Adapting Archipelagic Heritage to Climate Change: Evidence from Historic Shimoni Town and Wasini Island, Southern Kenya Coast

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Abstract

Sea-level rise, erosion, and accelerated beach loss are increasingly threatening Kenya's insular and archipelagic heritage landscapes. Across Shimoni's archipelago, consequences ranging from gradual decay, collapse to outright catastrophic loss of sea front mosques, tombs, wells, shrines, coral stone and wattle-daub buildings are indicative of absent heritage management and climate adaptation plans. To support climate sensitive conservation in historic Shimoni Town and Wasini Island, Island Vulnerability and Archipelagic Planning Systems Theory was examined to quantify landscape metrics, entropy and spatial change based on Landsat images from 1984-2023. Geo-spatial indicators selected to quantify ecological change include: Patch Density, Mean Patch Size, Largest Patch Index and Landscape Shape Index. These landscape metrics were selected to determine patch isolation, evenness, dominance and complexity, respectively. In 40 years, built-up and barren land areas increased by 73% and 32% respectively while mangrove cover and terrestrial vegetation decreased by 69% and 33% respectively. Coral outcrops and sandy beach decreased by 14% and 69%, respectively. Urban expansion quadrupled at a rate of 1.26km2/year indicated by Shannon's entropy values that increased from 0.003 to 0.024. Bare land and built up patch densities increased by 38% and 60% respectively. Mean patch sizes for mangrove and terrestrial vegetation decreased by 100m2 and 200m2 respectively. Overall. Landscape metrics highlighted increasing urban sprawl into heritage sensitive zones. Conservation and historic town planning is to consider stabilization, consolidation and adaptive reuse for flood vulnerable built heritage. Archipelagic planning is to consider the critical adjustment of shoreline setbacks, forest buffer zones, flood risk zones, mangrove restoration, afforestation, vertical densification, planned retreat and land use control to protect low lying historic sites from ongoing and future climate change.

Keywords: Archipelagic Heritage, Island Vulnerability, Climate Adaptation, Conservation, Southern Kenya Coast

Archipleagic Heritage and Climate Change

Archipelagic heritage to include sea front mosques, forts, tombs, wells, archaeology and sacred landscapes refers to interconnected cultural and natural resources that exist across groups of islands and surrounding seascapes (Hau'ofa, 1994; Baldacchino, 2015). Unlike conventional heritage approaches that focus on individual historic sites, Kenya's archipelagic heritage demonstrates that island urbanism evolved as a highly adaptive socio-ecological system integrating multiple cultural influences from Arabia, India and China shared over two millennia (Chittick, 1976; Fouéré, 2003; Fleisher, 2010). As a result, archipelagic seascapes to include Lamu in the northern coast (Figure 1) and Shimoni in the southern coast, reflect unique architectural heritage of great historical significance (Ghaidan, 1975; Horton, 1987; Allen, 1993; Wilson,2016). For instance, Lamu old town (Plate 1), founded in the fourteenth century, is inscribed on the World Heritage List as the oldest and best-preserved Swahili settlement in East Africa (Horton & Middleton, 2000; Wynne-Jones & Fleisher, 2015; UNESCO,2026).

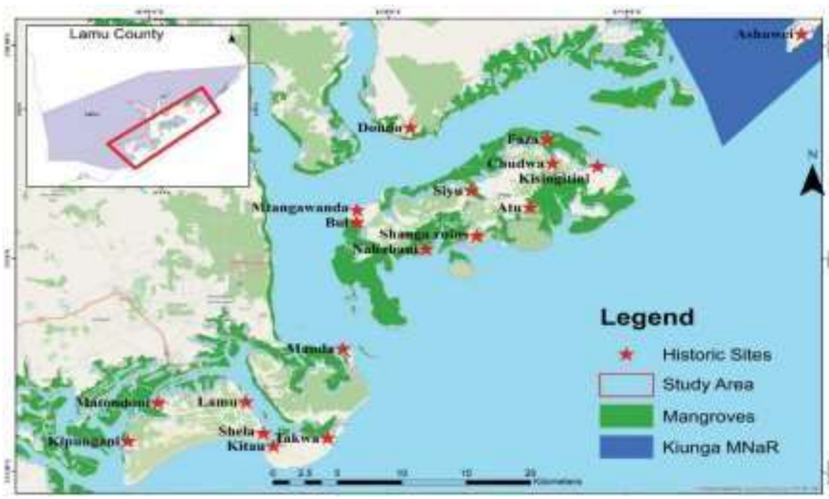

Figure 1::Lamu Archipelago, Northern Kenya Coast Source: Njiiri, et.al., (2025a)

Plate 1: Lamu World Heritage Site. Source: UNESCO (2026

However, climate driven sea level rise amplifies widespread beach loss, flooding and erosion by high tide action, resulting in unforeseen transformation of heritage space across sixty-six historic sites along Kenya's 584 km littoral (Vousdoukas et al.,2021; Hamza et al.,2022; Njiiri et al.,2024). Consequently, local maritime spatial planning and coastal zone management (Maina et al.,2021; Musyoka et al.,2022) has increasingly shifted toward reactive adaptation strategies characterized by increased sea-wall reinforcement, shoreline stabilization and costly engineering interventions as observed at Fort Jesus in Mombasa old town (Plate 2), Vasco da Gama Pillar in Malindi (Plate 3), Faza (Plate 4) and Kizingitini (Plate 5), on Pate Island in Lamu archipelago (UNEP,2022; NMK,2023; Chambon, 2024).

Plate 2: Sea walls, Fort Jesus.
Source : Njiiri, et.al., (2024

Plate 3: Vasco da Gama Pillar
Source: Njiiri, et.al., (2024)

Plate 4: Sea walls, Faza
Source: GoK (2019)

Plate 5: Plate 3: Sea walls, Kizingitini
Source: UNEP (2022)

However, prescriptive structural interventions generate unforeseen hydrologic, topographic and morphological problems to include: fragmented mangrove buffers, altered sediment flows and archaeological disturbances (Cacciotti et al.,2024; Brimblecomble et al.,2024; Shilabukha et al.,2025). Unfortunately, legislation governing Kenya's coastal land use, including procedures to be followed before any development is launched, takes precedence over analyses of rates of land cover change (Awour et al. 2008; Omoumbo 2011; GoK 2010;2019). As a result, plot boundaries are set at the highest water mark regardless of rates of shoreline change as observed at Ashuwei (Plate 6) and Kibuyuni (Plate 7), in Lamu and Shimoni archipelagos, respectively (UNEP, 2022; Gitau et al.,2023; NMK,2023; Njiiri et al.,2025).

Plate 6: Beach loss, Ashuwei
Source: Njiiri, et.al., (2024)

Plate 7: Erosion, Kibuyuni
Source: Njiiri, et.al., (2025)

In this regard, Island Vulnerability and Archipelagic Planning Systems Theory explains how climate change transforms maritime heritage through spatial reconfiguration and ecological fragmentation across island and archipelagic regions (Oki & Brasher, 2003; Bankoff, 2007; Nunn, 2013; Kelman, 2014; Baum et al., 2016; Mycoo, 2018; Shah et al., 2020; Bugnot et al.,2020; UNESCO, 2023). However, heritage planning tensions across archipelagic heritage in Zanzibar, Mauritius, Seychelles, Comoros, Madagascar, Mozambique, Fiji, Vanuatu, Hawaii, Cape Verde, Galapagos, New Zealand, Caribbean, Indonesia, Solomon Islands and Malaysia and the Philippines, indicate difficult trade-offs between heritage protection and climate adaptation (IPCC,2024; ICCROM,2024; UNESCO,2026).Consequently, international heritage frameworks advocate for the protection of maritime heritage to include: cultural landscapes, historic settlements, vernacular buildings, sacred shrines, archaeological sites, timber structures, and underwater heritage as integrated components of broader seascape systems (ICOMOS, 1990; 1996; 1999; UNESCO, 2026).

In this regard, Archipelagic Planning Systems Theory conceptualizes islands as interconnected socio-ecological systems linked through navigation, kinship, ritual practices, and shared ecological knowledge rather than isolated landscapes (Baldacchino, 2015; Hau'ofa, 1994; ICCROM, 2024; ICOMOS, 2021; UNESCO, 2026; UNFCCC, 2024). In Kenya, maritime heritage comprising sea-front mosques, tombs, wells, jetties, coral and wattle-daub settlements in the Lamu and Shimoni archipelagos is embedded within fishing, coral reef, mangrove, and lagoon ecosystems that sustain living heritage (Kusimba, 2017; NMK, 2023). However, conservation remains constrained by unplanned development, resource extraction, salinization, and land-use change, which fragment cultural landscapes, degrade ecosystems, and increase encroachment on historic sites (Maina et al., 2021; Gitau et al., 2023; Shilabukha, 2024; Van Katwijk et al., 1993; McClanahan & Obura, 1997; Schwarz, 2007; Abuya, 2016; Uku et al., 2021; Kairo et al., 2023; Mwakumanya, 2021; Fulanda et al., 2011; Obura et al., 2021; Chome, 2020; Kilaka et al., 2023; NEMA, 2017; UNEP, 2022; Wainwright et al., 2019; Mulwa et al., 2021; Painter et al., 2021; Taylor et al., 2019).

Further, declining availability of coral stone, mangrove poles, timber, lime plaster, and palm thatch weakens traditional construction skills and adaptive knowledge despite comprehensive national heritage and climate legislation (NMK, 2023; Wynne-Jones, 2016; Busaka, 2023). Unfortunately, fragmented heritage management, land tenure constraints, and weak integration of place-based adaptation continue to limit effective conservation across Lamu and Shimoni archipelagos (GoK, 2019; UNEP, 2022; NEMA, 2022; UNCCF, 2024; UNESCO, 2026). Fortunately, Island Vulnerability and Archipelagic Planning Systems

Theory advocates landscape metrics, entropy analysis, and multi-temporal spatial assessment to evaluate fragmentation, spatial complexity, and land-cover change for climate-responsive heritage adaptation (Alexander, 2013; Batty, 2013; Corner, 2006; Cosgrove, 1984; Forman, 1995; ICOMOS, 2021; Jokilehto, 2006; Kelman, 2015; McGarigal & Marks, 1995; Sauer, 1925; Turner et al., 2001; Waldheim, 2006; Wheeler, 2013; UNESCO, 2026).

The paper sought to determine vulnerability of maritime heritage to climate change in historic Shimoni Town and Wasini Island in Kenya's southern archipelago. In doing so, four landscape metrics were employed: patch density, mean patch size, largest patch index and landscape shape index (McGarigal & Marks, 1995; McGarigal et al., 2012; Turner et al., 2001). Patch density measured landscape fragmentation, mean patch size assessed landscape evenness, largest patch index evaluated landscape dominance, while landscape shape index examined spatial complexity (Forman, 1995; McGarigal et al., 2012; Turner et al., 2001; Alexander, 2013; Kelman, 2015). Collectively, landscape metrics provided a spatial-temporal framework for supporting climate-sensitive conservation, heritage management and adaptation strategies in historic Shimoni town and Wasini Island, southern Kenya coast.

Maritime Heritage in Historic Shimoni Town and Wasini Island, Southern Kenya Coast

Historic Shimoni town lies 90 kilometers south of Mombasa, on a peninsula 13 kilometers off the Mombasa-Lunga Lunga Road at the Kenya-Tanzania border in Kwale County, at 4.6471° S, 39.3805° E (Figure 2). Shimoni, classified as a national monument by the National Museums of Kenya in 2001, is named after site's caverns that stretch seven kilometers underground (Kiriama 2021; Busaka, 2023). Heritage significance is highlighted by an archipelagic system comprising of sacred forest, mangrove, coral reef, tidal and lagoon systems as well as Kisite-Mpunguti Marine National Park, which boasts East Africa's highest coral richness, with 203 endemic species and 60% coral cover (Obura, 2021; Jacobs et al.,2021; KMFRI,2024). Further, the archipelago highlights unique biological and geological history as well as ongoing climate change processes (UNEP,2022;NMK,2023). Twelve islands to include: Wasini, Kisite, Mpunguti, Sii, Nyuli, Mipwa, Minyani Mikubwa, Makotwe, Mwamba Kuu, Mijira and Kichwa Mtu are protected under the Wildlife Conservation and Management Act of 2018 and designated as Kenya's *man and nature* bio-reserve (Abungu,2019; Tschentscher et al.,2023; Njiiri et al., 2025; UNESCO, 2026)

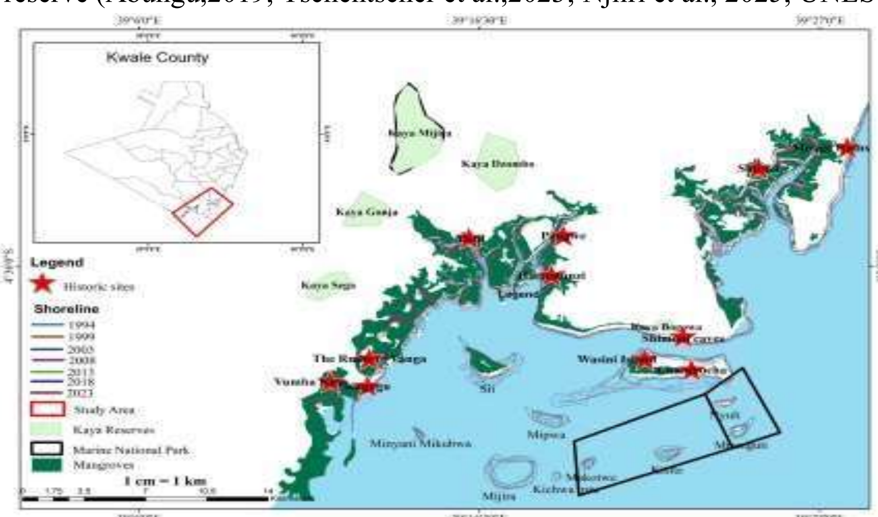

Figure 2: Shimoni Archipelago, Southern Kenya Coast
Source: Njiiri, et.al., (2024)

Notably *Kaya Bogowa* sacred forest, located on Wasini Island 2km offshore historic Shimoni town, is one of three of East Africa's remaining coral rag forests (Fungomeli et al.,2020). A coral rag forest is a distinct marine habitat defined by its position on ancient coral reefs that have cemented into limestone. As such, coral rag forests are home to indigenous hardwoods that have adapted to dry, salty, and nutrient-poor soils that cover low lying historic sites (IUCN,2025). The other two coral rag forests, *Kaya Diani* and *Kaya Waa*, are located in 40 kilometres north, in Ukunda, Msamweni sub county (UNEP,2022; Chambon,2024).

Maritime built heritage in Shimoni archipelago includes colonial era buildings, mosques, wells, tombs and jetties across seven intertidal sites namely, *Aleni, Shirazi, Pongwe, Hurumuzi, Kagugu, Chambocha* and the ruins at Vanga (Figure 2). However, erosion and widespread beach loss in historic Shimoni town and Wasini Island, is on the rise (Njiiri et al.,2024;2025). Consequences ranging from surface corrossion (Plate 8), surface blackening (Plate 9), collapse, to outright catastrophic loss of sea front mosques (Plate 10 and 11) are indicative of absent climate and heritage adaptation plans. Further, due to rapid loss of mangrove and forest cover, sudden onset high intensity rainfall amplifies structural failure patterns observed in colonial era buildings, dated 1882, to include: British administrative headquaters (Plate 12), colonial prisons, colonial armouries (Plate 13) as well as coral block buildings on Shimoni's sea front (Plate 14) and wattle-daub buildings on Wasini's Mkwiro beach (Plate 15). In totality, susceptibility of maritime built heritage to salt driven damage remains high due to the age, location and hygroscopic nature of coral stone, lime mortar, timber, and thatching material that constitutes it (NMK,2023; Busaka, 2023; Njiiri et al.,2024;2025).

Plate 8: Surface corrosion, Colonial headquarters

Plate 9: Surface blackening, Colonial headquarters

Plate 10: Collapsed Mosque by the Sea

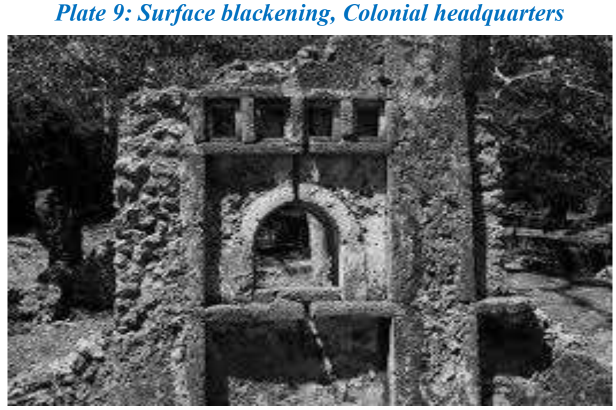

Plate 11: Cracked Mosque ruins

Plate 12: Collapsed historic building

Plate 13: Eroded colonial armouries

Plate 14: Eroded coral block building

Plate 15: Crumbled wattle-daub building

Unfortunately, landscape transformation threatens not only built heritage, but also intangible cultural systems linked to sacred shrines, ritual grounds and underground caves (Plate 16 and 17) (Abungu, 2017; Mwangudza, 2019; Nyamwanga, 2020). Sacred forests in historic Shimoni to include Kaya *Majimwiru, Mwanagoto* and *Mzizima*, undergo frequent flooding and drought episodes resulting in ecological patch fragmentation, ritual discontinuity and cultural displacement (Lam et al.,2023; Nyachonga, 2025). Further, accelerated shoreline retreat and widespread beach loss in *Kaya Bogowa* on Wasini Island, results in submersion of shrines, sacred fig and baobab grooves that support ceremonial grounds and customary governance systems (Kiriama, 2012; Maina et al., 2021; Habel et al.,2023; NMK,2023; Gitau et al.,2025). Finally, unpredictable rainfall and prolonged humidity accelerates habitat loss as observed by the spread of invasive plants species to include: *Ipomoea indica*, *Leucaena leucocephala*, *Opuntia stricta*, *Eichhornia crassipes* and *Cuscuta campestris* (Betts et al., 2019), alongside destructive pests including: *Coptotermes formosanus*ermites and *Cryptotermes brevis* that desiccate palm thatched roofs, wattle and structural timber elements (Ogada et al., 2022; Cazalis et al. 2022).

Plate 16: Cave ritual space

Plate 17: Cave ritual pathway

To promote holistic protection of southern coast forests such as *Kaya Gonja, Marenji, Segeju, Mrima* and the largest in Kenya, *Kaya Dzombo* (Figure 2), the Forest Conservation and Management Act 2016, Water Act 2016, Shimoni-Vanga Joint CoManagement Area Plan 2024–2028, Integrated Coastal Zone Management Plan 2019–2023, Kwale County Spatial Plan 2022–2032, have been established. However, despite the comprehensive legal framework, Shimoni archipelago loses 25 hectares of mangrove cover annually, a trend expected to worsen with Fish Port-related development in Shimoni Town (Busaka, 2023; Chambon, 2024). Although shoreline erosion averages 5.34 metres per year (Njiiri et al., 2024;2025), heritage considerations remain weakly integrated into adaptation planning, limiting effective conservation and heritage management efforts (GoK, 2019; Abungu, 2019; UNEP, 2022; NMK,2023). As a result, ongoing ecological degradation threatens heritage tourism, underscoring the need for integrated climate adaptation strategies for the conservation of cultural and natural heritage in historic Shimoni town, Wasini Island and the wider cultural landscape in Kenya's southern archipelago.

Methodology

This study applied Archipelagic Planning Systems Theory to assess land-cover change and heritage vulnerability in historic Shimoni Town and Wasini Island. Using landscape metrics: patch density, mean patch size, largest patch index, and landscape shape index, together with multi-temporal spatial analysis (McGarigal & Marks, 1995; Turner et al., 2001; Alexander, 2013; Kelman, 2015), the methodology identified land-cover patterns affecting heritage adaptation over time. To provide a baseline for prioritizing ecosystem-based climate adaptation and integrated heritage conservation strategies, Landsat images of the study area (Table 1) were analysed using the post-classification change detection technique for periods 1984 – 2023.

Table 1: Sources of Satellite Data

Satellite Data/Sensor	Year of Acquisition	Spatial Resolution (m)
Landsat 5-Multi Spectral Scanner and Thematic Mapper	1984	30
Landsat 7-Enhanced Thematic Mapper	2003	30
Landsat 7-Enhanced Thematic Mapper	2013	30
Landsat 8-Operational Land imager and Thermal Infrared Sensor	2023	30

The post-classification technique was selected to reduce effects of spectral resolution and sensor differences (Srivastava et al.,2012). Atmospheric correction was done using the Dark Object Subtraction model to obtain surface reflectance (Lu et al., 2004). Landsat imageries were calibrated top-of atmosphere reflectance, with a cloud coverage of less than 10 % (Chavez, 1988). The step wise sequence for data acquisition, radiometric correction and supervised classification is illustrated in Figure 20. Maximum Likelihood classifier, a parametric statistical method, was selected to classify pixels in Landsat images into predefined land-cover classes through quantification of spectral signatures (Anderson et al.,1976; Paudel and Yuan, 2012). Based on spectral responses of features on Landsat images and prior field observation, seven land cover types were identified (Table 2).

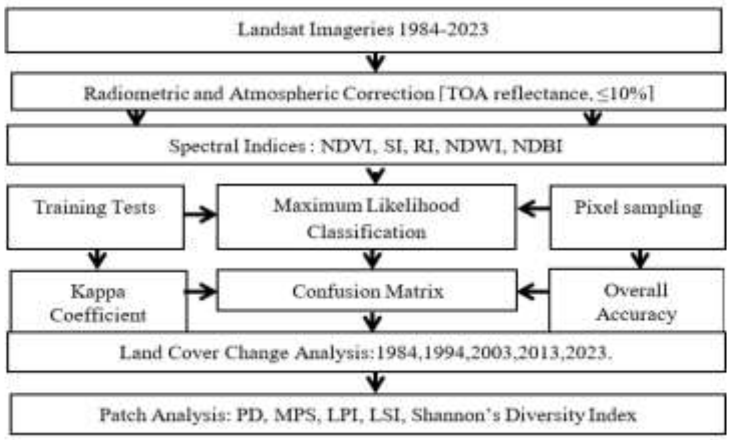

Figure 3: Data Analysis for Establishing Land Cover Change

Table 2: Land Cover Types

Land Cover	Description	Index
Forests	Hardwoods and artificially planted trees	NDVI (Normalized Difference Vegetation Index)
Mangroves	Tropical plants adapted to saline conditions	MNDVI (Modified Normalized Difference Vegetation Index)
Non-built	Open, burnt and bare areas	BI (Bare Soil Index)
Sandy beach	Loose deposits of sand and gravel	SI (Soil Index)
Rocky beach	Cliffs and outcrops that cover shorelines	Rock Index (RI)
Water body	Sea, streams, water pans	Normalized Difference Water Index (NDWI)
Built-up	Residential, commercial, industrial and transportation land use	NDBI (Normalized Difference Built-up Index)

The confusion matrix, a table that summarizes performance of the classification algorithm, was used to evaluate minimum accuracy requirements (Congalton, 2001; Foody, 2002). The confusion matrix, also known as an error matrix, shows the cross-tabulation of classified values against reference data. Using this approach, Overall Accuracy (OA), a representation of total classification accuracy and Kappa coefficient (κ), a level of agreement beyond what is expected by random chance, were computed to determine classification accuracy (Shao and Wu, 2008). For this purpose, Equations 1 and 2 were followed.

OA = Total number of pixel classified correctly / total number of pixels *100 (Equation 1)
Kappa coefficient (κ) = $(Po - Pe) / (1 - Pe)$ (Equation 2)

Where *Po*, represents the observed agreement between a classified map and reference data. *Pe,* represents the expected agreement by chance, based on the marginal frequencies in a confusion matrix. A Kappa value closer to 1 indicates strong agreement between classifications, while a value closer to 0 signifies agreement no better than random chance (Shivakumar and Rajashekararadhya, 2018). In order to analyse the rate of landscape fragmentation for the periods 1984–2003,2003–2013, 2013-2023 and 1984–2023, the annual rate of landscape fragmentation (RLF) for the specified periods was calculated by Equation 3.

Rate of landscape fragmentation RLF = $(BUA)_{in} - (BUA)_i / n*(BUA)_i$ (Equation 3)

Where BUA, is the built-up area while BUA_{i+n} and BUA_i are the built-up areas (in km^2) at time $i + n$ and i, respectively. n is the interval of the calculating period (in years) (Herold et al.2003). The change statistics for classified maps of two time periods was calculated by Equation 4.

Change (%) = $(A_{final\ year} - A_{initial\ year} / A_{initial\ year})$ *100 (Equation 4)

Where A, is the area coverage of each land cover type (in km^2). Positive percentage values suggest an increase whereas negative values imply a decrease in area coverage respectively (Xiao et al.,2005). Shannon's entropy was selected to establish the degree of spatial clustering or dispersion of urban patches over the study period. The study area was divided into concentric zones with a consecutive incrementing radius of 100metres from a centroid pinned at the British colonial headquarters built in 1882 (Figure 10). By clipping out the built-up areas of each zone, Shannon's entropy in each zone was calculated by Equation 5.

Shannon's entropy $H_n = \sum_{i=1}^{n} Pi$ In $(1 / Pi)$ (Equation 5)

Where H_n is the Shannon's entropy, P_i is the percentage of built-up areas in each zone computed as a ratio of built-up areas in i^{th} zone to the total built-up areas in all zones, n is the total number of zones (Yeh and Li, 2001). Shannon's entropy values vary between 0 and 1 (Ramachandra et al.,2012). Zero entropy values indicate that built-up areas have a highly concentrated distribution; whereas values closer to 1 indicate high dispersion of built-up areas (Mashagbah, 2016). Relative Shannon's entropy ($H'n$) highlights the spatial pattern of urban expansion as a measure of landscape fragmentation calculated by Equation 6.

Relative Shannon's entropy $H_n = [\ \sum_{i=1}^{n} Pi$ In $(1 / Pi)\ ] / (n)$ (Equation 6)

The change in the rate of urban dispersion between two time periods evaluates whether landscape fragmentation is towards a more dispersed or compact pattern (Yeh and Li, 2001). The magnitude of change rate of urban dispersion was calculated by Equation 7.

Rate of urban dispersion $\Delta H_n = H_n(t_1) - H_n(t_2)$ (Equation 7)

Where ΔHn, is the difference in entropy values between two time periods, $Hn(t_1)$, is the relative Shannon's entropy at time (t_1) and $Hn(t_2)$ is the relative Shannon's entropy at time (t_2) (Mashagbah 2016).

However, multi-temporal land cover change cannot capture all aspects of landscape fragmentation (Lausch, 2002; Gustafson and Parker, 1992). Thus, descriptive landscape metrics were compared across classified maps at patch level. Indicators selected to determine ecological patch configuration include Patch Density, Mean Patch Size, Largest Patch Index and Landscape shape index (Uuemaa et.al.2009; Turner and Gardner 2015; Hambrecht and Rockman 2017) (Table 3). The landscape metrics were selected to determine patch isolation, evenness, dominance and complexity, respectively (Naveh and Lieberman 1994; Leitao et.al.2008; Turner and Gardner 2015).

Table 3: Landscape Metrics

Landscape Metric	Description	Formula	Notes
Patch Density (PD)	PD equals the number of patches of the corresponding patch type divided by total landscape area, multiplied by 10,000 and 100 (to convert to 100 ha.).	PD = ni / A*10,000*100 Range: PD > 0, without limit Justification: Isolation index	ni = number of patches in the landscape of patch type (class)i. A = total landscape area (m2). References: (McGarigal and Marks, 1995; Singh et.al.,2015)
Mean Patch Size (MPS)	MPS equals sum of all patches of the corresponding patch type, divided by the number of patches of the same type, divided by 10,000 (to convert to ha.).	MPS = [$\sum_{j=1}^{n}$* aij] / ni * 1/10,000 Range: MPS > 0, without limit Justification: Evenness index	aij = area (m2) of patch ij. ni = number of patches in the landscape of patch type (class)i. References: (Olsen et al.,2006).
Largest Patch Index (LPI)	LPI equals the area (m2) of the largest patch of the corresponding patch type divided by total landscape area, multiplied by 100 (converted to %)	LPI = [$\sum_{j=1}^{n}$* aij] / A * 100 LPI = 100 when the entire landscape consists of a single patch of the corresponding patch type Range: 0 < LPI ≤ 100 Justification: Dominance index	aij = area (m2) of patch ij. A = total landscape area (m2). References: (Paudel and Yuan, 2012).
Landscape Shape Index (LSI)	LSI equals the sum of the landscape boundary (m), involving the corresponding patch type divided by the square root of the total landscape area (m2)	LSI = 0.25E / √A The higher the LSI value, the more discrete the patches are Range: LSI ≥ 1, without limit Justification: Complexity index	Where LSI represents value of landscape shape index; E represents total patches perimeter; A = total landscape area (m2) References: (Gustafson and Parker, 1992).

Results and Interpretation

Four Land cover change maps were validated by confusion matrices from which producer accuracy, user accuracy, overall accuracy and kappa coefficients were computed (Table 4). Overall accuracy values of 78.40%, 79.20%, 77.40%, and 78% as well as kappa coefficient values of 0.76, 0.77, 0.74, and 0.75 were achieved for the classified images of 1984, 2003, 2013 and 2023 shown in Figure 3, 4,5 and 6 respectively.

Table 4: Accuracy assessment for classified images of 1984, 2003,2013 and 2023

Land Cover Type	1984		2003		2013		2023	
	Producer	User	Producer	User	Producer	User	Producer	User
Water	78%	76%	80%	82%	77%	76%	79%	78%
Vegetation	81%	79%	82%	80%	80%	79%	81%	80%
Rocky Beach	85%	83%	86%	84%	83%	84%	85%	83%
Sandy beach	80%	82%	81%	83%	78%	80%	79%	80%
Mangrove	75%	77%	76%	79%	73%	74%	74%	75%
Built-up	83%	81%	84%	82%	82%	83%	83%	82%
Bare land	79%	78%	78%	79%	76%	78%	77%	79%
Overall accuracy (%)		78.40		79.20		77.40		78.00
Kappa coefficient (κ)		0.76		0.77		0.74		0.75

Accuracy results indicate strong agreement between ground truth data and classified maps. A kappa coefficient of 1 signifies perfect agreement between a classified image and a referenced one, while 0 indicates no agreement. Further, overall accuracy and kappa coefficient values met the minimum accuracy requirements for landscape change detection. In the periods 1984–2003, 2003–2013, and 2013–2023, built-up areas increased by 76%, 65% and 30%, while bare land increased by 9%, 13% and 19%, respectively (Table 5). During the same change periods, mangrove cover decreased by 17%, 6%, and 24% while terrestrial vegetation decreased by 11%, 8% and 8% respectively. Coral reefs decreased by 5%, 3% and5%, while sandy beach decreased by 79%, 62% and 12%, respectively (Table 5).

Table 5: Land cover change between 1984-2023

Land Cover Type	1984		2003		2013		2023		Land Cover Change (%)			
	km2	%	km2	%	km2	%	km2	%	1984-2003	2003-2013	2013-2023	1984-2023
Built up Area	0.46	1	0.80	2	1.32	4	1.71	5	76	65	30	73
Bare land	3.75	10	4.10	11	4.62	13	5.52	15	9	13	19	32
Vegetation	7.17	20	6.40	18	5.87	16	5.40	15	-11	-8	-8	-33
Mangrove	2.54	7	2.10	6	1.97	5	1.50	4	-17	-6	-24	-69
Rocky Beach	11.51	32	10.91	30	10.62	31	10.10	28	-5	-3	-5	-14
Sandy Beach	0.53	1	0.95	3	1.54	4	1.72	15	79	62	12	69
Water	10.47	29	10.79	30	10.10	28	10.06	28	-	-	-	-
Total	36.42	100	36.05	100	36.04	100	36.05	100				

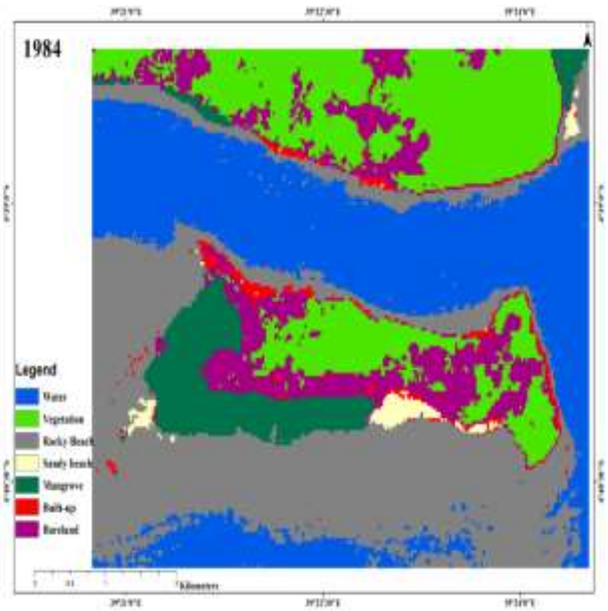

Figure 3: Land cover change, 1984

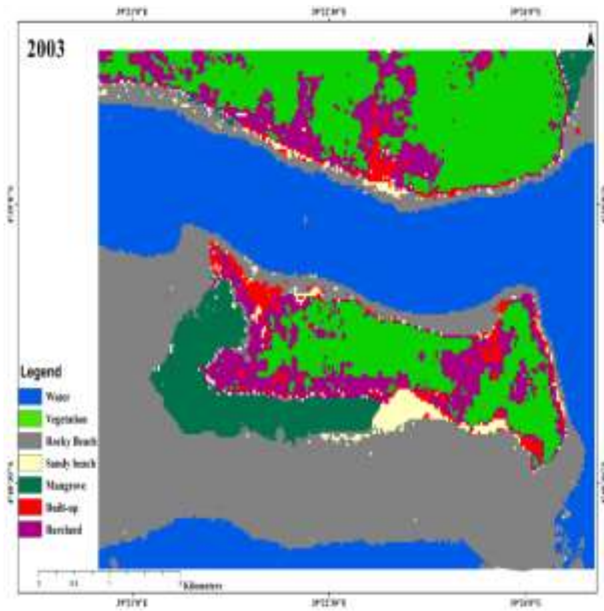

Figure 4: Land cover change, 2003

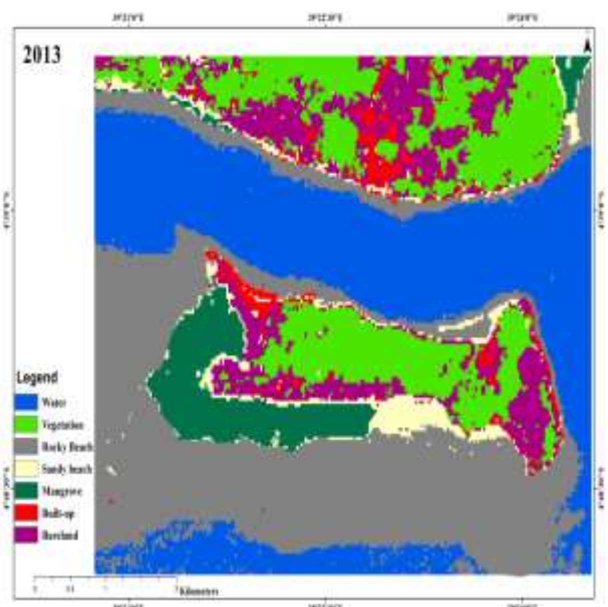

Figure 5: Land cover change, 2013

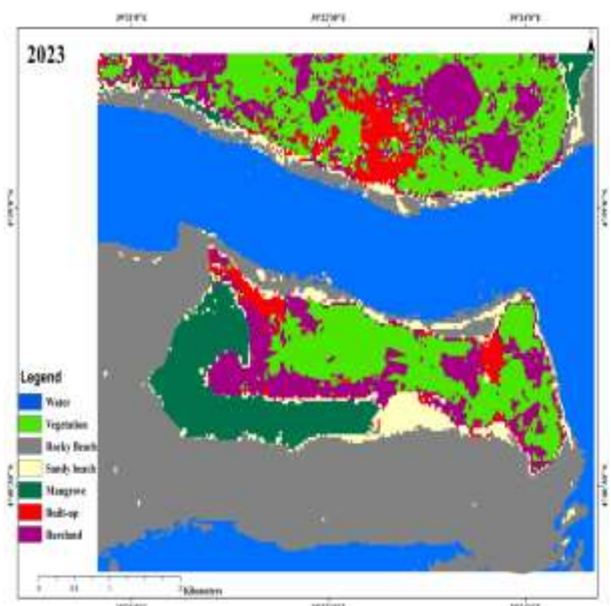

Figure 6: Land cover change, 2013

Legend		Water		Vegetation		Rocky beach		Sandy beach		Mangrove		Built up		Bare land

In 40 years, built-up and barren land areas increased by 73% and 32% respectively while mangrove cover and terrestrial vegetation decreased by 69% and 33% respectively. Coral reefs and sandy beach decreased by 14% and 69%, respectively. Thus, urban development took place at the expense of forests, mangroves and sandy beaches. The annual rate of change showed that built-up areas increased by 3.8% (0.35km^2/year) between 1984-2003, 6.4% (0.52km^2/year) between 2003-2013 and 2.9% (1.26km^2/year) between 2013-2023. Overall, built up areas increased by 27.5% (1.26km^2/year) from 1984 to 2023 (Table 6).

Table 6: Rate of urban expansion

Year	Built-Up Area (Km2)	Rate of Urban Expansion (%/Year)			
		1984-2003	2003-2013	2013-2023	1984-2023
1984	0.46	3.80			
2003	0.80		6.44		
2013	1.32			2.98	
2023	1.71				27.59
Change (km2/year)		0.35	0.52	1.26	1.26

Shannon's entropy values increased from 0.003 in 1984 to 0.015 in 2003 and 0.007 in 2013 to 0.024 in 2023 (Table 7). The relatively lower values of Shannon's entropy between 1984 and 2003 indicate compact distribution of built-up areas (Figure 6 and 7 for the inner five zones centred at the British colonial headquarters (Figure 9). However, an increasing trend in entropy values between 2013 and 2023 was observed for the outer ten zones indicating dispersion of built-up areas and ongoing urban sprawl (Figure 10).

Table 7: Shannon's entropy and changes in entropy between 1984-2023

Year	Shannon's Entropy	Changes in Entropy			
		1984-1994	1994-2003	2003-2013	2013-2023
1984	0.325	0.003			
2003	0.322		0.015		
2013	0.308			0.007	
2023	0.301				0.024

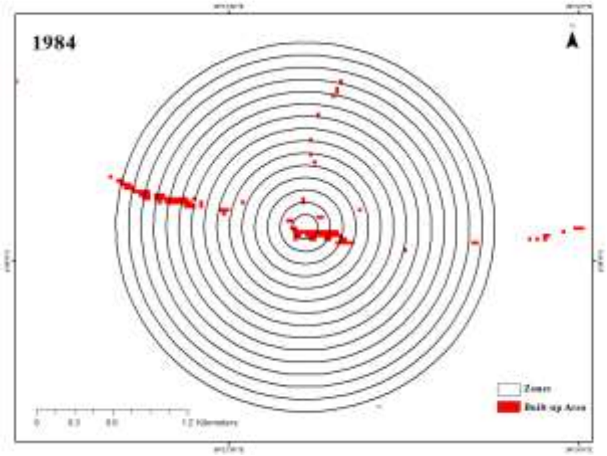

Figure 7: Built-up areas, 1984

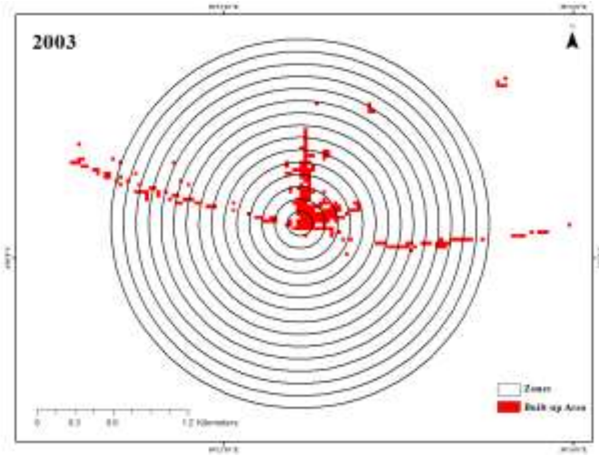

Figure 8: Built-up areas, 2003

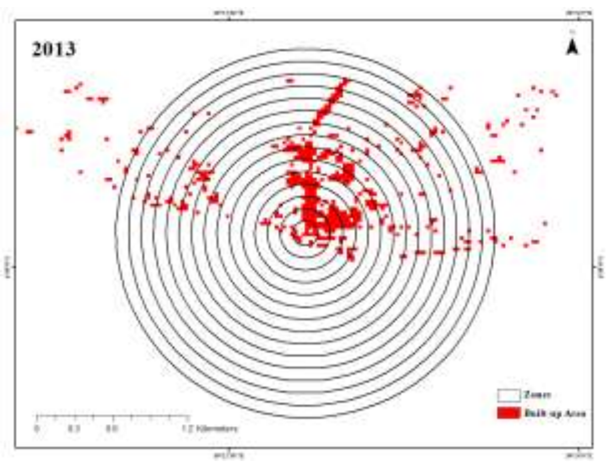

Figure 9: Built-up areas, 2013

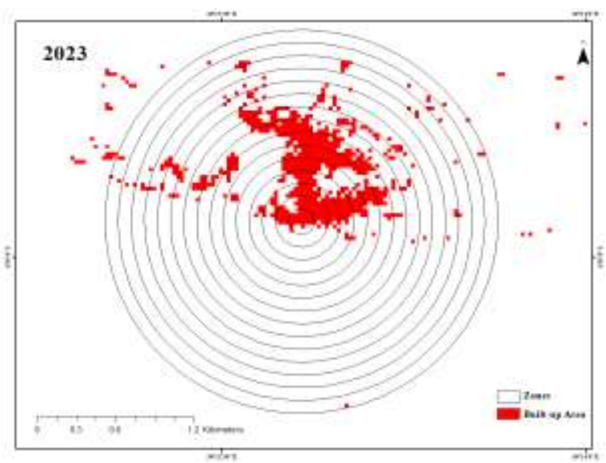

Figure 10: Built-up areas, 2023

Between 1984 and 2023, bare land patch density increased from 0.008 to 0.013 while built up patch density increased from 0.002 to 0.005 (Figure 11). Mangrove mean patch size decreased from 300m^2 to 200m^2 while vegetation mean patch size decreased from 500m^2 to 300m^2 (Figure 12). Thus, mean patch size was inversely related to the degree of fragmentation. Between 2013 and 2023, trends in largest patch index decreased by 50% for vegetation and bare land areas (Figure 13). Further, landscape shape index values for built up and mangrove areas were closer to zero while values for bare land and vegetation were closer to one (Figure 14) indicating clustering and dispersion, respectively. Overall, results of landscape patch analysis are in agreement with Shannon's entropy values, which substantiate gradual dispersion of urban growth and loss of natural land cover in the study area.

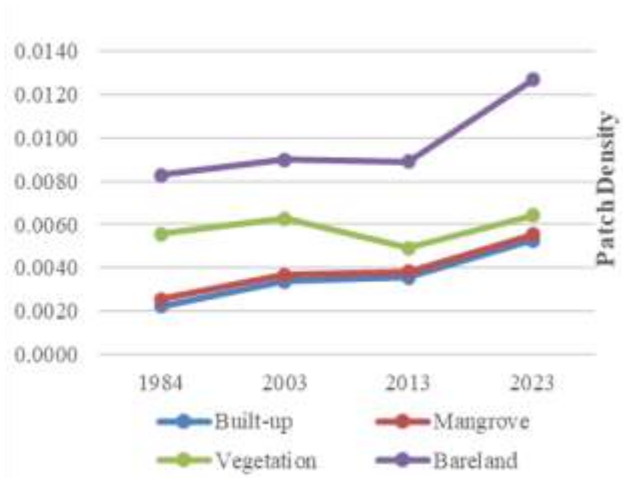

Figure 11: Patch Density

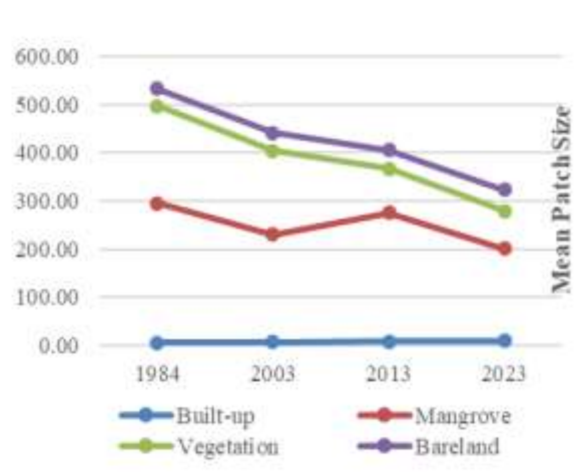

Figure 12: Mean Patch Size

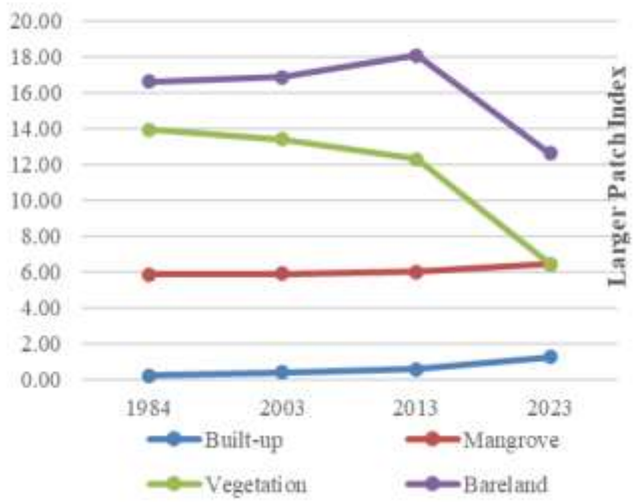

Figure 13: Largest Patch Index

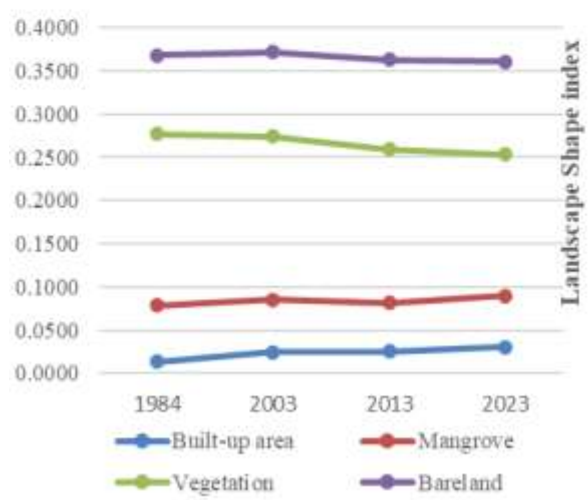

Figure 14: Largest Shape Index

Discussion and Conclusion

The findings support Island Vulnerability and Archipelagic Planning Systems Theory, which posits that climate and anthropogenic change transforms maritime heritage through spatial reconfiguration and ecological fragmentation across island landscapes (Oki & Brasher, 2003; Bankoff, 2007; Nunn, 2013; Kelman, 2014; Baum et al., 2016; Mycoo, 2018; Shah et al., 2020; Bugnot et al., 2020; UNESCO, 2023). The observed land-cover changes in Shimoni peninsula and Wasini Island indicate substantial alteration of mangrove, forest and lagoon systems that underpin maritime heritage values and adaptive capacity.

Over the 40-year period, built-up land increased by 73% while barren land expanded by 32%. In contrast, mangrove cover declined by 69%, terrestrial vegetation by 33%, coral reefs by 14%, and sandy beaches by 69%. The reduction of mangroves and beaches is particularly significant because these ecosystems provide shoreline stabilization, storm protection and biodiversity support, essential to maritime heritage conservation (ICCROM,2024; UNESCO, 2026). The annual rates of change further reveal an acceleration of urban expansion. Built-up land increased by 27.5% (1.26 km²/year) between 1984 and 2023. Shannon's entropy values increased from 0.003 in 1984 to 0.015 in 2003, declined slightly to 0.007 in 2013, and subsequently increased to 0.024 in 2023. This transition from compactness to dispersion is indicative of spatial reconfiguration processes highlighted by Archipelagic Planning Systems Theory, whereby development increasingly extends into heritage landscapes, creating new vulnerabilities and management challenges (IPCC,2024).

Landscape metric analysis further substantiates these patterns. Between 1984 and 2023, bare land patch density increased from 0.008 to 0.013, while built-up patch density increased from 0.002 to 0.005. Mangrove mean patch size decreased from 300 m² to 200 m², while vegetation mean patch size decreased from 500 m² to 300 m². Smaller and more isolated patches provide reduced ecosystem services that support heritage conservation and local livelihoods (UNCCF,2024; UNESCO,2026). Between 2013 and 2023, the largest patch index decreased by 50% for both vegetation and bare land classes. From a heritage perspective, the loss of dominant ecological patches undermines the integrity of cultural landscapes by disrupting ecological contexts within which maritime heritage sites have historically evolved (Hau'ofa, 1994; Baldacchino, 2015; Shah et al., 2020; ICCROM,2024).

Overall, the combined findings from land-cover change analysis, Shannon's entropy, and landscape metrics demonstrate a gradual transition from relatively compact and ecologically connected landscapes toward dispersed development patterns. In accordance with Island Vulnerability and Archipelagic Planning Systems Theory, the findings underscore the importance of integrated climate-sensitive planning, ecosystem-based adaptation, and heritage conservation strategies that maintain ecological connectivity in historic Shimoni, Wasini Island and the wider archipelago.

Recommendations

The observed 73% increase in built-up land, 69% decline in mangroves, and 69% loss of sandy beaches, combined with rising patch fragmentation, indicate urgent need for spatially targeted, ecosystem-based heritage adaptation. In response, the following interventions are recommended:

- Institutionalize landscape-based planning metrics under the National Land Use Policy (2017), and Physical and Land Use Planning Act (2019) to include: patch density, mean patch size, largest patch index for zoning high-risk heritage spaces.
- Promote vertical densification and compact urban development under the Urban Areas and Cities Act (2011) to reduce horizontal expansion into mangroves and forested heritage buffers.
- Restore mangrove and coastal buffer systems under the Environmental Management and Coordination Act (2015) and Kenya National Adaptation Plan (2015–2030), focusing on areas with severe mangrove loss to support shoreline stabilization.
- Stabilize and protect vulnerable heritage assets to include: mosques, wells, colonial ruins in low-lying and expanding settlement zones.
- Implement ecosystem-based restoration of vegetation using native species under the National Climate Change Action Plan (2023–2027) to enhance ecological connectivity.
- Strengthen alternative livelihoods through the Forest Conservation and Management Act (2016) and Shimoni–Vanga Co-Management Plan (2024–2028) to reduce pressure on forests and mangrove ecosystems.

- Develop a trans-regional ecological and heritage corridor network to connect fragmented landscapes and improve ecological continuity between Kaya forests.
- Design landscape-based heritage trails and interpretation systems informed by landscape patterns to enhance cultural tourism and heritage awareness.

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The authors report that there are no competing interests to declare.

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