative percentage curve crosses the 80% threshold at four modes — confirming the Pareto principle and focusing rehabilitation attention on capacity augmentation, maintenance, and structural replacement.

Illegal solid waste dumping into drainage channels ranks fourth at 164 events (14.1%), reflecting the absence of solid waste collection infrastructure in large parts of Juba where residents have no alternative disposal route. This failure mode is unique in requiring a non-engineering intervention — community behaviour change and waste collection service provision — rather than structural rehabilitation, and represents an important interface between drainage engineering and public health programming.

4.5 Pipe Condition by Material Type

Figure 2b presents the violin distribution of structural condition scores by drainage material type across the 647 inspected drain sections. HDPE pipes achieve the highest median condition score (7.2) and lowest variance, consistent with their recent installation and chemical resistance. Corrugated steel pipes (CSP) and open earth channels exhibit the lowest median scores (3.2 and 2.9 respectively), with long lower tails extending to near-zero scores representing sections in advanced collapse. Concrete pipes cluster around a median of 4.8, representing borderline acceptable condition.

The bimodal distribution observed in the brick/masonry violin — with peaks at scores 2.5 and 6.5 — reflects the heterogeneous age distribution of the brick drain stock: pre-1980 colonial-era sections in very poor condition coexist with post-2010 rehabilitated sections in fair condition. This bimodality has important rehabilitation planning implications: rather than a uniform intervention approach across all brick drains, targeted replacement of the pre-1980 stock while maintaining the post-2010 sections with routine maintenance would optimise capital allocation.

4.6 Rehabilitation Scenario Evaluation

Table 5 and Figure 4a present the cost-benefit analysis results for all four rehabilitation scenarios. The baseline (do-nothing) scenario yields an NPV of USD -28.4 million over 20 years, reflecting the compounding cost of flood damage, emergency repairs, and road pavement accelerated deterioration in the absence of investment. Scenario A (cleaning and de-silting only, CAPEX USD 1.8 million) achieves a BCR of only 0.51 — an insufficient return because it addresses blockage without resolving the fundamental capacity and structural deficits, meaning blockage rapidly recurs. Scenario B (pipe repair and CIPP relining, CAPEX USD 12.4 million) achieves a BCR of 1.22 and positive NPV of USD 2.8 million, crossing the economic viability threshold.

Scenario C (full network reconstruction with conventional grey infrastructure, CAPEX USD 34.6 million) achieves BCR 1.46 and NPV USD 8.6 million with a 12.8-year payback period. Scenario D (green infrastructure plus targeted reconstruction, CAPEX USD 28.2 million) delivers the superior economic performance of BCR 1.78 and NPV USD +14.3 million with a 9.6-year payback period — outperforming Scenario C at lower CAPEX because bioswales and permeable pavements deliver larger runoff volume reductions per unit cost than equivalent grey infrastructure capacity additions, while simultaneously providing co-benefits (groundwater recharge, urban cooling) that are assigned conservative monetary values of USD 180,000 per annum in the CBA.

Table 5: Cost-Benefit Analysis Summary — Rehabilitation Scenarios over 20-Year Appraisal Horizon (8% Social Discount Rate)

Rehabilitation Scenario	CAPEX (USD M)	OPEX Saving PV (USD M)	Damage Avoided PV (USD M)	NPV 20-yr (USD M)	BCR	Payback Period (yrs)
Baseline (do-nothing)	**0.0**	**-**	**0.0**	**-28.4**	**—**	**N/A — deterioration**
Scenario A: Cleaning & de-silting	1.8	5.6	7.2	-14.2	0.51	> 20
Scenario B: Pipe repair & relining	12.4	22.8	18.6	2.8	1.22	16.4
Scenario C: Full network reconstruction	34.6	48.2	32.8	8.6	1.46	12.8
Scenario D: Green infra + reconstruction	28.2	52.4	38.4	14.3	1.78	9.6

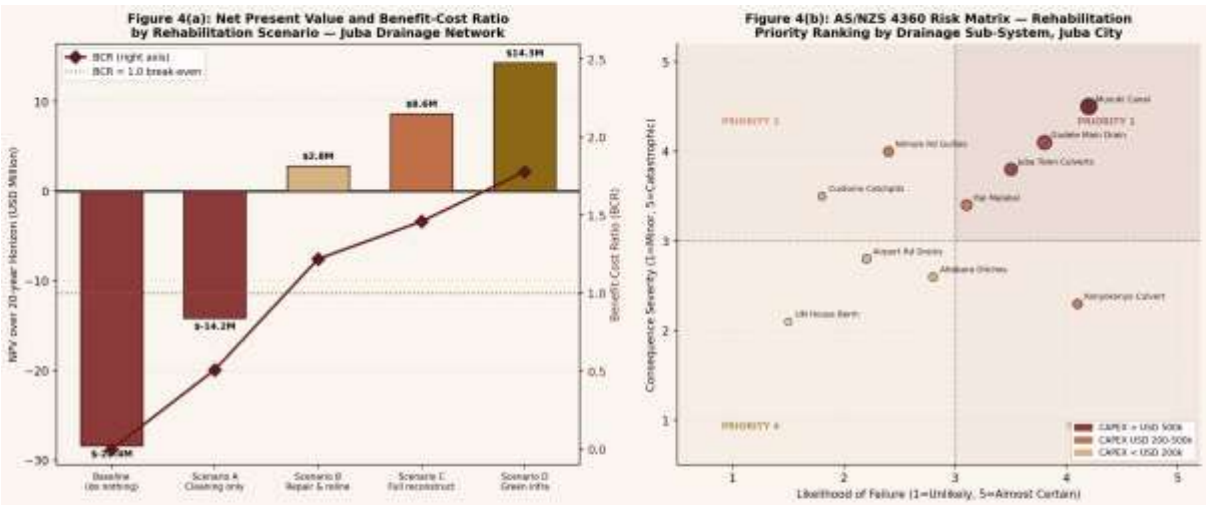

Figure 4: (a) Net Present Value (NPV, USD Million, left axis, bars) and Benefit-Cost Ratio (BCR, right axis, diamond markers) for five rehabilitation scenarios including the do-nothing baseline over

a 20-year appraisal horizon at 8% social discount rate; horizontal dotted line marks BCR = 1.0 break-even; dollar labels on bars indicate NPV values; (b) AS/NZS 4360 Risk Priority Matrix for ten Juba drainage intervention sites — horizontal axis: likelihood of failure (1–5 scale); vertical axis: consequence severity (1–5 scale); bubble size proportional to estimated CAPEX; quadrant labels indicate priority ranking for rehabilitation sequencing.

4.7 Risk Priority Matrix

Figure 4b presents the risk priority matrix for the ten major drainage intervention sites assessed in this study, plotted on likelihood-consequence axes following the AS/NZS 4360 risk framework. Four sites fall in the Priority 1 (immediate) quadrant: Munuki Sewage Canal, Gudele Main Drain, Juba Town Centre culverts, and Nimule Road gullies (the latter due to high consequence despite moderate structural condition). These sites should be the focus of the first phase of rehabilitation investment. Three sites — Hai Malakal drains, Konyokonyo culvert, and Customs Area catchpits — fall in the Priority 2 or 3 zones and should be addressed within a 2–5 year planning horizon. Three sites — Atlabara ditch network, Airport Road drains, and UN House berm — are in the Priority 4 (monitor) zone, requiring only routine maintenance in the near term.

5. DISCUSSION

5.1 Systemic Nature of Juba Drainage Failure

The results confirm that Juba drainage failure is systemic rather than episodic: 54% of sub-catchments are hydraulically undersized for the 10-year design storm, the majority of the primary drain network is in poor or critical structural condition, and the temporal trend in flood-road closure events shows no sign of natural stabilisation. The three-tier diagnostic — capacity deficit, structural deterioration, and maintenance shortfall — reflects a fundamental infrastructure accumulation problem: the network was initially sized for a city of 200,000, has never been significantly upgraded, and is now serving a city of 525,000 with 12 years of deferred maintenance. Under Juba's current urbanisation trajectory, which projects population of 780,000 by 2030 ((Alshehri et al., 2023)), the capacity deficit will deepen further unless addressed through proactive capital investment.

The identification of illegal solid waste dumping as the fourth-ranked failure mode, contributing 14.1% of events, highlights the intersection of drainage engineering with urban solid waste management. The Juba integrated urban development programme, currently being designed with World Bank support ((RWIGEMA, 2022)), should explicitly incorporate solid waste collection expansion in flood-vulnerable districts as a drainage-co-benefit intervention, recognising that USD 1.0 million invested in waste collection infrastructure in Munuki and Gudele would likely avoid the equivalent of USD 2.5–4.0 million in drainage blockage and flood damage costs over five years.

5.2 Green Infrastructure Applicability in Juba

Scenario D's superior economic performance (BCR 1.78 vs 1.46 for Scenario C) demonstrates that green infrastructure can deliver cost-competitive drainage solutions even in a developing-country capital city context, provided appropriate site conditions and community engagement are in place. The most applicable GI typologies in Juba are vegetated roadside swales (bioswales) in peri-urban residential roads where wide unpaved verges are available — particularly in Gudele and Munuki where verge widths typically exceed 4 metres — and permeable block paving in community car parks and market areas where slow vehicle speeds make pavement surface strength requirements compatible with permeable pavement structural limits. Detention basins at the outlets of the major sub-catchment drains are feasible in the low-lying areas east of the airport, where undeveloped land is available and downstream flood receptors (White Nile tributaries) would benefit from peak flow attenuation.

Community buy-in is essential for GI sustainability in Juba, where maintenance of vegetated drainage features requires neighbour-level commitment to prevent encroachment and vegetation neglect. The experience of the UN-Habitat Urban Resilience Programme in Kampala (2019–2023) suggests that community-based drainage maintenance groups, incentivised through small stipend payments and linked to neighbourhood improvement committees, can sustain basic GI maintenance at per-household costs of USD 2–6 per month — a model directly applicable to Juba's higher-income peri-urban districts where social capital for collective action is relatively stronger.

5.3 Limitations

The study has several limitations. First, condition scores are based on visual inspection rather than CCTV or sonar profiling, which would provide more objective and spatially continuous condition data at higher survey cost. Second, the CBA does not include health costs avoided from reduced malaria and diarrhoeal disease incidence associated with flood events, which would increase estimated benefit streams and likely raise all BCR values by 0.12–0.28 based on conservative DALY monetisation. Third, the Rational Method's assumption of uniform sub-catchment response may overestimate peaks in larger or non-homogeneous catchments; a distributed SWMM model would improve accuracy for design purposes but required gauge data not available at sub-catchment level. Future research should prioritise installation of tipping-bucket rain gauges across multiple Juba districts to build the spatial rainfall observation density needed for event-based distributed modelling.

6. CONCLUSION

This study has delivered the first comprehensive engineering assessment of urban road drainage failure in Juba City, South Sudan, establishing the hydrological, structural, and economic evidence base needed for evidence-driven rehabilitation planning. Key findings confirm that Juba drainage failure is systemic: 54% of sub-catchments are hydraulically undersized, 60% of the primary network is in poor or critical structural condition, and annual flood-road closure events have tripled from 18 to 54 over the 2012–2024 period against a stagnant maintenance budget. Pareto analysis identifies hydraulic undersizing, sediment blockage, and structural collapse as the dominant failure modes, guiding the targeting of rehabilitation investment.

IDF curve derivation from 42 years of pluviograph data provides Juba-specific design intensities that for the first time put urban drainage design on a locally calibrated footing, replacing the regional generic values previously applied. The OLS regression model ($C = 0.00918\ I_{pct} + 0.112$, $r = 0.94$) provides a practical impervious cover-runoff coefficient relationship for integration into the Juba Urban Master Plan. Cost-benefit analysis demonstrates that the green infrastructure plus targeted reconstruction approach (Scenario D) delivers the highest economic returns (BCR 1.78, NPV USD +14.3 million, payback 9.6 years) at lower capital cost than full conventional reconstruction, recommending it as the preferred rehabilitation strategy. The risk priority matrix provides JCC and the Ministry of Infrastructure with a transparent, evidence-based sequencing tool for phased investment programming over the 2025–2035 planning horizon.

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DECLARATIONS

Conflict of Interest: The author declares no conflict of interest.

Data Availability: Field survey records, IDF data tables, and CBA model spreadsheets are available from the corresponding author on request, subject to JCC data sharing consent.

Author Contributions: Aduot Madit Anhiem: Conceptualisation, Field Survey Design, Hydrological Analysis, Failure Mode Diagnostics, CBA, Writing — Original Draft, Writing — Review and Editing.

ReferencesAdelekan, I. O (2010). Vulnerability of poor urban coastal communities to flooding in Lagos, Nigeria. Environment and Urbanization, 22(2), 433–450. https://doi.org/10.1177/0956247810380141. https://doi.org/10.1177/0956247810380141 [Link]Lauren McPhillips; A. Marissa Matsler (2018). Temporal Evolution of Green Stormwater Infrastructure Strategies in Three US Cities. Frontiers in Built Environment, 4. https://doi.org/10.3389/fbuil.2018.00026 [Link]Ashley, R.M.; Balmforth, D.J.; Saul, A.J.; Blanskby, J.D. (2005). Flooding in the future – predicting climate change, risks and responses in urban areas. Water Science and Technology, 52(5), 265-273. https://doi.org/10.2166/wst.2005.0142 [Link]Awange, J.L.; Khandu; Schumacher, M.; Forootan, E.; Heck, B. (2016). Exploring hydro-meteorological drought patterns over the Greater Horn of Africa (1979–2014) using remote sensing and reanalysis products. Advances in Water Resources, 94, 45-59. https://doi.org/10.1016/j.advwatres.2016.04.005 [Link]Bell, Frederick C. (1969). Generalized Rainfall - Duration - Frequency Relationships. Journal of the Hydraulics Division, 95(1), 311-328. https://doi.org/10.1061/jyceaj.0001942 [Link]Chocat, B.; Ashley, R.; Marsalek, J.; Matos, M.R.; Rauch, W.; Schilling, W.; Urbonas, B. (2007). Toward the Sustainable Management of Urban Storm-Water. Indoor and Built Environment, 16(3), 273-285. https://doi.org/10.1177/1420326x07078854 [Link]Brodie Ramin (2009). Slums, climate change and human health in sub-Saharan Africa. Bulletin of the World Health Organization, 87(12), 886-886. https://doi.org/10.2471/blt.09.073445 [Link]Fletcher, Tim D.; Shuster, William; Hunt, William F.; Ashley, Richard; Butler, David; Arthur, Scott; Trowsdale, Sam; Barraud, Sylvie; Semadeni-Davies, Annette; Bertrand-Krajewski, Jean-Luc; Mikkelsen, Peter Steen; Rivard, Gilles; Uhl, Mathias; Dagenais, Danielle; Viklander, Maria (2014). SUDS, LID, BMPs, WSUD and more – The evolution and application of terminology surrounding urban drainage. Urban Water Journal, 12(7), 525-542. https://doi.org/10.1080/1573062x.2014.916314 [Link]Cira, Dean A. (2002). Urban Upgrading in Latin America and the Caribbean. https://doi.org/10.1596/10408 [Link]Glenn Lyons; Greg Marsden (2019). Opening out and closing down: the treatment of uncertainty in transport planning's forecasting paradigm. Transportation, 48(2), 595-616. https://doi.org/10.1007/s11116-019-10067-x [Link]The Lancet Microbe (2021). Climate change: fires, floods, and infectious diseases. The Lancet Microbe, 2(9), e415-e415. https://doi.org/10.1016/s2666-5247(21)00220-2 [Link]Croese, Sylvia; Miyauchi, Yohei (2022). The transcalar politics of urban master planning: the Japan International Cooperation Agency (JICA) in Africa. Area Development and Policy, 8(3), 298-320. https://doi.org/10.1080/23792949.2022.2127413 [Link]Szafnicki, Konrad; Graillot, Didier (1996). Knowledge-based real-time fault detection and supervision of urban drainage systems. Automatica, 32(7), 1043-1047. https://doi.org/10.1016/0005-1098(96)00045-3 [Link]Kirpich, Z. P (1940). Time of concentration of small agricultural watersheds. Civil Engineering (ASCE), 10(6), 362..Nowogoński, Ireneusz (2021). Runoff Volume Reduction Using Green Infrastructure. Land, 10(3), 297. https://doi.org/10.3390/land10030297 [Link]Hope Hui Rising (2015). Water Urbanism: Building More Coherent Cities. Scholars' Bank (University of Oregon). https://scholarsbank.uoregon.edu//handle/1794/19350 [Link]Lwasa, Shuaib (2010). Adapting urban areas in Africa to climate change: the case of Kampala.

Current Opinion in Environmental Sustainability, 2(3), 166-171. https://doi.org/10.1016/j.cosust.2010.06.009 [Link]Tarnavsky, Elena; Grimes, David; Maidment, Ross; Black, Emily; Allan, Richard P.; Stringer, Marc; Chadwick, Robin; Kayitakire, Francois (2014). Extension of the TAMSAT Satellite-Based Rainfall Monitoring over Africa and from 1983 to Present. Journal of Applied Meteorology and Climatology, 53(12), 2805-2822. https://doi.org/10.1175/jamc-d-14-0016.1 [Link]Shahram Molavi; Nitin Muttil; Huu Tran (2011). Urban flood modelling and climate change: A Melbourne area case study. Chan, F., Marinova, D. and Anderssen, R.S. (eds) MODSIM2011, 19th International Congress on Modelling and Simulation.. https://doi.org/10.36334/modsim.2011.i6.molavi [Link]Nagar, Richa (2017). Dar es Salaam. University of Illinois Press. https://doi.org/10.5406/illinois/9780252038792.003.0003 [Link]Francesco Checchi; Christopher I Jarvis; Kevin van Zandvoort; Abdihamid Warsame (2023). Mortality among populations affected by armed conflict in northeast Nigeria, 2016 to 2019. Proceedings of the National Academy of Sciences, 120(30), e2217601120-e2217601120. https://doi.org/10.1073/pnas.2217601120 [Link]Brian Lucas (2021). Urban Flood Risks, Impacts, and Management in Nigeria. https://doi.org/10.19088/k4d.2021.018 [Link]Amal Elamin; Sara Abdullah; Abda ElAbbadi; Almoghirah Abdellah; Abdul Hakim; Naiema Wagiallah; John Pastor Ansah (2024). Sudan: from a forgotten war to an abandoned healthcare system. BMJ Global Health, 9(10), e016406-e016406. https://doi.org/10.1136/bmjgh-2024-016406 [Link]Marko P. Hekkert; Roald A.A. Suurs; Simona O. Negro; Stefan Kuhlmann; R.E.H.M. Smits (2006). Functions of innovation systems: A new approach for analysing technological change. Technological Forecasting and Social Change, 74(4), 413-432. https://doi.org/10.1016/j.techfore.2006.03.002 [Link]George T. Merovich (2007). Stream water quality and benthic macroinvertebrate ecology in a coal-mining, acid-sensitive region. https://doi.org/10.33915/etd.2594 [Link]Croese, Sylvia (2013). Uncovering African agency: Angola's management of China's credit lines. South African Journal of International Affairs, 20(3), 460-462. https://doi.org/10.1080/10220461.2013.841841 [Link]Barbero, Ever; Rangarajan, Shalini (2002). Long-Term Testing of Trenchless Pipe Liners. 4th International Pipeline Conference, Parts A and B, 107-118. https://doi.org/10.1115/ipc2002-27064 [Link]Sherman, C. W (1931). Frequency and intensity of excessive rainfalls at Boston, Massachusetts. Transactions ASCE, 95, 951–960..Ogbozige, Francis (2022). Development of Intensity-Duration-Frequency (IDF) Models for Manually Operated Rain Gauge Catchment: A Case Study of Port Harcourt Metropolis Using 50years Rainfall Data. Engineering and Technology Journal, 40(5), 627-635. https://doi.org/10.30684/etj.2021.131839.1064 [Link]C. Ozioma, Owuama (2022). A Drainage System for Road Construction on Flat Terrain. Applied Methods in Design and Construction of Bridges, Highways and Roads - Theory and Practice. https://doi.org/10.5772/intechopen.105019 [Link]Majer, Chol Gabriel; Adea, Maxwel (2023). Impact of Transformational Leadership Styles on South Sudanese Women Entrepreneurs: A Case Study of Juba City South Sudan. International Journal of Science and Business, 28(1), 67-83. https://doi.org/10.58970/ijsb.2205 [Link]Unknown Author (2001). Water Resources Management In Developing Countries And Eastern Europe. Water Privatisation.

https://doi.org/10.4324/9780203302484.ch5 [Link]Emilie K. Stander (2007). The effects of urban hydrology and elevated atmospheric deposition on nitrate retention and loss in urban wetlands. Rutgers University Community Repository (Rutgers University). https://doi.org/10.7282/t3pk0gj4 [Link]Nick Watts; Markus Amann; Nigel W. Arnell; Sonja Ayeb-Karlsson; Jessica Beagley; Kristine Belesova; Maxwell Boykoff; Peter Byass; Wenjia Cai; Diarmid Campbell-Lendrum; Stuart Capstick; Jonathan Chambers; Samantha Coleman; Carole Dalin; Meaghan Daly; Niheer Dasandi; Shouro Dasgupta; Michael Davies; Claudia Di Napoli; Paula Domínguez-Salas; Paul Drummond; Robert Dubrow; Kristie L. Ebi; Matthew J. Eckelman; Paul Ekins; Luis E. Escobar; Lucien Georgeson; Su Golder; Delia Grace; Hilary Graham; Paul Haggar; Ian Hamilton; Stella M. Hartinger; Jeremy Hess; Shih-Che Hsu; Nick Hughes; Slava Mikhaylov; Marcia Pescador Jimenez; Ilan Kelman; Harry Kennard; Gregor Kiesewetter; Patrick L. Kinney; Tord Kjellström; Dominic Kniveton; Pete Lampard; Bruno Lemke; Yang Liu; Zhao Liu; Melissa Lott; Rachel Lowe; Jaime Martínez-Urtaza; Mark Maslin; Lucy McAllister; Alice McGushin; Celia McMichael; James Milner; Maziar Moradi-Lakeh; Karyn Morrissey; Simon Munzert; Kris A. Murray; Tara Neville; Maria Nilsson; Maquins Odhiambo Sewe; Tadj Oreszczyn; Matthias Otto; Fereidoon Owfi; Olivia Pearman; David Pencheon; Ruth Quinn; Mahnaz Rabbaniha; Elizabeth Robinson; Joacim Rocklöv; Marina Romanello; Jan C. Semenza; Jodi D. Sherman; Liuhua Shi; Marco Springmann; Meisam Tabatabaei; Jonathon Taylor; Joaquín Triñanes; Joy Shumake-Guillemot; Bryan N. Vu; Paul Wilkinson; Matthew Winning; Peng Gong; Hugh Montgomery; Anthony Costello (2020). The 2020 report of The Lancet Countdown on health and climate change: responding to converging crises. The Lancet, 397(10269), 129-170. https://doi.org/10.1016/s0140-6736(20)32290-x [Link]DR. PIERRE-CELESTIN RWIGEMA (2022). IMPACT OF TEACHER'S WELFARE ON QUALITY OF EDUCATION IN EAST AFRICAN COMMUNITY: THEORETICAL PERSPECTIVE. Strategic Journal of Business & Change Management, 9(1). https://doi.org/10.61426/sjbcm.v9i1.2217 [Link]Natalia V. Bhattacharjee; Austin E Schumacher; Amirali Aali; Yohannes Habtegiorgis Abate; Rouzbeh Abbasgholizadeh; Mohammadreza Abbasian; Mohsen Abbasi-Kangevari; Hedayat Abbastabar; Samar Abd ElHafeez; Sherief Abd-Elsalam; Mohammad Abdollahı; Mohammad-Amin Abdollahifar; Meriem Abdoun; Auwal Abdullahi; Mesfin Abebe; Samrawit Shawel Abebe; Olumide Abiodun; Hassan Abolhassani; Meysam Abolmaali; Mohamed Abouzid; Girma Beressa Aboye; Lucas Guimarães Abreu; Woldu Aberhe; Michael R.M. Abrigo; Dariush Abtahi; Hasan Abualruz; Bilyaminu Abubakar; Eman Abu-Gharbieh; Niveen ME Abu-Rmeileh; Tadele Girum Girum Adal; Mesafint Molla Adane; Oluwafemi Adeagbo; Rufus Adesoji Adedoyin; Victor Adekanmbi; Bashir Aden; Victor Abiola Adepoju; Olatunji Adetokunboh; Juliana Bunmi Adetunji; Daniel A Adeyinka; Olorunsola Adeyomoye; Qorinah Estiningtyas Sakilah Adnani; Saryia Adra; Rotimi Felix Afolabi; Shadi Afyouni; Muhammad U. Afzal; Saira Afzal; Shahin Aghamiri; Antonella Agodi; Williams Agyemang-Duah; Bright Opoku Ahinkorah; Austin J Ahlstrom; Aqeel Ahmad; Danish Ahmad; Firdos Ahmad; Muayyad Ahmad; Sajjad Ahmad; Tauseef Ahmad; Ali Ahmed; Ayman Ahmed; Haroon Ahmed; Luai A. Ahmed; Meqdad Saleh Ahmed; Syed Anees Ahmed; Marjan Ajami; Budi Aji; Gizachew Taddesse Akalu; Hossein Akbarialiabad; Rufus Akinyemi; Mohammed Ahmed Akkaif; Sreelatha Akkala; Hanadi Al Hamad; Syed Mahfuz Al Hasan;

Mohammad Al Qadire; Tareq Mohammed Ali AL-Ahdal; Samer O Alalalmeh; Tariq A. Alalwan; Ziyad Al-Aly; Khurshid Alam; Rasmieh Al-Amer; Fahad Alanezi; Turki M Alanzi; Almaza A. Albakri; Mohammed ALBashtawy; Mohammad T AlBataineh; Hediyeh Alemi; Sharifullah Alemi; Megbaru Alemu; Ayman Al-Eyadhy; Adel Al-Gheethi; Khalid F. AlHabib; Noora Alhajri; Fadwa Alhalaiqa; Robert Kaba Alhassan; Abid Ali; Beriwan Abdulqadir Ali; Liaqat Ali; Mohammed Usman Ali; Rafat Ali; Syed Shujait Ali; Sheikh Mohammad Alif (2024). Global fertility in 204 countries and territories, 1950–2021, with forecasts to 2100: a comprehensive demographic analysis for the Global Burden of Disease Study 2021. The Lancet, 403(10440), 2057-2099. https://doi.org/10.1016/s0140-6736(24)00550-6 [Link]E. M. Forster; Oliver Stallybrass (1973). The manuscripts of Howards End. Medical Entomology and Zoology. https://ci.nii.ac.jp:443/ncid/BA21244991 [Link]Khaled Alshehri; Zhenghui Gao; Michael Harbottle; Devin Sapsford; Peter John Cleall (2023). Life cycle assessment and cost-benefit analysis of nature-based solutions for contaminated land remediation: A mini-review. Heliyon, 9(10), e20632-e20632. https://doi.org/10.1016/j.heliyon.2023.e20632 [Link]Kiichi Sasaki; Vũ Anh Tuấn; Nguyễn Thu Hằng; Do Thuy Trang (2020). Development of maximum and minimum temperature guidance with Kalman filter for 63 cities in Vietnam up to 10 days ahead. Journal of Hydro-meteorology, 5(5), 51-64. https://doi.org/10.36335/vnjhm.2020(5).51-64 [Link]Unknown Author (2023). 2/2023. ADIKTOLOGIE Journal. https://doi.org/10.35198/01-2023-002 [Link]Amesh A. Adalja; Tom Inglesby (2022). A Novel International Monkeypox Outbreak. Annals of Internal Medicine, 175(8), 1175-1176. https://doi.org/10.7326/m22-1581 [Link]Kwok Tai Chui; Brij B. Gupta; Jiaqi Liu; Varsha Arya; Nadia Nedjah; Ammar Almomani; Priyanka Chaurasia (2023). A Survey of Internet of Things and Cyber-Physical Systems: Standards, Algorithms, Applications, Security, Challenges, and Future Directions. Information, 14(7), 388-388. https://doi.org/10.3390/info14070388 [Link]Farshid Vahedifard; Amir AghaKouchak; Elisa Ragno; Shahriar Shahrokhabadi; Iman Mallakpour (2017). Lessons from the Oroville dam. Science, 355(6330), 1139-1140. https://doi.org/10.1126/science.aan0171 [Link]M. D. Zaidman; H. Gwyn Rees; Andrew Young (2002). Spatio-temporal development of streamflow droughts in north-west Europe. Hydrology and earth system sciences, 6(4), 733-751. https://doi.org/10.5194/hess-6-733-2002 [Link]

ReferencesAdelekan, I. O (2010). Vulnerability of poor urban coastal communities to flooding in Lagos, Nigeria. Environment and Urbanization, 22(2), 433–450. https://doi.org/10.1177/0956247810380141. https://doi.org/10.1177/0956247810380141 [Link]Lauren McPhillips; A. Marissa Matsler (2018). Temporal Evolution of Green Stormwater Infrastructure Strategies in Three US Cities. Frontiers in Built Environment, 4. https://doi.org/10.3389/fbuil.2018.00026 [Link]Ashley, R.M.; Balmforth, D.J.; Saul, A.J.; Blanskby, J.D. (2005). Flooding in the future – predicting climate change, risks and responses in urban areas. Water Science and Technology, 52(5), 265-273. https://doi.org/10.2166/wst.2005.0142 [Link]Awange, J.L.; Khandu; Schumacher, M.; Forootan, E.; Heck, B. (2016). Exploring hydro-meteorological drought patterns over the Greater Horn of Africa (1979–2014) using remote sensing and reanalysis products. Advances in Water Resources, 94, 45-59. https://doi.org/10.1016/j.advwatres.2016.04.005 [Link]Bell, Frederick C. (1969). Generalized Rainfall - Duration - Frequency Relationships. Journal of the Hydraulics Division, 95(1), 311-328. https://doi.org/10.1061/jyceaj.0001942 [Link]Chocat, B.; Ashley, R.; Marsalek, J.; Matos, M.R.; Rauch, W.; Schilling, W.; Urbonas, B. (2007). Toward the Sustainable Management of Urban Storm-Water. Indoor and Built Environment, 16(3), 273-285. https://doi.org/10.1177/1420326x07078854 [Link]Brodie Ramin (2009). Slums, climate change and human health in sub-Saharan Africa. Bulletin of the World Health Organization, 87(12), 886-886. https://doi.org/10.2471/blt.09.073445 [Link]Fletcher, Tim D.; Shuster, William; Hunt, William F.; Ashley, Richard; Butler, David; Arthur, Scott; Trowsdale, Sam; Barraud, Sylvie; Semadeni-Davies, Annette; Bertrand-Krajewski, Jean-Luc; Mikkelsen, Peter Steen; Rivard, Gilles; Uhl, Mathias; Dagenais, Danielle; Viklander, Maria (2014). SUDS, LID, BMPs, WSUD and more – The evolution and application of terminology surrounding urban drainage. Urban Water Journal, 12(7), 525-542. https://doi.org/10.1080/1573062x.2014.916314 [Link]Cira, Dean A. (2002). Urban Upgrading in Latin America and the Caribbean. https://doi.org/10.1596/10408 [Link]Glenn Lyons; Greg Marsden (2019). Opening out and closing down: the treatment of uncertainty in transport planning's forecasting paradigm. Transportation, 48(2), 595-616. https://doi.org/10.1007/s11116-019-10067-x [Link]The Lancet Microbe (2021). Climate change: fires, floods, and infectious diseases. The Lancet Microbe, 2(9), e415-e415. https://doi.org/10.1016/s2666-5247(21)00220-2 [Link]Croese, Sylvia; Miyauchi, Yohei (2022). The transcalar politics of urban master planning: the Japan International Cooperation Agency (JICA) in Africa. Area Development and Policy, 8(3), 298-320. https://doi.org/10.1080/23792949.2022.2127413 [Link]Szafnicki, Konrad; Graillot, Didier (1996). Knowledge-based real-time fault detection and supervision of urban drainage systems. Automatica, 32(7), 1043-1047. https://doi.org/10.1016/0005-1098(96)00045-3 [Link]Kirpich, Z. P (1940). Time of concentration of small agricultural watersheds. Civil Engineering (ASCE), 10(6), 362..Nowogoński, Ireneusz (2021). Runoff Volume Reduction Using Green Infrastructure. Land, 10(3), 297. https://doi.org/10.3390/land10030297 [Link]Hope Hui Rising (2015). Water Urbanism: Building More Coherent Cities. Scholars' Bank (University of Oregon). https://scholarsbank.uoregon.edu//handle/1794/19350 [Link]Lwasa, Shuaib (2010). Adapting urban areas in Africa to climate change: the case of Kampala. Current Opinion in Environmental Sustainability, 2(3), 166-171.

https://doi.org/10.1016/j.cosust.2010.06.009 [Link]Tarnavsky, Elena; Grimes, David; Maidment, Ross; Black, Emily; Allan, Richard P.; Stringer, Marc; Chadwick, Robin; Kayitakire, Francois (2014). Extension of the TAMSAT Satellite-Based Rainfall Monitoring over Africa and from 1983 to Present. Journal of Applied Meteorology and Climatology, 53(12), 2805-2822. https://doi.org/10.1175/jamc-d-14-0016.1 [Link]Shahram Molavi; Nitin Muttil; Huu Tran (2011). Urban flood modelling and climate change: A Melbourne area case study. Chan, F., Marinova, D. and Anderssen, R.S. (eds) MODSIM2011, 19th International Congress on Modelling and Simulation.. https://doi.org/10.36334/modsim.2011.i6.molavi [Link]Nagar, Richa (2017). Dar es Salaam. University of Illinois Press. https://doi.org/10.5406/illinois/9780252038792.003.0003 [Link]Francesco Checchi; Christopher I Jarvis; Kevin van Zandvoort; Abdihamid Warsame (2023). Mortality among populations affected by armed conflict in northeast Nigeria, 2016 to 2019. Proceedings of the National Academy of Sciences, 120(30), e2217601120-e2217601120. https://doi.org/10.1073/pnas.2217601120 [Link]Brian Lucas (2021). Urban Flood Risks, Impacts, and Management in Nigeria. https://doi.org/10.19088/k4d.2021.018 [Link]Amal Elamin; Sara Abdullah; Abda ElAbbadi; Almoghirah Abdellah; Abdul Hakim; Naiema Wagiallah; John Pastor Ansah (2024). Sudan: from a forgotten war to an abandoned healthcare system. BMJ Global Health, 9(10), e016406-e016406. https://doi.org/10.1136/bmjgh-2024-016406 [Link]Marko P. Hekkert; Roald A.A. Suurs; Simona O. Negro; Stefan Kuhlmann; R.E.H.M. Smits (2006). Functions of innovation systems: A new approach for analysing technological change. Technological Forecasting and Social Change, 74(4), 413-432. https://doi.org/10.1016/j.techfore.2006.03.002 [Link]George T. Merovich (2007). Stream water quality and benthic macroinvertebrate ecology in a coal-mining, acid-sensitive region. https://doi.org/10.33915/etd.2594 [Link]Croese, Sylvia (2013). Uncovering African agency: Angola's management of China's credit lines. South African Journal of International Affairs, 20(3), 460-462. https://doi.org/10.1080/10220461.2013.841841 [Link]Barbero, Ever; Rangarajan, Shalini (2002). Long-Term Testing of Trenchless Pipe Liners. 4th International Pipeline Conference, Parts A and B, 107-118. https://doi.org/10.1115/ipc2002-27064 [Link]Sherman, C. W (1931). Frequency and intensity of excessive rainfalls at Boston, Massachusetts. Transactions ASCE, 95, 951–960..Ogbozige, Francis (2022). Development of Intensity-Duration-Frequency (IDF) Models for Manually Operated Rain Gauge Catchment: A Case Study of Port Harcourt Metropolis Using 50years Rainfall Data. Engineering and Technology Journal, 40(5), 627-635. https://doi.org/10.30684/etj.2021.131839.1064 [Link]C. Ozioma, Owuama (2022). A Drainage System for Road Construction on Flat Terrain. Applied Methods in Design and Construction of Bridges, Highways and Roads - Theory and Practice. https://doi.org/10.5772/intechopen.105019 [Link]Majer, Chol Gabriel; Adea, Maxwel (2023). Impact of Transformational Leadership Styles on South Sudanese Women Entrepreneurs: A Case Study of Juba City South Sudan. International Journal of Science and Business, 28(1), 67-83. https://doi.org/10.58970/ijsb.2205 [Link]Unknown Author (2001). Water Resources Management In Developing Countries And Eastern Europe. Water Privatisation. https://doi.org/10.4324/9780203302484.ch5 [Link]Emilie K. Stander (2007). The effects of urban hydrology and elevated atmospheric deposition on nitrate retention and loss in urban wetlands. Rutgers University

Community Repository (Rutgers University). https://doi.org/10.7282/t3pk0gj4 [Link]Nick Watts; Markus Amann; Nigel W. Arnell; Sonja Ayeb-Karlsson; Jessica Beagley; Kristine Belesova; Maxwell Boykoff; Peter Byass; Wenjia Cai; Diarmid Campbell-Lendrum; Stuart Capstick; Jonathan Chambers; Samantha Coleman; Carole Dalin; Meaghan Daly; Niheer Dasandi; Shouro Dasgupta; Michael Davies; Claudia Di Napoli; Paula Domínguez-Salas; Paul Drummond; Robert Dubrow; Kristie L. Ebi; Matthew J. Eckelman; Paul Ekins; Luis E. Escobar; Lucien Georgeson; Su Golder; Delia Grace; Hilary Graham; Paul Haggar; Ian Hamilton; Stella M. Hartinger; Jeremy Hess; Shih-Che Hsu; Nick Hughes; Slava Mikhaylov; Marcia Pescador Jimenez; Ilan Kelman; Harry Kennard; Gregor Kiesewetter; Patrick L. Kinney; Tord Kjellström; Dominic Kniveton; Pete Lampard; Bruno Lemke; Yang Liu; Zhao Liu; Melissa Lott; Rachel Lowe; Jaime Martínez-Urtaza; Mark Maslin; Lucy McAllister; Alice McGushin; Celia McMichael; James Milner; Maziar Moradi-Lakeh; Karyn Morrissey; Simon Munzert; Kris A. Murray; Tara Neville; Maria Nilsson; Maquins Odhiambo Sewe; Tadj Oreszczyn; Matthias Otto; Fereidoon Owfi; Olivia Pearman; David Pencheon; Ruth Quinn; Mahnaz Rabbaniha; Elizabeth Robinson; Joacim Rocklöv; Marina Romanello; Jan C. Semenza; Jodi D. Sherman; Liuhua Shi; Marco Springmann; Meisam Tabatabaei; Jonathon Taylor; Joaquín Triñanes; Joy Shumake-Guillemot; Bryan N. Vu; Paul Wilkinson; Matthew Winning; Peng Gong; Hugh Montgomery; Anthony Costello (2020). The 2020 report of The Lancet Countdown on health and climate change: responding to converging crises. The Lancet, 397(10269), 129-170. https://doi.org/10.1016/s0140-6736(20)32290-x [Link]DR. PIERRE-CELESTIN RWIGEMA (2022). IMPACT OF TEACHER'S WELFARE ON QUALITY OF EDUCATION IN EAST AFRICAN COMMUNITY: THEORETICAL PERSPECTIVE. Strategic Journal of Business & Change Management, 9(1). https://doi.org/10.61426/sjbcm.v9i1.2217 [Link]Natalia V. Bhattacharjee; Austin E Schumacher; Amirali Aali; Yohannes Habtegiorgis Abate; Rouzbeh Abbasgholizadeh; Mohammadreza Abbasian; Mohsen Abbasi-Kangevari; Hedayat Abbastabar; Samar Abd ElHafeez; Sherief Abd-Elsalam; Mohammad Abdollahı; Mohammad-Amin Abdollahifar; Meriem Abdoun; Auwal Abdullahi; Mesfin Abebe; Samrawit Shawel Abebe; Olumide Abiodun; Hassan Abolhassani; Meysam Abolmaali; Mohamed Abouzid; Girma Beressa Aboye; Lucas Guimarães Abreu; Woldu Aberhe; Michael R.M. Abrigo; Dariush Abtahi; Hasan Abualruz; Bilyaminu Abubakar; Eman Abu-Gharbieh; Niveen ME Abu-Rmeileh; Tadele Girum Girum Adal; Mesafint Molla Adane; Oluwafemi Adeagbo; Rufus Adesoji Adedoyin; Victor Adekanmbi; Bashir Aden; Victor Abiola Adepoju; Olatunji Adetokunboh; Juliana Bunmi Adetunji; Daniel A Adeyinka; Olorunsola Adeyomoye; Qorinah Estiningtyas Sakilah Adnani; Saryia Adra; Rotimi Felix Afolabi; Shadi Afyouni; Muhammad U. Afzal; Saira Afzal; Shahin Aghamiri; Antonella Agodi; Williams Agyemang-Duah; Bright Opoku Ahinkorah; Austin J Ahlstrom; Aqeel Ahmad; Danish Ahmad; Firdos Ahmad; Muayyad Ahmad; Sajjad Ahmad; Tauseef Ahmad; Ali Ahmed; Ayman Ahmed; Haroon Ahmed; Luai A. Ahmed; Meqdad Saleh Ahmed; Syed Anees Ahmed; Marjan Ajami; Budi Aji; Gizachew Taddesse Akalu; Hossein Akbarialiabad; Rufus Akinyemi; Mohammed Ahmed Akkaif; Sreelatha Akkala; Hanadi Al Hamad; Syed Mahfuz Al Hasan; Mohammad Al Qadire; Tareq Mohammed Ali AL-Ahdal; Samer O Alalalmeh; Tariq A. Alalwan; Ziyad Al-Aly; Khurshid Alam; Rasmieh Al-Amer; Fahad Alanezi; Turki M Alanzi;

Almaza A. Albakri; Mohammed ALBashtawy; Mohammad T AlBataineh; Hediyeh Alemi; Sharifullah Alemi; Megbaru Alemu; Ayman Al-Eyadhy; Adel Al-Gheethi; Khalid F. AlHabib; Noora Alhajri; Fadwa Alhalaiqa; Robert Kaba Alhassan; Abid Ali; Beriwan Abdulqadir Ali; Liaqat Ali; Mohammed Usman Ali; Rafat Ali; Syed Shujait Ali; Sheikh Mohammad Alif (2024). Global fertility in 204 countries and territories, 1950–2021, with forecasts to 2100: a comprehensive demographic analysis for the Global Burden of Disease Study 2021. The Lancet, 403(10440), 2057-2099. https://doi.org/10.1016/s0140-6736(24)00550-6 [Link]E. M. Forster; Oliver Stallybrass (1973). The manuscripts of Howards End. Medical Entomology and Zoology. https://ci.nii.ac.jp:443/ncid/BA21244991 [Link]Khaled Alshehri; Zhenghui Gao; Michael Harbottle; Devin Sapsford; Peter John Cleall (2023). Life cycle assessment and cost-benefit analysis of nature-based solutions for contaminated land remediation: A mini-review. Heliyon, 9(10), e20632-e20632. https://doi.org/10.1016/j.heliyon.2023.e20632 [Link]Kiichi Sasaki; Vũ Anh Tuấn; Nguyễn Thu Hằng; Do Thuy Trang (2020). Development of maximum and minimum temperature guidance with Kalman filter for 63 cities in Vietnam up to 10 days ahead. Journal of Hydro-meteorology, 5(5), 51-64. https://doi.org/10.36335/vnjhm.2020(5).51-64 [Link]Unknown Author (2023). 2/2023. ADIKTOLOGIE Journal. https://doi.org/10.35198/01-2023-002 [Link]Amesh A. Adalja; Tom Inglesby (2022). A Novel International Monkeypox Outbreak. Annals of Internal Medicine, 175(8), 1175-1176. https://doi.org/10.7326/m22-1581 [Link]Kwok Tai Chui; Brij B. Gupta; Jiaqi Liu; Varsha Arya; Nadia Nedjah; Ammar Almomani; Priyanka Chaurasia (2023). A Survey of Internet of Things and Cyber-Physical Systems: Standards, Algorithms, Applications, Security, Challenges, and Future Directions. Information, 14(7), 388-388. https://doi.org/10.3390/info14070388 [Link]Farshid Vahedifard; Amir AghaKouchak; Elisa Ragno; Shahriar Shahrokhabadi; Iman Mallakpour (2017). Lessons from the Oroville dam. Science, 355(6330), 1139-1140. https://doi.org/10.1126/science.aan0171 [Link]M. D. Zaidman; H. Gwyn Rees; Andrew Young (2002). Spatio-temporal development of streamflow droughts in north-west Europe. Hydrology and earth system sciences, 6(4), 733-751. https://doi.org/10.5194/hess-6-733-2002 [Link]